Modelling acoustic properties of partially saturated nano-porous media

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Introduction

Application of dynamic poroelastic models to the data measured on partially saturated rocks is challenging, because the poroelastic effects in such complex media are often obscured by other phenomena, such as squirt flow. Nanoporous Vycor glass, which has narrow pore size distribution provides an excellent medium for testing those models.

To test applicability of poroelastic patchy saturation models to nano-porous materials, we consider ultrasonic measurements during adsorption and desorption of n-Hexane vapor on nanoporous Vycor glass (Page et al., 1995). As vapor pressure is increased from zero to the saturation pressure, the vapor is adsorbed on the pore walls, resulting in gradual increase of the liquid fraction. The reverse process occurs when pressure is decreased, but the 'drying' of the nanopoorus glass is heterogeneous, resulting in a very different velocity-saturation relationship.

Methodology

On adsorption, we model ultrasonic properties of partially saturated glass using Continuous Random Model (CRM) of Műller and Gurevich (2005), also known as the Dynamic equivalent medium approach (DEMA). In this model, the liquid fraction is considered a random function of position, controlled by the correlation length d ("patch size'), which may itself vary with saturation. A systematic approach to application of CRM to laboratory measurements on a partially saturated sandstone (Cadoret et al., 1998), including definition of all the model parameters, was proposed by Kobayashi and Mavko (2016). We apply their approach to nanoporous glass.

As noted by Kobayashi and Mavko (2016), during imbibition, some significant portion of the liquid fraction should be uniform. In other words, if we consider the medium to be saturated with a binary mixture of two fluids, one of these fluids should be liquid, while the other should be a uniform mixture of liquid and vapor with liquid fraction S_{L0}, which itself increases with the increasing overall liquid saturation S_L. This is even more so for nanoporous media, where adsorption tends to produce rather uniform patterns. Our modelling shows that there is a strong coupling between the patch size and uniformly saturated fractions, which cannot be resolved with ultrasonic data only. However this can be resolved using light scattering data (Ogawa and Nakamura, 2013). Very weak light scattering during adsorption shows that 99.3% of the increase of the saturation is uniform. Yet the saturation is not entirely unfirm, as shown by the deviation of the longitudinal modulus from the unform saturation limit (as discussed in the next section).

The desorption process results in macroscopic liquid patches, and cannot be modelled with CRM. We model this process with elastic finite element methods.

Results

The results of CRM and FEM modelling for adsorption and desorption, respectively, are shown in Figure 1. For adsorption the characteristic length ('patch size') is ~400 nm, which is much larger than the pore size (<10 nm). On desorption, the glass cylinder dries from the surface and the patch size is simply liquid fraction times the cylinder radius. In all cases the fit is very good.

(a) *(b)*

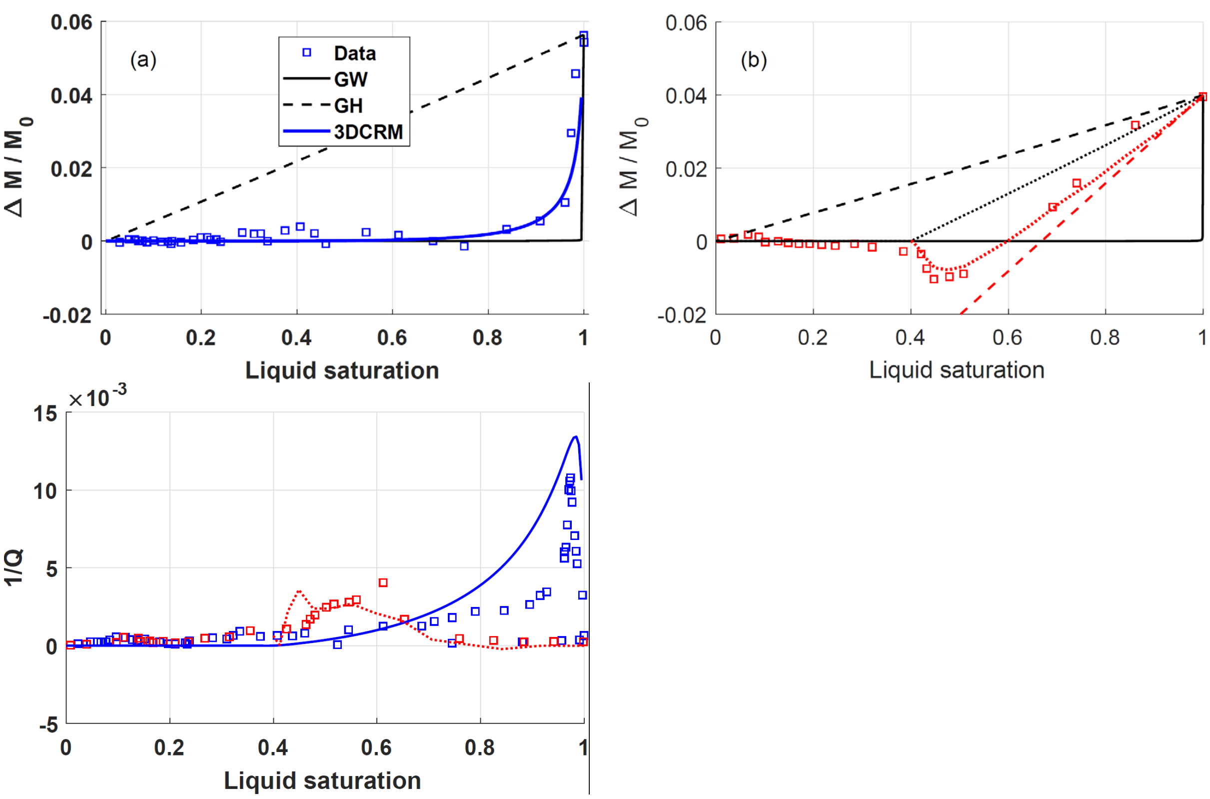

Figure 1: Relative change of the longitudinal modulus (a, b) and inverse quality factor (c) during adsorption (blue) and desorption (red) as estimated from ultrasonic measurements (squares), uniform limit (black solid lines), patchy limit (black dashed lines), poroelastic (CRM) modelling (coloured solid lines) and finite element simulations (dotted lines).

Conclusions

Our analysis shows that both on adsorption and desorption, the condensate in the pore space forms patches much larger than the typical pore radius. The patch sizes are much larger on desorption than on adsorption. These results suggest that ultrasonic measurements are a promising method for studying fluid distributions in nano-porous geomaterials such as shale or coal.

References

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