# Tracking Hot Rocks


THE SETTING

- Western Canada
- SAGD Well Pair
- Steam Injection
- Geomechanical Deformation

Pinnacle

**THE BACKGROUND**

Monitoring steam chamber growth is critical to optimizing heavy oil recovery. But low-pressure steam-assisted gravity drainage (SAGD) are seismically quieter and require a level of sensitivity available through complementary use of both microseismic and tiltmeter technologies.

Steam injection results in geomechanical strains from increased pore pressure, thermal stress and changes in material properties associated with heating the reservoir. This mechanical deformation results in seismic deformation and the release of seismic energy as fractures adjust to the strain field. In some fields, this can also lead to casing deformation and well integrity issues.

Previous studies have reported microseismic activity and surface deformations for cyclic steam injections (CSS). But SAGD typically uses lower injection pressures and rates, which results in less seismic activity and surface deformation. Measuring the movement requires Pinnacles most sensitive monitoring equipment, including precision surface tiltmeters and digital seismic array.

PINNACLE PERFORMS

Pinnacle Technologies believed the solution for SAGD monitoring lay in a combined approach that measured microseismic activity with sensitive seismometers and surface deformation with precise tiltmeters.

To demonstrate that the complimentary technologies could track steam injection, Pinnacle monitored a steam injection project using passive microseismic and surface tiltmeter deformation. Monitoring was conducted during the initial steam injection warm-up phase of a SAGD well pair. The wells were at a depth of about 500 m, with the horizontal section of the laterals extending approximately 1000 m.

An existing vertical wellbore about 60 m from the toe of the lateral and 175 m offset was used for the microseismic monitoring during approximately 6 weeks of steam injection. An array of 20 surface tiltmeters was also deployed to monitor the surface deformation prior to and after the microseismic monitoring period.

The microseismic system used a retrievable fiber-optic wireline based array, with mechanical coupling. The array consisted of 8 triaxial geophones, sampled at 0.25 ms.

The tiltmeter array consisted of 20 surface tiltmeters capable of resolving tilt as small as one billionth of a radian (0.00000005 degrees).

Over 2,000 microseismic events were recorded during the 6 week recording period. Among the results, radiation patterns of some of the steam injection microseisms are consistent with a casing failure (which are distinct from another group of events which had radiation patterns consistent with shear failure of the reservoir rocks). The same signal characteristic is used at Cold Lake, Albert, Canada, to automatically detect casing failures.

While smaller in magnitude, these completion deformation events are consistent with the deformation mechanism of a tensile casing failure and are believed to represent small deformations resulting from thermal expansion of the well's uncemented slotted liner in the well.

The tiltmeter investigation focused on the area around the wellbore by limiting the inversion domain to eliminate noises not associated with the twin wells. Data shows

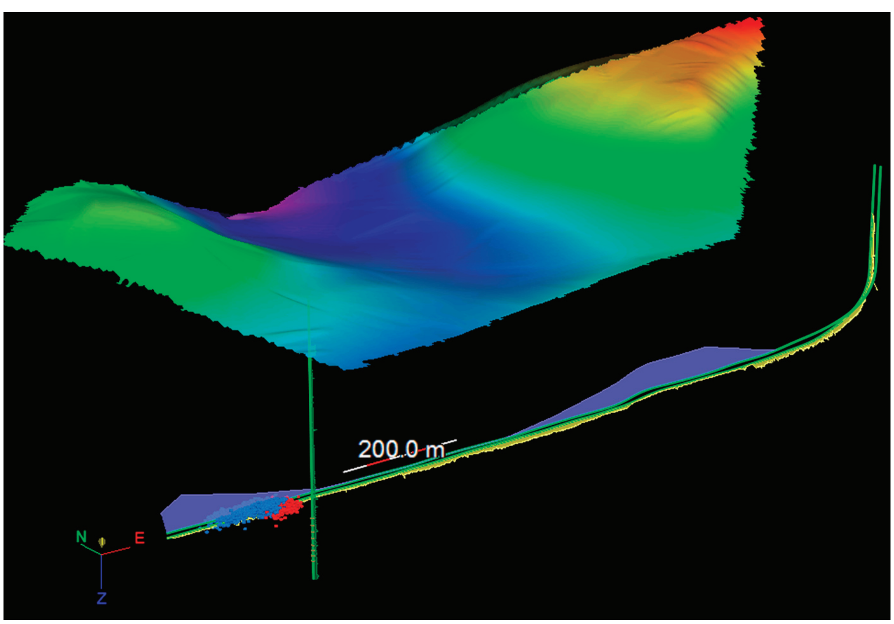


Fig. 1. Cross-sectional view of the entire SAGD well pair shows surface uplift, completion deformation (red) and reservoir fracturing (blue) microseisms and strain anomalies (dark green) at toe and heel of the well.

that strain was confined to the extremities of the heel and toe of the wellbore, as expected from the distribution of the surface uplift. Microseisms were also observed at the toe and may have occurred at the heel, but it was too distant from the observation well for measurement.

