Oscillatory flow in elastic tubes: experiments and implications for pore-scale modeling

P. Kurzeja[a*]
[a] Institute of Mechanics, TU Dortmund, Dortmund, Germany
* corresponding author: patrick.kurzeja@udo.edu

Abstract:

Oscillatory flow of compressible fluids in elastic tubes constitutes a key element in the description of pore-scale hydromechanics. Applications also include fluid transport in boreholes, technical apparatus or the blood system, to name only a few. The assumptions and limitations of the respective descriptions vary accordingly[1]. The present study is based on the work of Kurzeja *et al.*[2] and involves the theory of Bernabé[3]. It focuses on the influence of tube deformability that is often neglected or simplified. For instance, Biot's pioneering approach[4] predicts wave propagation through a deformable macroscopic rock, yet it assumes a rigid tube network on the pore scale allowing only a single and fluid-bound propagation mode.

Experimental excitations show that the rigid-tube assumption is valid for steel tubes filled with air and different liquids, respectively (water and two different aqueous sodium-tungstate solutions). In contrast, the rigid-tube assumption fails strongly for silicone tubes filled with liquids. Back calculating the propagation speed along the tube, the wave mode in liquid-filled silicone is highly attenuated and associated to the silicone's low shear-wave velocity. A low solid shear-frame modulus can thus cause significant macroscopic attenuation. Accordingly, a theoretical description needs to extend the rigid-tube approach by the solid's shear compliance.

Yet another modification is required for silicone tubes when filled with air. The experiments indicate an air-bound wave evolving around Biot's characteristic frequency. Interestingly, this observation is well described by the simple rigid-tube assumption but not by its former extension. This underlines that predictions of a more complex model do not necessarily perform better. Alternatively, accounting for both the solid's shear and bulk compliance yields a correct model prediction for the silicone-air combination. It successfully considers the air-bound wave to be a dispersive, second wave - faster that the solid's shear mode but slower than the solids bulk/longitudinal mode. In conclusion, the prototype system of oscillatory flow in elastic tubes allows evaluating significant assumptions that are relevant for various material combinations in hydromechanical systems. In particular, the influence of pore-scale elastic properties must be considered carefully to correctly predict the propagation speed and associated attenuation modes.

---

[1] Tijdeman, H. (1975). *J. Sound Vib.* 39, 1-33.
[2] Kurzeja, P., Steeb, H., Strutz, M.A. and Renner, J. (2016). *J. Acoust. Soc. Am.* 140, 4378-4395.
[3] Bernabé, Y. (2009). In *Rock Physics and Natural Hazards*, Pageoph Topical Volumes ed. by S. Vinciguerra and Y. Bernabé (Birkhäuser, Basel), 969-994.
[4] Biot, M.A. (1956). *J. Acoust. Soc. Am.* 28, 179-191.