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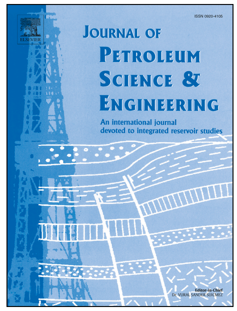

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Development of a Digital Rock Physics workflow for the analysis of sandstones and tight rocks

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Abstract

Predicting petrophysical properties by means of digital core analysis strongly relies on the operator expertise and becomes very challenging when dealing with clay microporosity, due to resolution limits and a general lack of recommendations. In the standard workflow, 3D images of rock samples are acquired via X-ray computed tomography and processed, to reconstruct pore geometries that are used to set up numerical experiments for the calculation of physical properties, such as permeability. In the present paper, the limits of the standard workflow are investigated and specific strategies are proposed to make the entire process less operator dependent and more reliable when dealing with tight samples. A global thresholding technique is applied for the identification of the pore space. The quality of its performance has been found to be strongly related to contrast, noise and presence of rock microporosity. Threshold selection is more robust if contrast enhancement and denoising algorithms, like bilateral filter and non-local means, are applied. Furthermore, microporosity shall not be excluded from the reconstructed pore space, since it is fundamental in providing connectivity of the flow paths. The selected value for thresholding is used inside an image-based meshing strategy, to create a computational grid directly on the 3D stack of images. Methods to compute porosity, specific surface and average pore diameter are described. Absolute permeability is computed by performing Computational Fluid Dynamics (CFD) simulations of single-phase incompressible flows in the reconstructed pore space. A model to include the presence of an increased resistance to the fluid flow in the microporous region is proposed and validated by comparison with experimental measurements.

Keywords: Tight rocks, Sandstones, Micro-CT imaging, CFD, Microporosity, Permeability

1. Introduction

Along with conventional reservoirs, low-permeability formations are nowadays considered as valuable resources for oil and gas production (U.S. Energy Information Administration, 2015, American Association of Petroleum Geologists, 2015). The economic assessment prior to field development cannot avoid an accurate evaluation of rock properties, such as porosity, permeability and capillary pressure. Nonetheless, tight reservoirs are characterized by such low permeabilities, typically less than 0.1 md, that most of the standard techniques applied to assess conventional reservoirs are unpractical and/or lead to unreliable evaluations (Wang et al., 2015).

The limits of traditional experimental methods has rapidly turned digital core analysis into a commercial predictive tool (Blunt et al., 2013, Fredrich et al., 2014). As a matter of fact, digital analysis is nowadays regarded with interest not only for its capability of predicting the main petrophysical properties, but also because it gives a valuable physical insight into the micro-scale phenomenona. In the standard workflow, cores are imaged, for instance by X-ray micro-tomography, to obtain a digital reconstruction of the inner pore structure. Then, numerical methods are used to simulate single and multiphase flow to retrieve the petrophysical properties of interest. The complete digital process involves several modeling choices, such as the choice of the parameters employed for the processing and segmentation of the image, the size of the subvolume used for the simulations, the solver and the boundary conditions. The choice of the representative sample size is particularly critical because it directly affects the computational cost of the numerical simulation (Blunt et al., 2013, Andrä et al., 2013a). Even so, most challenges are related to the processing of the image dataset for the reconstruction of the void space, as it is difficult to define a standard workflow able to provide accurate results over wide range of porosities and permeabilities. After the tomographic acquisition images are usually processed, for example by adjusting contrast or by reducing brightness inhomogeneities and noise. At the present, several techniques have been proposed to perform an automatic image editing and segmentation (Schlüter et al., 2014, Iassonov et al., 2009, Eibenberger et al., 2008, Buades et al., 2005, Huang and Chau, 2008), but porosity estimations are still inaccurate in rocks where a significant fraction of the porosity is below the image resolution (Awang et al., 2015, Long et al., 2013, Golab et al., 2010, Sok et al., 2009). As for tight sandstones and carbonates, the resolution of Micro Computed Tomography (micro-CT) scanners, which is in the order of few microns, is not enough to resolve micro-porous structures. On the contrary, these features can be clearly observed and identified with a resolution of nanometers, e.g. with

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