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Predicting Acoustical Performance of High Surface Area Particle Stacks with a Poro-Elastic Model

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Predicting Acoustical Performance of High Surface Area Particle Stacks with a Poro-Elastic Model

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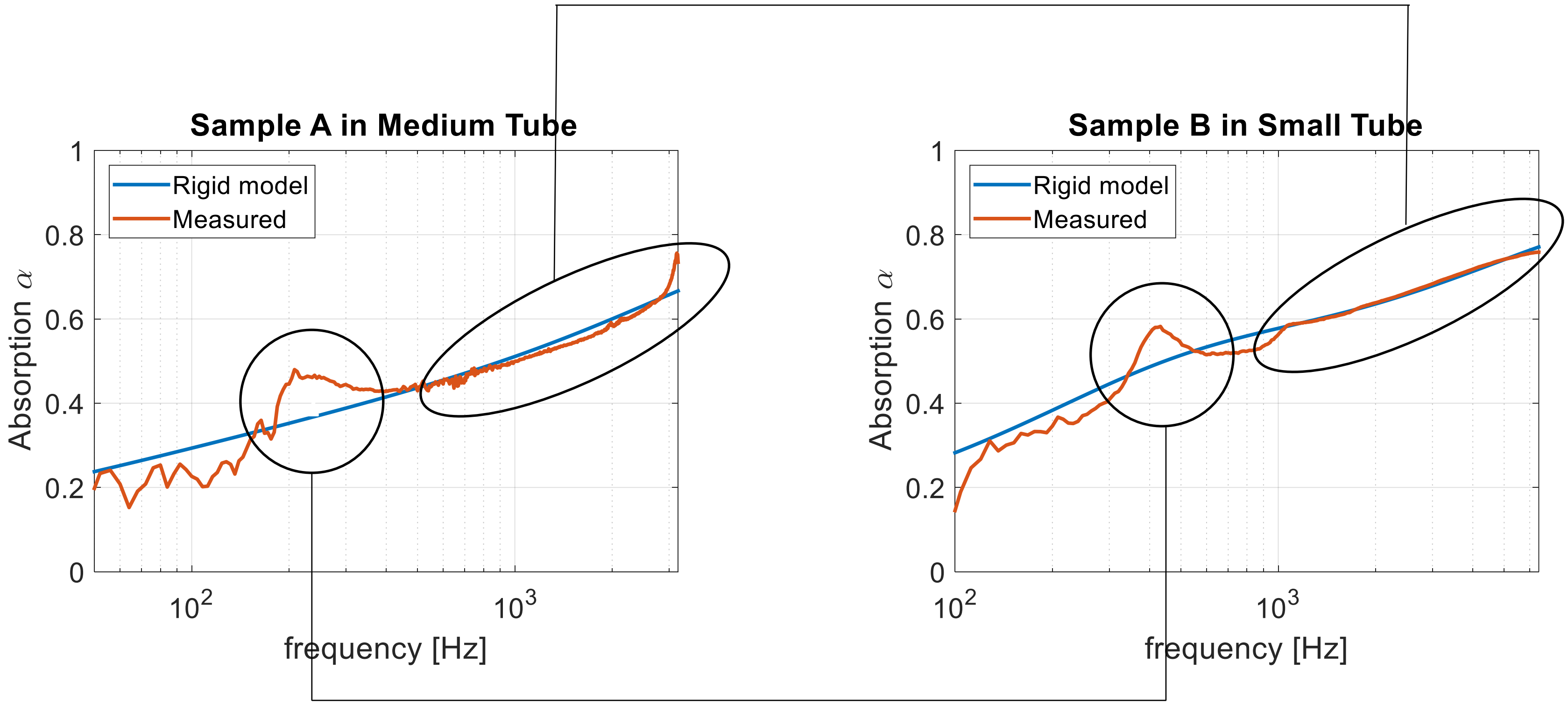
CONTENT

- Granular Activated Carbon (GAC)
  A review of rigid model for triple porosity particles
- Measurement
  The two-microphone measurement of rigidly backed particle stacks
- Poro-Elastic Model and Its Stable Approach
  The proposed poro-elastic model for GAC
- Particle Swarm Optimization
  Introduce the settings of the fitting procedure
- Fitting Result
  Show fitted results of two types of particles and compare them with corresponding measurement
- Conclusion