Seismic and surface deformations were compared in cumulative seismic moments and applied to a timeline showing injection details (rate, pressure and cumulative volume) for the steam injection through the tubing into the toe of the well. Surface lift over the toe region was also compared.

THE RESULTS

The combined monitoring of passive seismic and surface deformation provides insight into mechanisms leading to casing deformations and also potentially identifies circumstances that may lead to casing failures. It can track fluid movements in the reservoir, allowing optimum well and pattern design and subsequent operational improvements including as optimization of steam volumes, rates and cycle timing.

Finally, the combined monitoring can be used to track unwanted steam breakouts,, offering critical information for reservoir engineering and management during steam injection.

Among the study results, analysis suggests a period of rapid reservoir seismic deformation corresponding to development of a fracture network which is then permeated with steam, resulting in a sudden advance of the steam into previously unheated reservoir.

The seismic deformation is presumed to be associated with stress- or pressure-related induced shear failure on pre-existing fractures, since the injection pressures are believed to be below frac pressure. This induced fracturing, whether associated with activation of pre-existing fractures or creation of new fractures, could provide a stimulated region of enhanced permeability.

Comparison of microseismic and tiltmeter data also suggests that the warm-up phase has not provided uniform steam coverage conformance along the length of the well pairs.

Although this limited conformance may not hold true during the actual SAGD production phase, this case study highlights the potential to track conformance so that the injection design to be modified for complete conformance.

The study also suggests that integration of microseismic events and strain may also be used in calibration of a geomechanically-linked reservoir simulator. Because geomechanical deformation associated with the steam heating can result in alterations to the permeability and porosity, incorporating geomechanical analysis into a flow simulator is critical for modeling the reservoir performance.

The volumetric strain could also be modified by including the microseismic locations to constrain the strain by matching the observed points of shear failure with the passive seismic deformation. The inverted strain and observed failure regions can be used to constrain the geomechanical model results and along with conventional temperature and pressure measurements to validate the simulator.

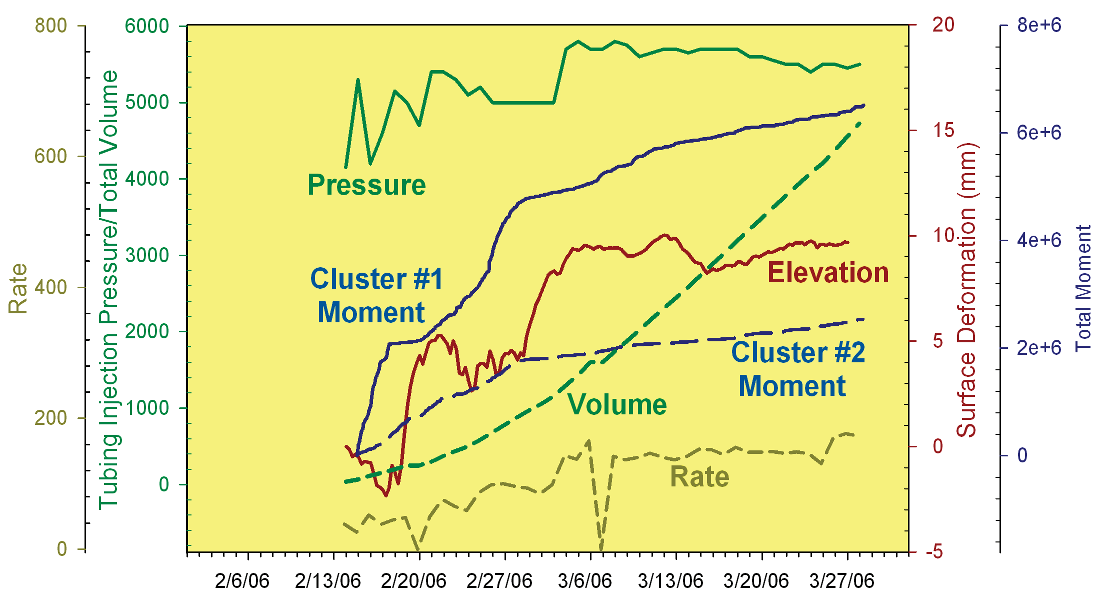


Figure 2. Time line of the injection data shows total recorded seismic moment/deformation and surface uplift over the toe of the well.

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