Wave propagation in rocks saturated by two immiscible fluids.

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Introduction

The purpose of this paper is to combine the approaches of patchy saturation and squirt flow into a consistent model valid over the full range of frequencies and saturations. Our view is that the patch effect results from systematic variations in the induced pore-pressure between the two fluids, and we capture this effect through a simple model depending on a single non-dimensional parameter. This model then allows us to calculate the squirt-flow behaviour through analysis of the average pressures in the two fluids. We illustrate the prediction of this new model in the context of the permeable Utsira sand found in the CO_2 storage site of the Sleipner field (Arts et al., 2008). Assuming reservoir conditions, we predict velocity versus saturation for either liquid or supercritical CO_2.

Theory

We examine the simplest possible model, where the induced fluid pressures in each phase are simply proportional to each other, with the same constant of proportionality. Specifically, we assume a relation between the pressure of CO_2 and pressure P_W of water that has the form:

$$P_{\mathrm{CO_2}} = qP_{\mathrm{w}}, \qquad \frac{K_{\mathrm{CO_2}}}{K_{\mathrm{w}}} < q < 1$$

Possible reasons for this variation between fluid pressures include capillary or membrane effects as well as the influence of uneven spatial variation in the fluid distributions due to patches. We use this relation in the squirt flow model of Chapman et al. (2002) which is based on a network of ellipsoidal microcracks and spherical pores.

Results

The impact of the new parameter q in the squirt flow theory affects two key parameters, the effective fluid modulus K_f and the characteristic frequency ω_0. The effective fluid modulus resembles the empirical model used by Brie et al. (1995) where the role of the Brie parameter is played by a rescaled version of q as was shown in recent work by Papageorgiou et al. (2016). This work demonstrates how the characteristic frequency depends from saturation and q in an intertwined way. We show this dependence in Figure 1 for a water - CO_2 system and different values of the parameter q. The dependence of the sandstone velocity and attenuation from saturation and q is then calculated and shown in figure 2.

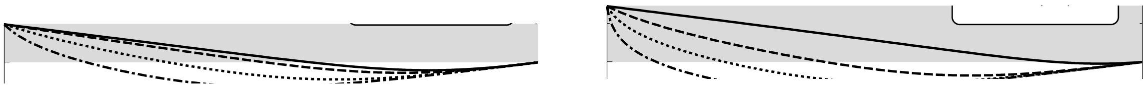

Figure 1: The nondimensional characteristic frequency variation with water saturation for different values of the parameter q for liquid (left) and supercritical (right) CO2

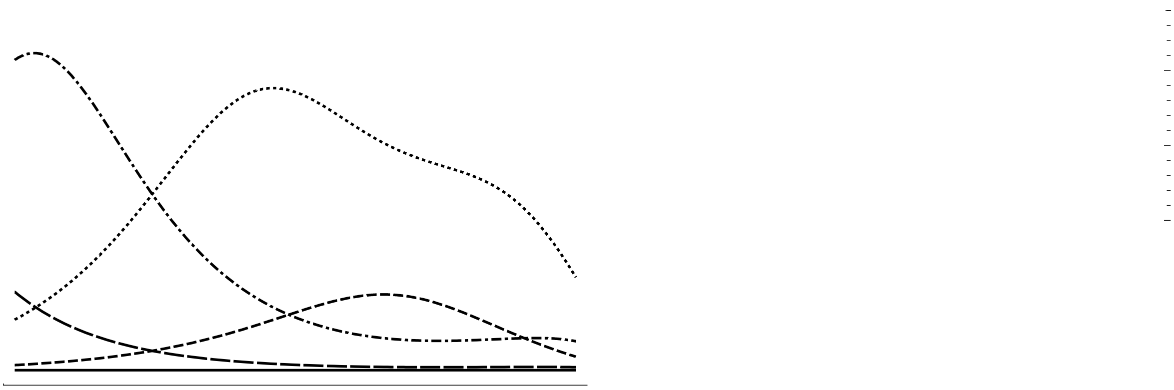

Figure 2: The variation of velocity and attenuation with water saturation for different values of non dimensional frequency. An intermediate value of q (patchiness) has been assumed. The graphs are for liquid (left) and supercritical (right) CO2 mixed with water.

Conclusions

We have presented an extension to the model of Papageorgiou et al. (2016) that includes the effects of capillary pressure, which enters the model as a non-dimensional parameter q. We have shown that this parameter affects both the stiffness and the mobility of the effective fluid. Our results demonstrate that, in partial saturation scenaria, the characteristic squirt frequency may be lower than that dictated by the mobility of the more viscous fluid. By applying our results to an example drawn from CO_2 storage we assessed the impacts of the above modelling approach in the velocity and attenuation of a sand of a saline aquifer, partially saturated by either liquid or supercritical CO_2.

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