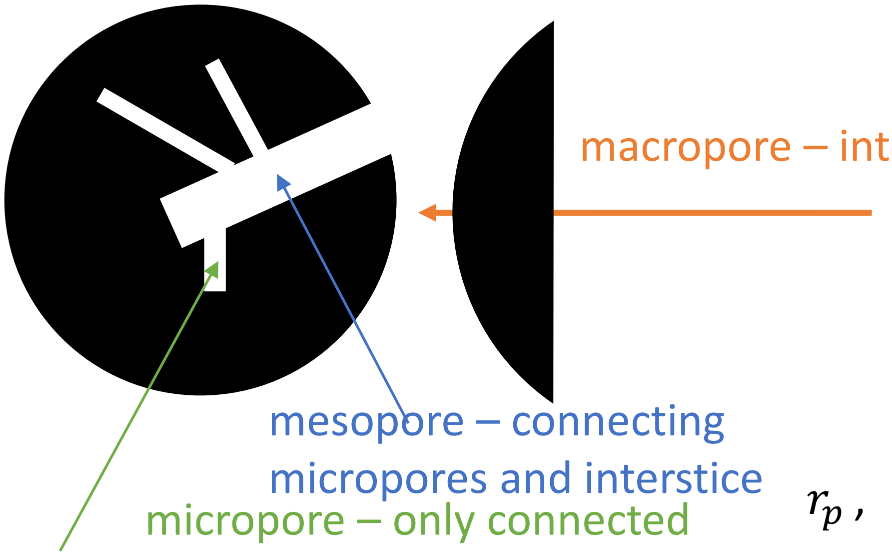
WHY PORO-ELASTIC MODEL

asymptotic behavior matches



resonance peak not predicted

TRIPLE POROSITY MODEL



macropore – interstice

mesopore – connecting micropores and interstice

micropore – only connected with mesopores, not directly connected to the interstice

Such material shows excellent low frequency absorption due to its sorption process inside the pores, which brings this material into our interest to further study its properties.

The bulk modulus of different scales are connected in series,

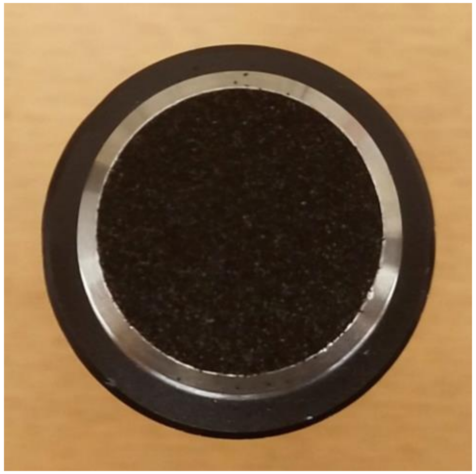
$$B = \left(\frac{1}{B_p} + \frac{1-\phi_p}{B_u} F_d\right)^{-1}$$

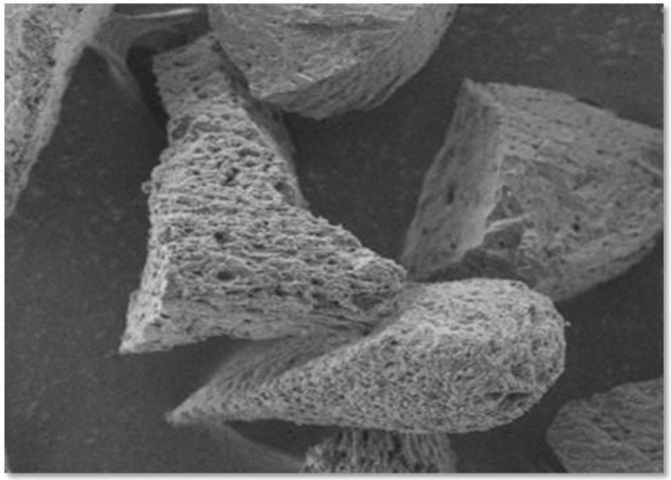
$$B_u = \left(\frac{1}{B_m} + \frac{1-\phi_m}{B_n} F_{nm}\right)^{-1}$$

