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Fast calculation of formation factors of 3-D pore-scale images of geo-materials by renormalization

Yoshito Nakashima[1*], Tsukasa Nakano[1]

[1]AIST

The formation factor, the dimensionless electric resistivity of porous rock/sediment saturated with conductive fluid, is an important quantity in geophysical exploration for petroleum reservoirs and groundwater aquifers. In the rock physics related to such exploration, there is a need to calculate formation factors from large three-dimensional (3-D) images of porous rocks/sediments obtained by X-ray microtomography. In the present study, we applied a renormalization technique to quickly estimate the formation factors for various pore-scale image sets of real geo-materials (sandstones, pumice, lava, and sandy sediments). In this method, the effective formation factor is first calculated using Ohm's law and Kirchhoff's law for small subsystems of 2x2x2 = 8 voxels, and this is then upscaled based on the arrangement of voxels in the 3-D image. This method is several orders of magnitude faster than the conventional method because the time-consuming iterative algorithm for solving the 3-D large-scale Laplace equation is not employed. Application of this technique to microtomographic images of real porous rocks/sediments revealed that its accuracy increases with increasing porosity and pore elongation along the direction of the applied electric field and with decreasing pore/grain size. Most importantly, a high degree of elongation of the pore structure along the applied field ensures good accuracy even if the porosity is low and the pore/grain size is large. Taking these effects into consideration, the method can be used to produce a rough but quick estimate of the formation factors for large pore-scale images of geo-materials. Because steady-state thermal and material diffusion obeys the same Laplace equation, the renormalization technique presented here can also be applied to estimate thermal/material diffusivity for natural geo-materials and industrial composite materials, particularly for those having strong prolate structural anisotropy parallel to the applied field gradient.

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