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# Effect of Pore Size Polydispersity on Acoustic Properties of High-Porosity Solid Foams

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This work numerically investigates the influence of pore size polydispersity on the acoustic behavior of high-porosity open-cell solid foams, using proxy geometries defined by Laguerre tessellations [1]. The polydispersity degree of a random foam is characterized by the coefficient of variation of the pore size,  $C_d = \sigma_d/d$ , where  $d$  is the number-weighted size average of pores and  $\sigma_d$  is the corresponding standard deviation. All windows are opened with an identical aperture ratio denoted by  $\tau_o$  and defined as  $\tau_o = \sqrt{S_o/S_w}$ , where  $S_o$  is the area of the window aperture and  $S_w$  is the total area of the window (see Fig. 1). The main results are as follows. First, the effect of the size of the periodic unit cell (PUC) or domain size  $L$  on transport parameters was examined. It was found that the size of the PUC required for simulating acoustic properties of random foams is parameter-dependent and depends on the polydispersity degree. Specifically, the results indicate that the viscous permeability  $k_0$  predominantly controls convergence for the acoustic properties, and that foams exhibiting high polydispersity require a large number of pores to achieve proper convergence in terms of morphological characteristics and acoustic properties (see Fig. 2a). Indeed, it is seen that reaching convergence for the other transport parameters (namely, the thermal permeability  $k'_0$ , the viscous  $\Lambda$  and thermal  $\Lambda'$  characteristic lengths, and the tortuosity  $\alpha_\infty$ ) requires a smaller domain size  $L/d$ . Second, the influence of polydispersity on the dimensionless transport parameters  $\mathcal{TP}^*$  was analyzed. It was found that the high-frequency tortuosity  $\alpha_\infty$  is almost independent of the polydispersity degree  $C_d$ , while increasing  $C_d$  leads to a systematic increase of the remaining macroscopic parameters (when compared to the monodisperse case); See Fig. 2b. The simulations also revealed that the ratio of the dimensionless transport parameters does not depend on the membrane aperture ratio. These important observations imply that the main curves shown in Fig. 2b can be used to predict the transport and sound absorbing properties of random polydisperse foams, based on a limited number of parameters—namely,  $C_d$ ,  $\tau_o$ , and  $d$ . Third, the proposed method was employed to identify the pore size average  $d$  and polydispersity degree  $C_d$  in real foam samples (with or without membranes), solving an inverse problem with transport parameters determined through direct characterization (see Tab. 1).

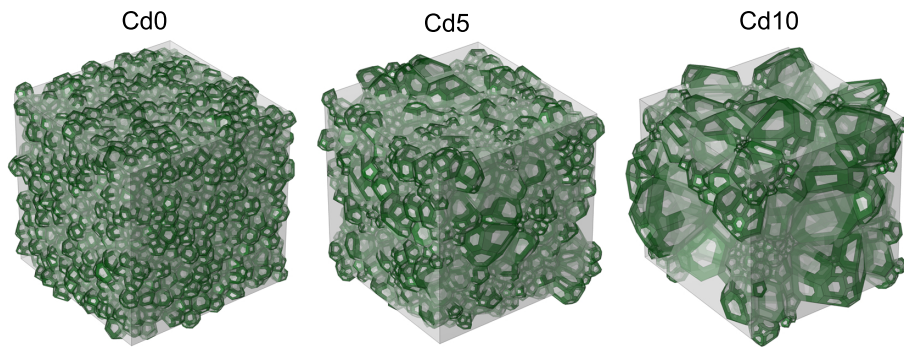


Figure 1: Illustration of the numerically generated foam structures, corresponding to an increase of the polydispersity degree. In this example, the coefficient of variation of the pore size is respectively equal to 3.0%, 44% and 73% (from left to right). Periodic conditions are imposed during the generation process. The size of the domain  $L$  corresponds to  $L/d = 10$ ,  $d$  being the average pore diameter.