r_p, r_m, r_n denote the particle radius, mesopore radius, and micropore radius. ϕ_p, ϕ_m, ϕ_n, and ϕ_{tb} denote the porosity on intergranular scale, mesoscale, micro-scale, and the overall porosity. The relation between the porosities on different scales:

$$\phi_{tb} = \phi_p + (1-\phi_p)[\phi_m + (1-\phi_m)\phi_n]$$

MEASUREMENT





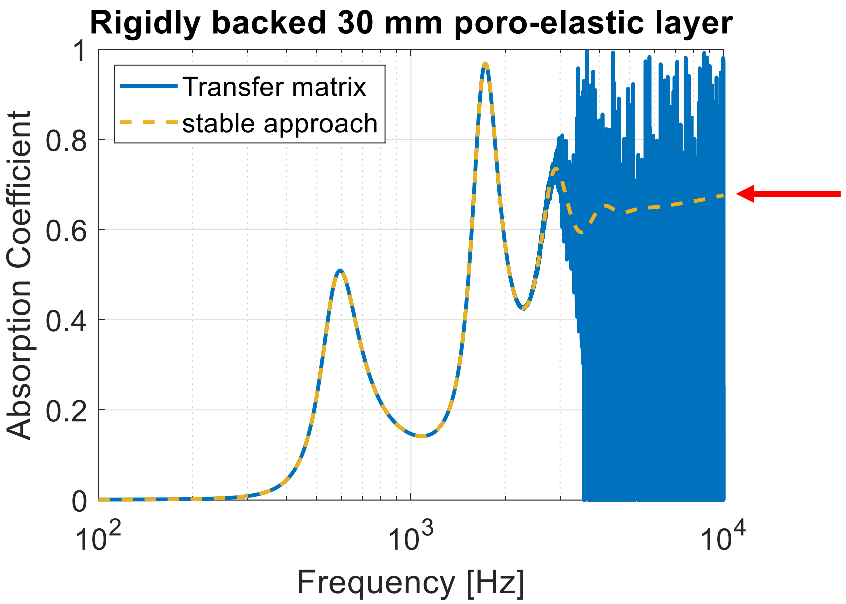
The particle stacks were measured in vertically-positioned standing wave tube with two microphones, following standard E1050.

The stacks were 30mm-thick, and rigidly backed.

The test result in medium tube is valid up to 3200 Hz, while in small tube it is valid up to 6400 Hz.

