

Estimation of water film thickness in pores under the presence of trapped gas

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When water infiltrates into a dry or partially saturated geological medium, the capillary trapping of gas as discontinuous clusters occurs. The trapped (residual) gas is known to influence the hydraulic conductivity of geological media (e.g., *Nishiyama et al.*, 2012, *Water Resour. Res.*), and is considered as an effective mechanism in the storage of carbon dioxide in aquifers. Previous experimental observation using a sand column has implied the presence of wetting film between trapped non-wetting phase and grain surfaces (*Conrad et al.*, 1992, *Water Resour. Res.*). Other study has shown that the dissolution and precipitation of minerals occur as long as a water film of a thickness of a few nanometers covers mineral surfaces (*Stipp et al.*, 1996, *Am. Mineral.*). It is inferred from these results that to consider the presence of water film on pore walls is essential for quantifying the dissolution and precipitation and the mass transport in geological media under the occurrence of gas trapping. Because the rate of mass transport is expected to be affected by the thickness of water film, the estimation of film thickness is important. Thus, we constructed a theoretical model predicting the thickness of water film under the condition that gas is trapped in pores.

The water film on a mineral surface is subject to van der Waals and electric double layer forces perpendicular to the plane of the film. The relationship between the film thickness and the pressure (disjoining pressure) associated with the forces acting in the film can be described on the basis of Derjaguin-Landau-Verwey-Overbeek theory. Because the disjoining pressure can be converted to relative humidity in the surrounding gas, we first obtained the relationship between film thickness and relative humidity. When we consider the pore space where gas is confined by pore water, the relationship between relative humidity and pore diameter can be determined on the basis of the Kelvin equation. Combining these relationships, we finally obtained the expression describing the film thickness-pore diameter relation. The expression shows that the water film thickness changes depending on the pore diameter, mineral type, electric potential at the water-gas and water-mineral interfaces, and pore solution composition. Especially for the system in which the ion concentration in pore solution is low ($<10^{-4}$ M) and the mineral has a high electric potential (e.g., quartz in contact with dilute pore solution), pore diameter is the most important factor controlling the water film thickness. In this case, the thicker film exists in pores having larger diameter. The broader the pore size distribution of a given geological medium, the broader the range of the film thickness. The expression presented in this study will be useful in modeling the reaction and mass transport in the water film in geological media under the occurrence of gas trapping.

Keywords: water film, capillary trapping, residual gas, disjoining pressure