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Mixing-rules of viscosity, electrical conductivity and density of NaCl, KCl and CaCl2 aqueous solutions derived from experiments

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Upper-crustal fluids often contain an abundance of dissolved ions significantly affecting their thermo-physical properties. Knowledge of these properties and their relation to both type and concentration of ionic species is of predominant importance for a variety of geotechnical applications, e.g. the provision of energy from deep-seated geothermal reservoirs.

We conducted extensive and systematic series of measurements on the viscosity, electrical conductivity and density of synthetic geothermal brines containing varying amounts of dissolved NaCl, KCl and CaCl2 salts. The investigations were performed at ambient pressure and temperatures between 20°C and 80°C, using a Höppler-viscometer, a commercial hand-held four-electrode conductivity meter, and a combination of volumetric and mass measurements for density, respectively. The maximum molalities investigated were 4 mol/kg for KCl and 5 mol/kg for NaCl and CaCl2, respectively.

Despite analytical simplicity the results obtained were in good to excellent agreement with tabulated values. The investigations on electrical conductivity showed excellent agreement with Kohlrausch's law of independent migration of ions as well as tabulated values for the respective limiting molar conductivities. Cation-valency strongly affects the dependence of all three thermo-physical properties on salt concentration. At a given temperature, CaCl2 brine shows a decrease in conductivity, a dramatic increase in viscosity, and a departure from linearity for density with concentration above molalities of approximately 3 mol/kg.

Moreover, systematic measurements performed with mixtures of the three salts yielded mixing-rules for all three parameters. The predictions of these rules applied to a natural geothermal brine of known chemical composition were in excellent agreement with direct measurements performed with this fluid. After evaluation, such relationships then permit reasonable estimates on thermo-physical properties of fluids having more complex compositions without the need for further measurements. For example, the viscosity of a solution containing an arbitrary composition of NaCl, KCl and CaCl2 can be reasonably predicted by stoichiometrically weighting the individual viscosities measured at the total concentration of the mixture.

In our contribution we will critically present the data in comparison to existing data and communicate the mixing-rules derived. Also, we will stress the validity of the conventional conductivity-viscosity relationship based on the balance between electrical and viscous forces. This will constrain the species- and concentration-dependence of both effective ionic radii and ionic mobility and finally might provide insight into the mechanistic origin of the observed valency-dependence of all three thermo-physical parameters.