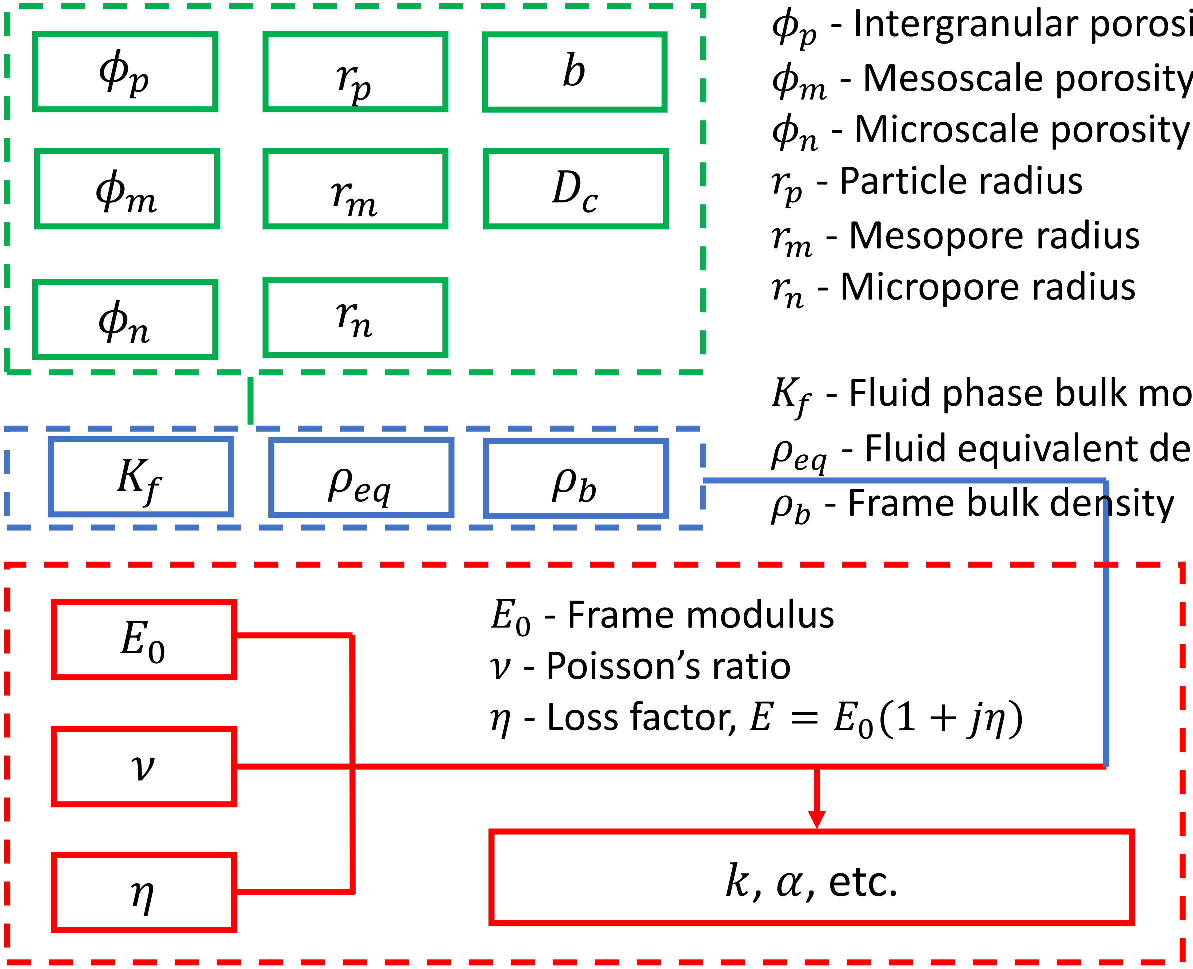
PORO-ELASTIC MODEL

- Three waves are propagating in the porous material:
  Compressional wave in frame
  Compressional wave in fluid phase
  Shear wave in frame
- The poroelastic model was built based on the stable approach, proposed by Dazel, Groby, Brouard, and Potel in 2013.
- By comparing the absorption coefficient obtained from the transfer matrix approach and the stabilized approach, one can find perfect matching at low frequencies, before the transfer matrix approach begins to diverge.



σ[rayls/m]	ϕ	α_∞	ρ_b[kg/m^3]
1.5×10^6	0.92	1.3	24
E[Pa]	Loss factor	ν	θ
6000	0.004	0.27	0

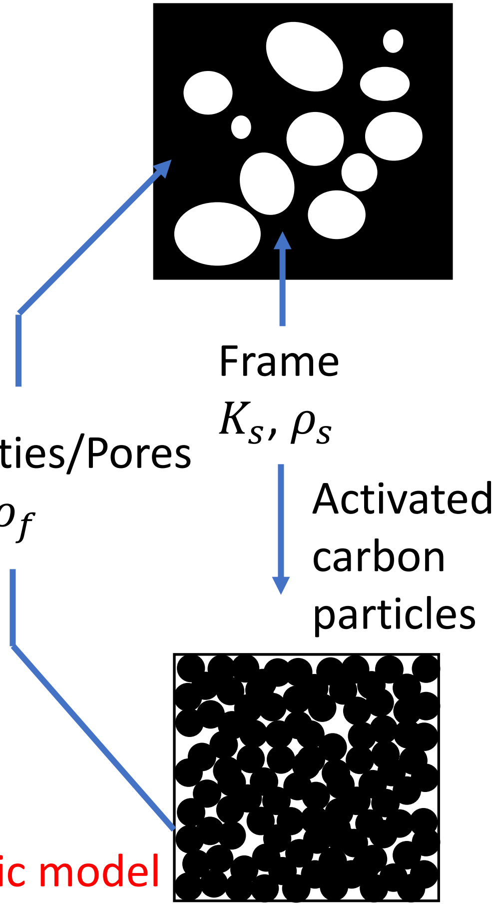
PORO-ELASTIC MODEL



b - Langmuir constant
D_c - Configurational diffusivity
ϕ_p - Intergranular porosity
ϕ_m - Mesoscale porosity
ϕ_n - Microscale porosity
r_p - Particle radius
r_m - Mesopore radius
r_n - Micropore radius

