Electrical impedance measurement of geothermal reservoir rocks: Effects of water saturation, salinity, and fracture porosity

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Estimation of underground water saturation is essential in geothermal fields, particularly for Enhanced Geothermal System (EGS). Recently, electromagnetic exploration using magnetotellurics (MT) has been applied to geothermal fields for estimating water saturation. However, the relationship between the electrical impedance obtained through this method and the water saturation in reservoir rocks has not been well known. In addition, there are few researches about the effects of salinity and fracture (porosity) on this relationship. Our goal is to elucidate the basic relationship between electrical impedance as well as effect of salinity and fracture porosity on it via fluid-flow experiments. In this research, we prepared two types of specimen from geothermal reservoir rocks; A) contains artificially induced thermal cracks (porosity = 10.5%) and B) initially contains a single fracture (porosity = 3.8%). In fluid-flow tests, specimens were initially 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 and 0.1wt% KCl, 0.19 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, and 16 MPa) to vary the water saturation in the specimens. 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 Type A specimen, electrical impedance dramatically decreased from 10^5 to 10^3 Ωdue to the brine injection. This remarkable change could be caused by the replacement of pre-filled nitrogen gas with the brine. After the brine injection, electrical impedance decreased with increasing injection pressure (small changes in water saturation) by 40%. However, P-wave velocity was almost constant (less than 1%) at that time. These results indicate that electrical impedance varied with small changes in water saturation. In other words, electrical impedance could be sensitive to minor changes in water saturation in the reservoirs compared with P-wave velocity. As a result of Type B specimen, we observed salinity effect on electrical impedance (up to 60%) and its decreasing trend against the water saturation is slightly different from the result of Type A specimen. These dependencies (water saturation, salinity, and porosity) on electrical impedance could be explained by the total ion content within a specimen.

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