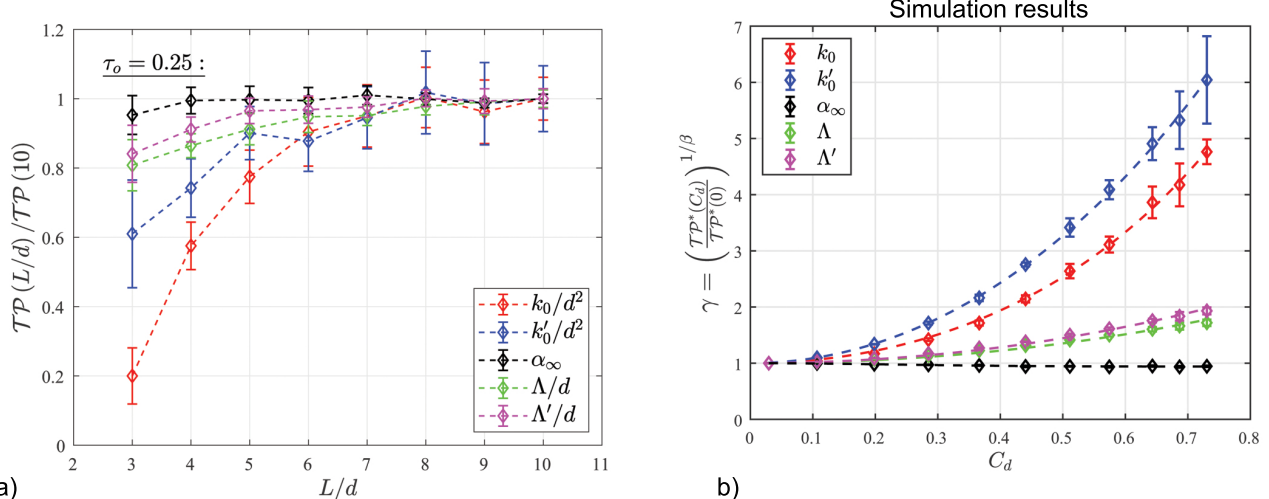


Figure 2: a) Convergence of transport parameters for Cd10. b) Simulation results ( $\beta = 1$  for  $\Lambda$ ,  $\Lambda'$  and  $\alpha_\infty$ ;  $\beta = 2$  for  $k_0$  and  $k'_0$ ). The error bars correspond to standard deviations.

Foam	$d$ ( $\mu\text{m}$ )	$C_d$ (-)	$\tau_o$ (-)	$\phi$ (-)	$k_0$ ( $\times 10^{-10} \text{m}^2$ )	$\alpha_\infty$ (-)	$\Lambda$ ( $\mu\text{m}$ )	$\Lambda'$ ( $\mu\text{m}$ )
<u>Melamine</u>								
Direct Charac.	—	—	—	$0.99 \pm 0.002$	$16.71 \pm 1.78$	$1.02 \pm 0.01$	$100 \pm 10$	$190 \pm 15$
Refs. [2, 3]	232	—	—	0.986	9.69	1.03	144	250
Ref. [4]	305	—	—	0.986	16.71	1.03	190	329
Our model	118	0.51	—	$\approx 1$	16.71	1.03	100	185
<u>Polyurethane</u>								
Direct Charac.	—	—	—	$0.96 \pm 0.020$	$14.49 \pm 2.20$	$1.79 \pm 0.03$	$66 \pm 4$	$286 \pm 59$
Refs. [2, 3]	220	—	—	0.986	8.71	1.03	137	237
Ref. [4]	284	—	—	0.986	14.49	1.03	177	306
Ref. [5]	1092	0	0.35	0.986	14.49	1.79	101	358
Our model	593	0.38	0.35	$\approx 1$	14.49	1.79	66	244

Table 1: Macroscopic parameters of the studied foam samples. "Direct charac." corresponds to the values given in Foam-X user's guide available for benchmark purposes. The other estimates are obtained by means of previously published models (Refs. [2, 3, 4, 5]) of the literature and the proposed approach ("Our model").

## References

- [1] C. T. Nguyen, V. Langlois, J. Guilleminot, F. Detrez, A. Duval, M. Bornert, P. Aïmediu and C. Perrot, *Polydisperse solid foams: Multiscale modeling and simulations of elasto-acoustic properties including thin membrane effects*, Int. J. Solids Struct. **249**, pp. 111684, 2022.
- [2] K. V. Horoshenkov, K. Attenborough and S.N Chandler-Wilde *Padé approximants for the acoustical properties of rigid frame porous media with pore size distributions*, J. Acoust. Soc. Am., **104**, pp. 1198-1209, 1998.
- [3] K. V. Horoshenkov, *A review of acoustical methods for porous material characterisation*, Int. J. Acoust. Vib. **1**, pp. 99-103, 2017.
- [4] C. Perrot, F. Chevillotte, M. T. Hoang, G. Bonnet, F. X. Bécot, L. Gautron and A. Duval, *Microstructure, transport, and acoustic properties of open-cell foam samples: Experiments and three-dimensional numerical simulations*, J. Appl. Phys. **111**, pp. 014911, 2012.
- [5] M. T. Hoang and C. Perrot, *Solid films and transports in cellular foams*, J. Appl. Phys. **112**, pp. 054911, 2012.