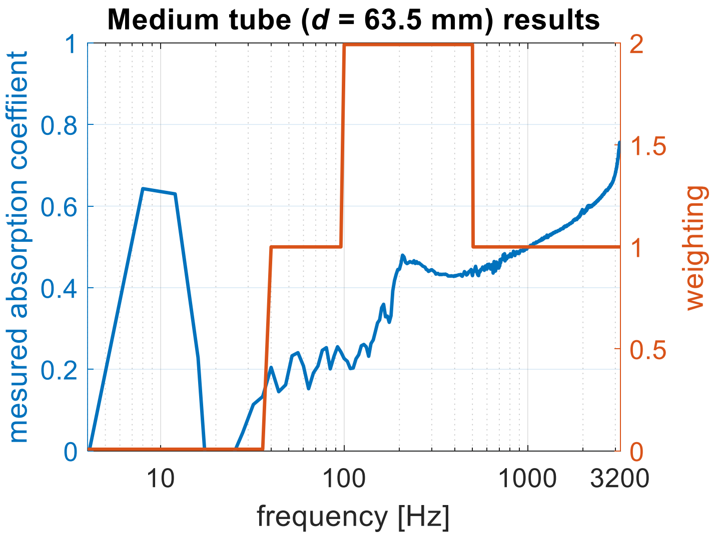
K_f - Fluid phase bulk modulus
ρ_{eq} - Fluid equivalent density
ρ_b - Frame bulk density

E_0 - Frame modulus
ν - Poisson's ratio
η - Loss factor, $E = E_0(1 + j\eta)$

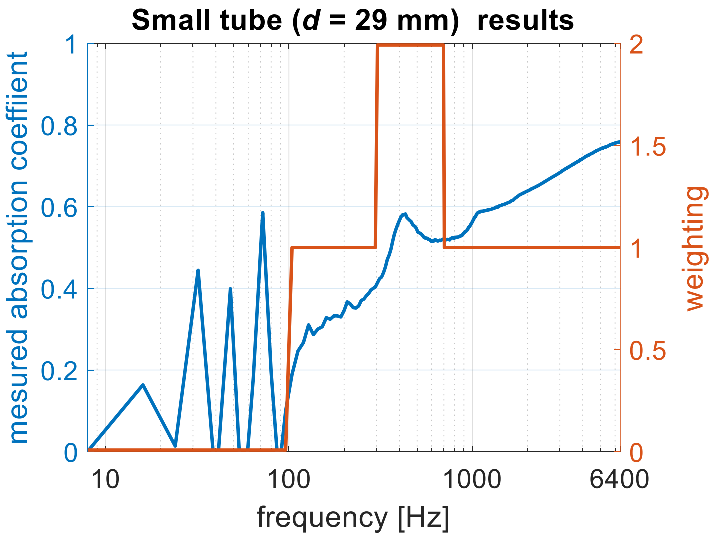


PARTICLE SWARM OPTIMIZATION

All parameters are fitted with constrained particle swarm algorithm, which is realized by a package available at https://github.com/sdnchen/psomatlab



Medium tube (*d* = 63.5 mm) results



Small tube (*d* = 29 mm) results

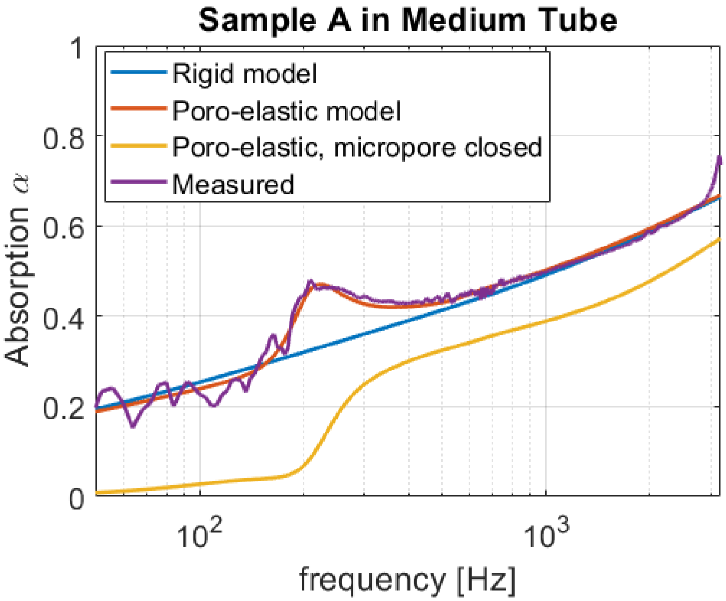
$$\min_{\mathbf{x}} \quad f(\mathbf{x}) = \mathbf{w}^{\mathrm{T}}(\mathbf{a} - \mathbf{a}_m)^2/N$$

