Seismic Signatures of Fluid Injection into Deforming Reservoirs

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ABSTRACT

During fluid injection operations, time-lapse geophysical surveys allow operators to monitor the fluid flow in the field. Knowledge of flow patterns, of reservoir pressure, temperature, and saturation assesses the sweep efficiency during enhanced oil recovery (EOR), helps avoid early water breakthrough and reduces risks associated with carbon dioxide sequestration. In the Middle East, increasing the production from mature fields is a key driver for EOR operations and monitoring technology.

The time-lapse seismic method is an established geophysical tool to monitor fluid migration in subsurface reservoirs. Interpreting seismic signals in terms of dynamic reservoir properties such as saturation and pressure requires a sound understanding of the rock physics. The effect of saturation changes on seismic velocities is described by Gassmann fluid substitution. At the same time, injection-related increase of reservoir pressure causes an expansion of the reservoir and an uplifting of the overburden rock. The movement of reflector horizons causes travel time shifts. In addition, seismic velocity is reduced if the rock undergoes expansion and increases in areas of rock compaction. The relative magnitudes of velocity change due to saturation changes or due to reservoir deformation depend on the density and mechanical properties of the fluids and the porous rock matrix.

In order to better understand the signatures fluid migration, the monitoring is combined with flow simulation, rock physics, and 3D stress field modeling in an integrated workflow. While flow simulation provides pressure and saturation, the role of geomechanics is to compute the rock deformation and associated stress changes from the dynamic pressure fields in the reservoir. The numerical model takes into account the movement of faults and the elastoplastic rheology of the rock, providing an accurate description of the reservoir deformation. Finally, the rock physics model establishes the link between dynamic reservoir properties on the one hand and seismic impedance on the other hand. Impedance changes computed using an integrated workflow may then be compared to the results of a seismic inversion.