New method for characterising the nano- to macro-scale voidage within black shale and for modelling shale gas recovery efficiency

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Abstract. We present a major new advance in the ability to characterise the nano-voidage of tight reservoirs, demonstrated using intact, rather than crushed, black shale samples.

The approach involves cleaning of 1 cm3 samples, followed by helium pycnometry and mercury intrusion. The major advance is in the subsequent modelling, which uses two new developments: (i) the correction and extension of the high pressure mercury intrusion curve to include nanoscale characteristics, recently demonstrated for nuclear reactor carbon (Jones et al., Carbon, March 2018), and (ii) a complete void size mapping based on coupled inverse and forward modelling of the full percolation characteristic (Matthews et al., Transport in Porous Media, September 2018). The approach is a major improvement on Lattice-Boltzmann and Markov chain approaches, for example that of Chen et al. (Scientific Reports 2014) which suggests an unjustified maximum number of features at 20 nm.

Important applications include:

(i) quantitative measurement of the repository void sizes in unconventional cores in the range 1 nm to 6 um,

(ii) generation of a void network which matches experimental percolation measurements, and which can be used for gas and liquid flow simulations, and

(iii) calculation of absolute permeability in the presence of trapped fluids and fines, to better understand EOR efficiency and the rate of decline of well productivity.

Shale samples are cleaned with IPA (Cornwall, 2001, SCA) since toluene can cause secondary porosity (Burger et al., 2014, SCA), followed by methanol extraction and drying. The surface accessible porosity is measured with helium pycnometry. The percolation characteristic is measured with mercury intrusion porosimetry between 4 nm and 6 um, and extended down to 1 nm using the helium pycnometry result.

Modelling is carried out with the PoreXpert software, which generates a void structure by quasi-Bayesian inverse modelling of the experimental percolation characteristic, and stochastically bridges the gap in the experimental percolation characteristic between 1 and 4 nm. Forward modelling of the percolation then allows void clusters to be identified, which are normally wrongly characterised from the slope of the percolation characteristic against applied pressure. The resulting void size mapping is a fully quantitative match to the experimental sample in terms of the volumes, cross-sections and connectivities of the voids. It is also the basis for further simulations, currently relative permeability changes caused by diethyl ether enhanced huff puff recovery in samples extracted from the kitchen zone of the Vaca Muerta shale formation, Argentina.