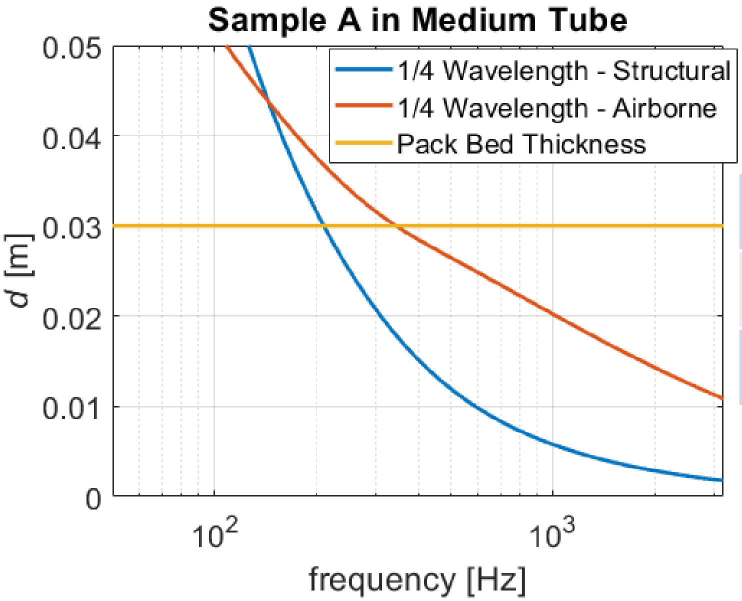
$$\text{s.t.} \quad \mathbf{x}_{lb} < \mathbf{x} < \mathbf{x}_{ub}$$

$$\rho_{lb} < \rho_c\left(1 - \phi_p - (1 - \phi_p)(\phi_m + (1 - \phi_m)\phi_n)\right) < \rho_{ub}$$

