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Oscillatory waves in residual saturated porous media: Theoretical and numerical investigations

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Understanding the dynamical and acoustical behavior of porous rocks is of great importance in geophysics, e.g. earthquakes, and for various seismic applications, e.g. hydrocarbon exploration. While many studies investigated wave propagation in fully-saturated porous rocks analytically and numerically, studies for partially-saturated porous rocks are rare. However, several physical processes relevant at low frequencies take place only in partially saturated rocks but not in fully saturated rocks, such as for example capillarity-induced resonance of oil blobs [2] or wave-induced fluid flow [6, 1] Capillarity-induced resonance of trapped oil blobs at residual saturation can be excited by sound waves and is caused by the contact-line dynamics [2, 3]. The resonant oscillations of fluid blobs can also cause considerable attenuation at the resonance frequency. However, in models describing such resonance effects the porous skeleton is often assumed rigid and only relative movements between the discontinuous fluid blobs and the solid skeleton are considered.
We present a three-phase model describing wave propagation phenomena in residual-saturated porous media. The model consists of a continous non-wetting phase and a discontinuous wetting phase and is an extension of classical biphasic (Biot-type) models. The model includes resonance effects of single liquid bridges or liquid clusters with miscellaneous eigenfrequencies taking into account a viscoelastic restoring force (pinned oscillations and/or sliding motion of the contact line). For the quasi-static limit case, i.e. $\omega \to 0$, the results of the model are identical with the phase velocity obtained with the Gassmann-Wood limit.
In the present investigation, our aim is to study attenuation due to fluid oscillations and attenuation due to wave-induced flow with a macroscopic three-phase continuum model, i.e. a mixture consisting of one solid constituent building the elastic skeleton and two immiscible fluid constituents. Thus we develop the governing field equations, especially the momentum interaction between the inherent constituents. Furthermore, we study monochromatic waves in transversal and longitudinal direction and discuss the resulting dispersion relations for a typical reservoir sandstone equivalent (Berea sandstone). Finally, we discuss 2-dim numerical results based on fully-coupled transient Galerkin finite element methods.

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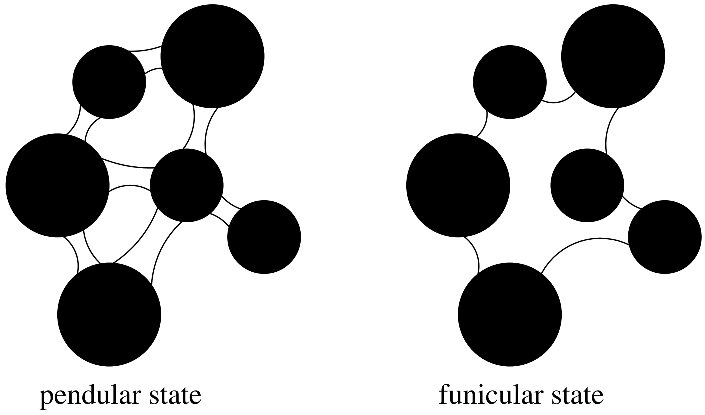

Figure 1: A residual-saturated porous medium. Left: pendular state with individual liquid bridges, Right: funicular state with a liquid cluster, cf. [4]

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