Fundamental study of seismic emission tomography in terms of fluid pressure fluctuations

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Since it is essential to know where fluid moves in the subsurface, seismic emission tomography (SET) is now becoming a fundamental tool in the development of natural resources. The method has been applied in plural oilfields and provides images of fluid paths in the subsurface. However, the relationship between observed seismic data and fluid behavior in the subsurface has not been well understood yet, and there remains some skepticism to the performance of SET. In the present study, we conducted a numerical experiment for the understanding of the mechanism of seismic emission at the locations of subsurface fluid paths in order to extract more information about fluid behavior from observed seismic data. After that, we conduct quantitative assessment at seismic emission tomography utilizing micro-seismic signals induced by subsurface fluid flows inside fractures. We simulate fluid flow in a fracture using the Lattice Boltzmann method (LBM). We adopt two numerical models, i) intermittent flow in a parallel plate, and ii) a pore throat model with an oil droplet. We calculate stress changes at the fracture wall induced by unsteady flow for i) and multi-phase flow for ii). The unsteady flow is generated by cyclic pressure change at the inflow boundary. In this case, inner portion of the fracture is filled only water or oil. In the multi-phase flow, we consider transport of oil droplet in a fracture with a throat filled by water. After those experiment, we simulate seismic wave propagation and calculate received waveform at surface geophones. In the parallel plate model, larger shear stress change can be observed in the case of oil than water. This stems from more rapid change in fluid velocity close to the fracture wall due to the high viscosity of oil. In the case of the multi-phase flow in the pore throat model, about 8 Pa and 28 Pa of shear and normal stress changes are observed at the fracture wall when an oil droplet passes through the pore throat, whose width is 1 mm. Our results show that seismic wave generated in pore throat model where a oil droplet passing through a pore throat would have 10-27 m in the displacement amplitude at about 2 km distance. Although the amplitude of seismic waves generated by a single pore throat cannot be detected in field observations, the superposition of seismic waves would amplify the signal from the reservoir. We also confirmed that the integration of seismic waves over time using auto and cross correlations with those acquired at a place with some distance could magnify the detection capability. If there is 16000 pore throat in the sub-surface, taking correlation receive seismic wave over 20 days using passive seismic emission tomography. We think that the induced seismicity by fluid flow is strongly dependent on fluid flux, viscosity, volume fraction of multiple fluid phases in flow, geometry of fracture network, and many others. Further work is planned to investigate the relation of seismic wave amplitude with these parameters.

Keywords: seismic emission tomography, fracture modeling, Lattice Boltzmann method