$0.95\rho_m$ Where ρ_m is measured bulk density $1.05\rho_m$

FITTING RESULTS

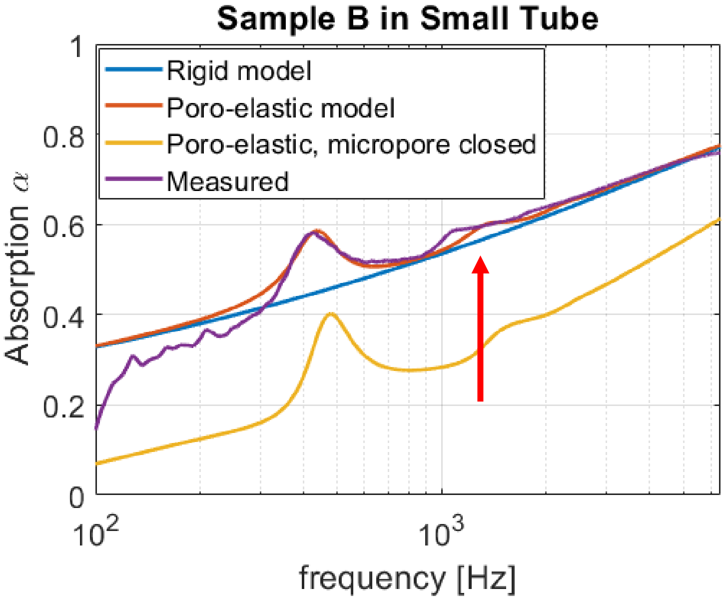


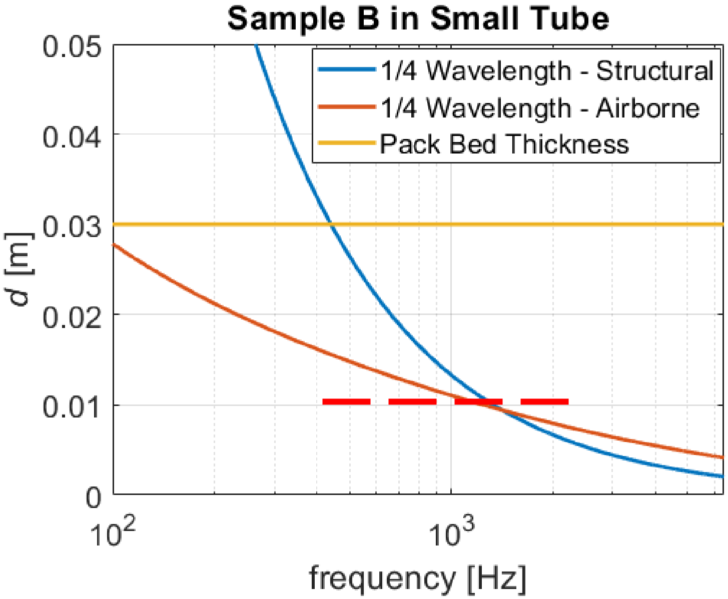


E_0 [Pa]	$\mathbf{2.3090 \times 10^5}$
η	$\mathbf{0.2963}$
ν	$\mathbf{0.0357}$

	r_p [mm]	r_m [μm]	r_n [nm]	ϕ_p	ϕ_m	ϕ_n	b[Pa^{-1}]	D_c [m^2/s]
Lower bound	0.105	0.01	0.2	0.260	0.1	0.3	5×10^{-7}	5×10^{-11}
Fitted value	**0.1111**	**5.2526**	**0.3637**	**0.4278**	**0.1671**	**0.5518**	$\mathbf{5.3967 \times 10^{-6}}$	$\mathbf{2.6404 \times 10^{-10}}$
Upper bound	0.2125	10	0.5	0.476	0.4	0.8	1×10^{-5}	5×10^{-10}

