Electrical impedance measurement of geothermal reservoir rock under fluid-flow test

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The estimation of underground water saturation is essential in geothermal fields, particularly for an enhanced geothermal system (EGS). Recently, electromagnetic exploration using magnetotellurics (MT) has been applied to the geothermal fields for estimating water saturation. However, the relationship between the electrical impedance obtained through this method and the water saturation in the reservoir rock has not been well known. Our goal is to elucidate this basic relationship via fluid-flow experiments, and as our first step, we developed a technique to measure and analyze the electrical impedance of geothermal reservoir rocks under fluid-flow test. In this test, at first, reservoir rock samples were filled with nitrogen gas (P_p = 10 MPa) under 20 MPa of confining pressure; the gas emulates the superheated steam that is observed in the geothermal fields. Then, brine (1wt% KCl, 1.75 S/m), which emulates the artificial recharge to the reservoir, was injected into the samples. After the flow rate of the drainage fluid stabilized, the brine injection pressure was increased (11, 12, 14, 16 and 18 MPa) and decreased (18, 16, 14, 12 and 11 MPa) to vary the water saturation in the samples. During the test, water saturation, permeability, electrical impedance (at a frequency of 10^{-2}-10^{5} Hz) and elastic wave velocity were measured. As a result of fluid-flow test on andesite (Makizono lava formation, Japan), the electrical impedance dramatically decreased from 10^5 to 10^3 Ω because of the brine injection. This remarkable change could be due to the replacement of pre-filled nitrogen gas with the brine. After the brine injection, the electrical impedance decreased with increasing injection pressure (small changes in water saturation) by up to 40%. After increasing the injection pressure, the pressure was decreased to study the hysteresis of each parameter. The electrical impedance increased with decreasing injection pressure in the pressure-decreasing phase, and this electrical impedance was smaller than that observed in the pressure-increasing phase (up to 27% at 11 MPa of injection pressure). However, the P-wave velocity was almost constant (less than 1%) at that time. These results indicate that the electrical impedance varied with small changes in water saturation in the pressure-decreasing phase, whereas P-wave velocity did not show any variations. In other words, this suggests that electrical impedance could be sensitive to minor changes in water saturation compared with P-wave velocity. Therefore, electrical impedance could have potential to monitor changes in water saturation in geothermal reservoirs.

Keywords: electrical impedance, elastic wave velocity, water saturation, fluid-flow test, EGS (Enhanced Geothermal System)

