Low-frequency broadband dissipation using Micro-Capillary Plates

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1 Introduction

The study of new absorbers for control of low-frequency noise constitutes a continuous area of research. Micro-perforated panels (MPPs) [1] can be adjusted to work optimally at low frequencies, but confined in a narrow frequency band as they build on the principle of Helmholtz resonances. To get rid of these limitations, the use of unbacked panels has been considered as an alternative to cavity-backed partitions. Optimization results have shown that reducing the size of the hole diameters down to 10 μm can then provide wideband absorption, but at the expense of an increase of the manufacturing cost. This work aims at investigating the acoustic properties of ultra-perforated membranes called micro-capillary plates (MCPs). Although these devices are currently used as image intensifiers or detectors of cosmic rays, they also found potential applications in the field of acoustics [2] to achieve low-frequency anechoic terminations. A MCP is a slab made up of a resistive material with typical thickness between 1 mm and 5 mm, composed of a regular array of slots or micro-channels densely distributed over the whole surface. The micro-channel diameters are between 10 μm and 50 μm and typical perforation ratios vary between 50% and 70%. In this work, we further investigate the potential of MCPs as wideband acoustic absorbers. An analytical approach will be used to describe different working regimes and to perform a parametric study to provide the performance prediction as a function of the constitutive physical parameters. We will compare results for different micro-capillary plates, working in the slip-flow regime, with those corresponding to a classical micro-perforated panel, operating in the classical continuum regime. The results obtained for the optimised configuration will be validated by the estimation of the absorption coefficient in a Kundt tube, presenting good agreement with the analytical predictions and validating the model. Finally, we will carry on a comparison with published results using a wire-mesh or a textile screen that are able to provide a controlled resistance that may adapt to the particular problem. We will finish with the conclusions and some ideas for further research.

2 Micro-Capillary Plate modelling

Rarefaction effects should be considering in the field of microfluids when characteristics lengths are of the order of 1 μm [4]. Well-established continuum laws have to be verified. In particular, a classification is done in terms of the ratio between the mean free path λ and the characteristic length L of the control volume, that is taken for this application as the diameter of the perforations. This quantity is called the Kundsen number, $\mathrm{Kn} = \lambda / L$,and characterizes rarefaction effects on the microchannels [4]. In particular, when $\mathrm{Kn} < 10^{-3}$ the flow is in the continuum regime and classical boundary conditions at the wall are fulfilled. On the other hand, when $10^{-3} \le \mathrm{Kn} \le 10^{-1}$, the flow is in the slip-flow regime, where a velocity and temperature jump have to be considered at the wall surface. Typically, most of the microsystems that work with gases are situated in the slip flow regime. Assuming straight cylindrical channels with longitudinal axis in harmonic regime ($e^{j\omega t}$),we apply linearized momentum and energy conservation to obtain the viscous transfer impedance of the channel, given per unit length, given by

$$Z_v = j\omega\rho_0 t\left\{1-\frac{2}{k_v r_0}\frac{J_1(k_v r_0)}{\left[J_0(k_v r_0)-B_v k_v r_0 J_1(k_v r_0)\right]}\right\}^{-1} \tag{1}$$

where $k_v = \sqrt{-j\omega\rho_0/\mu}$ is the viscous diffusion wavenumber, μ the air dynamic viscosity, ρ_0 the air density, and J_0 and J_1 are the Bessel functions of the first kind of orders 0 and 1 respectively. In this work we have simulate the acoustic performance of different specimens working in the slip-flow regime to perform an optimisation of the energy dissipated inside the materials by the proper selection of the constitute parameters.

3 Experimental study

The verification of the prediction is performed in a semi-anechoic environment using a small Kundt tube for the classical determination of the absorption coefficient with a inner radius of 1.50 cm [5]. It is situated vertically and connected on one side to a loudspeaker, drive n by a random pressure field up to 7 kHz. The micro-capillary sample is place on the upper side using an 3D PVC printed adaptor as its inner radius is smaller than the duct inner radius. Measured results are presented in Figure 1 in red for the unbacked and backed configurations. They are compared to the predictions with different anechoic loads. As it can be appreciated, good agreement is achieved for the unbacked configuration when assumed unflanged radiation load that consider the radiation impedance of the adaptor termination determined experimentally using a miniature pressure-velocity probe.

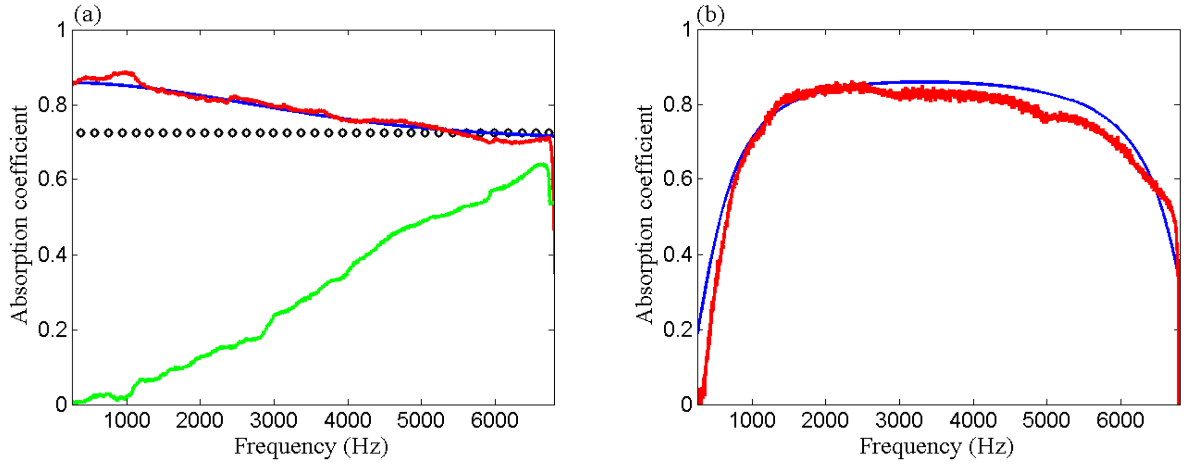

Figure 1 : (a) Normal incidence absorption coefficients of unbacked MCP: measured (red) and calculated assuming unflanged (blue) and anechoic (black circle) radiation loads, and that measured of the open adaptor termination (green); (b) Normal incidence absorption coefficient of MCP4 rigidly-backed by a cavity of depth 24 mm: measured (red) and calculated (blue).

4 Comparison of absorbers performance

Many materials used in demanding environments in the field of noise control are cover with a resistive layer used for protection, that can be selected to maximize the normal sound absorption of porous multilayers [6]. The proposed micro-capillary plates will be compared to show advantages and weakness in relation with other similar devices.

References

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