On the characterization of acoustical porous media
I focus on porous materials...
I focus on porous materials... composed with 2 phases

ACOUSTIC characterization provides parameters describing visco-thermal dissipation in fluid phase.

VISCO-ELASTIC characterization provides parameters describing the skeleton motion.
Visco-elastic Characterization


Forthcoming Inter-laboratory test on elastic characterization:
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One issue: Many acoustic parameters

Material morphology and number of parameters

Straight cylindrical pores

Slanted cylindrical pores

Non uniform sections

Non-uniform sections with possible constrictions

Model and parameter examples

Zwikker-Kosten
\[ \phi \sigma = \eta/k_0 \]

Miki
\[ \phi \sigma \alpha_\infty \]

Attenborough
\[ \phi \sigma \alpha_\infty b \]

Wilson
\[ \rho_\infty \tau_{\text{vor}} \ K_\infty \ \tau_{\text{ent}} \]

Johnson-Champoux-Allard-Lafarge
\[ \phi \sigma \alpha_\infty \Lambda \ \Lambda' \ k_0' \]

Johnson-Champoux-Allard-Pride-Lafarge
\[ \phi \sigma \alpha_\infty \Lambda \alpha_0 \ \Lambda' \ k_0' \alpha_0' \]

→ Most descriptive models need 5 to 8 acoustic parameters
Open porosity \( \phi \)

Network of connected pores (open porosity)

Closed pore (part of skeleton)

Dead-end pore

Range of values:
less than 0.01 (for facings)
to more than 0.99
Open porosity - Pressure difference (~pycnometer)

L. L. Beranek 1942, DOI: 10.1121/1.1916172
Champoux et al. 1990, DOI: 10.1121/1.1894653
ISO 4590 (2002), Link: www.iso.org
Leclaire et al. 2003, DOI: 10.1063/1.1542666
Open porosity - Pressure difference (~pycnometer)

**PROS**
- Applied on all types of materials
- Accuracy of 0.01

**CONS**
- Requires large samples for accurate results
Open porosity - Archimedes’ principle / Fluid saturation

1

2

Panneton & Gros 2005 Link: www.ingentaconnect.com
Salissou & Panneton 2007, DOI: 10.1063/1.2749486
Open porosity - Archimedes’ principle / Fluid saturation

**Pros**
- Easy set-ups unless use of fluids other than air or water

**Cons**
- Usually lower accuracy compared to pressure difference
  (saturate the pore network can be difficult)
Static air flow resistivity $\sigma$

$\phi \vec{v} = -\frac{1}{\sigma} \vec{\nabla} p$

Range of values:

$[0, +\infty]$ N.s.m$^{-4}$
Static air flow resistivity - Pressure difference

Laminar flow of dry air

Differential pressure transducers

\[ \Delta P_1 \]

\[ \Delta P_2 \]

Resistivity Reference

Material sample

ISO 9053 (1991), Link: [www.iso.org](http://www.iso.org)

(currently under revision, send comments to luc.jaouen@matelys.com)
Static air flow resistivity - Pressure difference

Laminar flow of dry air

Differential pressure transducers

ΔP₁  ΔP₂

Resistivity Reference

Material sample

PROS
- Direct measurement

CONS
- Boundary conditions can highly impact the results
Static air flow resistivity - Low freq. asymptote of $\text{Im}(\tilde{\rho})$

Set-up at ENTPE / Matelys

Panneton & Olny 2006, DOI: 10.1121/1.2169923
Static air flow resistivity - Low freq. asymptote of $\Im(\tilde{\rho})$

**Measurements with an impedance tube at audible frequencies.**

**Pros:**
- Measurements with an impedance tube at audible frequencies.

**Cons:**
- Asymptote can be difficult to identify.
HF limit of the dynamic tortuosity $\alpha_\infty$

"We shall consider the value of $\alpha_\infty$ to be a measure of the disorder in the system."

D. L. Johnson, J. Koplik, R. Dashen

Range of values:

$[1 \quad - \quad 3]$
HF limit of dynamic tortuosity - Electric liquid saturation

R. J. S. Brown 1980, DOI: 10.1190/1.1441123
Johnson et al. 1982, DOI: 10.1103/PhysRevLett.49.1840
HF limit of dynamic tortuosity - Electric liquid saturation

**PROS**

- Direct measurement.

**CONS**

- Skeleton must be an electrical insulator.
- Open-porosity is required.
HF limit of dynamic tortuosity - 2 other methods

- Ultrasound waves:
  Give estimations for $\alpha_\infty$ and $\Lambda, \Lambda', (\phi)$

- Impedance tube:
  Give estimations for $\alpha_\infty$ and $\Lambda, \Lambda', k'_0$. 
Viscous ($\Lambda$) & thermal ($\Lambda'$) characteristic lengths

Range of values:

$[10 \quad \text{to} \quad 1000] \, \mu m$

$\Lambda \leq \Lambda'$
Static thermal permeability $k'_0$

Range of values:

\[ \left[ 0 \quad +\infty \right], \quad \text{with } k'_0 \geq k_0 \]
$\alpha_\infty, \Lambda, \Lambda', (\phi) - Ultrasounds$

Picture courtesy of W. Lauriks

Allard et al. 1994, DOI: 10.1063/1.1145097
Leclaire et al. 1996, DOI: 10.1121/1.415378
Leclaire et al. 1996, DOI: 10.1063/1.363817
Groby et al. 2010, DOI: 10.1121/1.3283043
\( \alpha_\infty, \Lambda, \Lambda', (\phi) \) - Ultrasounds

**Pros**

- Can quickly map heterogeneity

**Cons**

- Multiple scattering can occur
  - (measurements with 2 fluids thus needed)
Impedance tube

Set-up at ENTPE / Matelys

\alpha_\infty, \Lambda, \Lambda', k'_0

Panneton & Olny 2006, DOI: 10.1121/1.2169923
Olny & Panneton 2008, DOI: 10.1121/1.2828066
$\alpha_\infty, \Lambda, \Lambda', k'_0$ - Impedance tube

**PROS**
- Estimations at audible frequencies
- Analytical inversions (no fit)

**CONS**
- Porosity and resistivity must be known
- Sensible to frame vibrations, air leakages
A note about perforated facings

Jaouen & Bécot 2011, DOI: 10.1121/1.3552887
Conclusions & perspectives

There is and will be no perfect method but a bundle of complementary methods.

Acoustic characterization

- Many methods exist,
- still $\alpha_0$ and $\alpha'_0$ are not characterized.
  (perspectives at low freq. with long impedance tube).

Visco-elastic characterization

- Broadband characterization is still the exception.
- Too few work on anisotropy.
Thank you for your attention.
See you at SAPEM'17