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Monitoring SAGD Steam Injection Using Microseismicity and Tiltmeters

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Abstract

A combination of microseismic and surface deformation monitoring with an array of tiltmeters was used to monitor the warm-up phase of a SAGD well pair. A sequence of microseismic events was recorded with signal characteristics suggesting deformation associated with thermal expansion of the wellbore, in addition to events apparently associated with induced fracturing in the reservoir. Integration of the microseismic data with volumetric strain, inverted from the measured surface deformation, indicates a discrete deforming region near the toe of the well. The volumetric strain also shows another region near the heel of the well, although the area is too far from the microseismic observation well for any associated microseismicity to be recorded. The central portion of the well pair did not have significant deformation, indicating poor steam conformance during this warm-up phase. A comparison of the temporal response of the microseismic deformation with the surface uplift, suggests a lag between periods of accelerated seismic deformation followed by an associated period of accelerated uplift a few days later. This timing suggests the creation of a fracture network and related seismic deformation, which then fills with steam and starts to expand over a period of a few days. In a related paper⁹, stress changes associated with the volumetric strain are used to examine potential geomechanical failure zones that match the observed locations of microseisms. Together the volumetric strain, computed stress changes, and failure zones could be used to calibrate a geomechanically linked reservoir simulator.

Introduction

Steam injection for reservoir stimulation is an important factor for the economic development of heavy oil reservoirs. Monitoring the steam chamber growth is critical to optimize the heavy oil recovery, confine the stimulation to the reservoir and identify bypassed regions. Steam injection results in geomechanical strains associated with increased pore pressure,

thermal stress changes and dramatic changes in material properties associated with heating the reservoir sufficiently to mobilize the heavy oil/bitumen¹⁻³. This geomechanical deformation may be expressed through seismic deformation and the release of seismic energy as fractures adjust to the strain field⁴, and also may result in surface expansion or subsidence⁵. Monitoring the microseismic activity with sensitive seismometers and surface deformation with precise tiltmeters could allow the steam injection to be tracked with complimentary technologies that respond to different expressions of the geomechanical deformation associated directly with the steam injection. In some fields, this geomechanical deformation also leads to casing deformations and well integrity problems which may result in operational problems^{5,6}. The combined monitoring of passive seismic and surface deformation provides insight into these mechanisms leading to casing deformations and also potentially identifies circumstances that may lead to casing failures. The combined monitoring also 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 passive seismic and surface deformation monitoring can also be used to track unwanted steam breakouts. Thus, combined monitoring of passive seismic and surface deformations offers critical information for several reservoir engineering and management issues during steam injection.

Many steam injections are at relatively low injection pressure, which may be below the “frac” pressure required to create tensile hydraulic fractures⁷. Nevertheless, fracture activation may still occur as increased pore pressures induce shear movement along pre-existing fractures. This potential mechanism for seismic deformation is further enhanced by thermal stress changes and the material property changes moving the rockmass closer to shear failure. There are, therefore, a number of factors which lead to the potential occurrence of microseisms/microearthquakes both for relatively high pressure cyclic steam stimulation or “huff and puff” injection (CSS) and lower pressure injections such as steam-assisted gravity drainage (SAGD).

Previous studies have reported microseismic activity^{4,6,8} and surface deformations for cyclic steam injections.⁵ SAGD typically use lower injection pressures and rates compared to CSS⁷, and result in less seismic and surface deformation. Furthermore, many of the heavy oil reserves in Western Canada where SAGD injections are commonplace, are