FITTING RESULTS

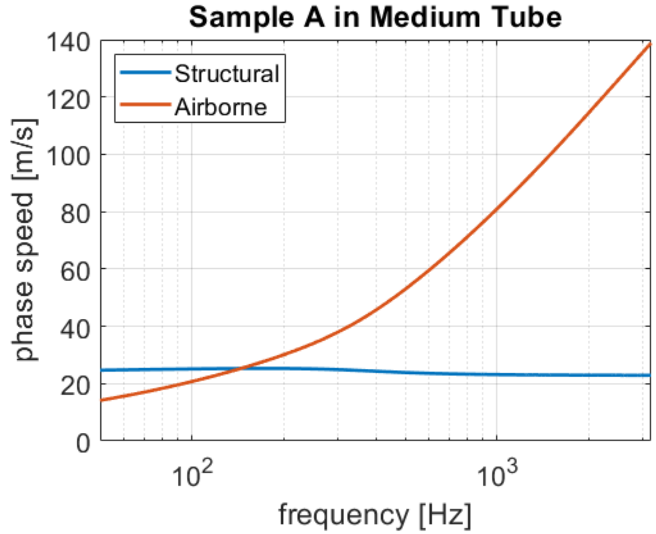

Sample B in Small Tube

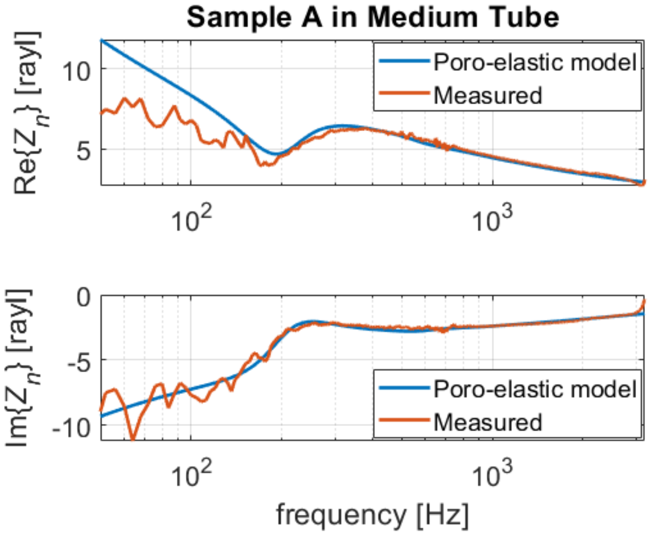

Sample B in Small Tube

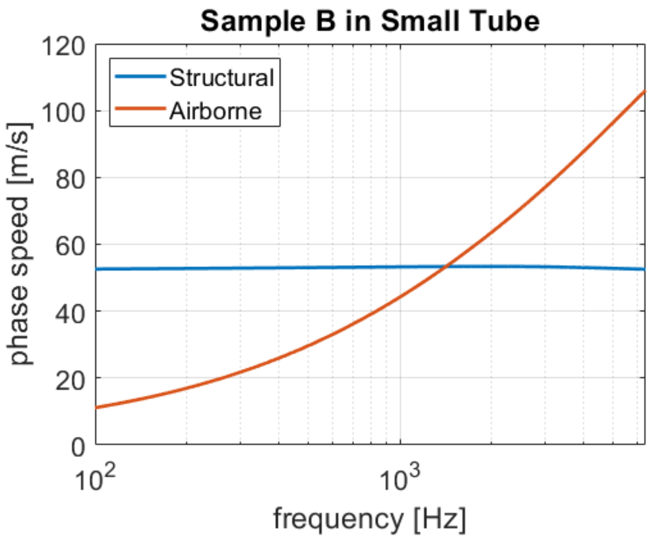
E_0 [Pa]	$\mathbf{5.2113 \times 10^5}$
η	$\mathbf{0.3552}$
ν	$\mathbf{0.3753}$

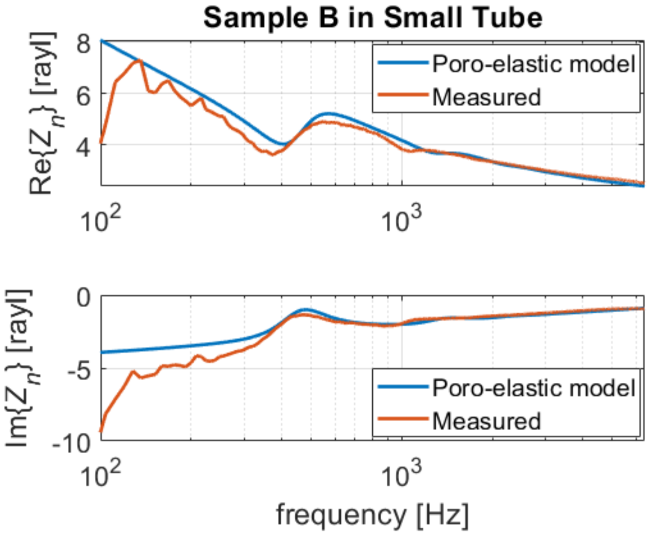
	r_p [mm]	r_m [μm]	r_n [nm]	ϕ_p	ϕ_m	ϕ_n	b[Pa^{-1}]	D_c [m^2/s]
Lower bound	0.075	0.01	0.2	0.260	0.2	0.35	5×10^{-7}	5×10^{-11}
Fitted value	**0.1160**	**4.5014**	**0.2000**	**0.3524**	**0.4668**	**0.4989**	$\mathbf{7.2657 \times 10^{-6}}$	$\mathbf{8.8559 \times 10^{-11}}$
Upper bound	0.161	10	0.5	0.476	0.8	0.55	1×10^{-5}	5×10^{-10}

FITTING RESULTS









CONCLUSIONS

- The poro-elastic model can predict the behavior of the particle stack at high frequencies,
  where rigid model generates similar results.

- The poro-elastic model can capture the resonance peak,
  at the frequency where the stack thickness corresponds to a quarter wavelength of structural wave.

- In some cases, a second peak in absorption coefficient is also predicted by the poro-elastic model,
  at the frequency where the stack thickness corresponds to three quarter wavelengths of structural wave.

- The fitting results from poro-elastic model gives reasonable bulk density prediction,
  in these two cases, this prediction is constrained in $\pm 5\%$ range of measured value.

- The absorption coefficient is significantly benefited from the micropores,
  which is consistent with the conclusion drew from the rigid model.

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