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 tailored to work optimally at low frequencies, but they are 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 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, denoted 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 to achieve low-frequency anechoic terminations [2]. 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 with respect to other traditional absorbers as well as their optimization. An analytical effective approach will be presented that describes different working flow regimes. It will enable to perform efficient parametric studies that provide the performance prediction of MCPs as a function of their constitutive physical parameters. Results are compared for different MCPs, working in the slip-flow regime, against those corresponding to classical MPPs, operating in the continuum regime. The simulation results obtained for optimised MCP configurations will be validated by measurements of their absorption coefficient in a Kundt tube, showing good agreement with the analytical predictions. Moreover, we will carry out a comparison against published results using a wire-mesh or a textile screen as resistive layers that are able to provide a controlled resistance suited to the particular problem of interest.

2 Micro-Capillary Plate modelling

Rarefaction effects should be considered in the field of microfluidics when characteristics lengths are of the order of 1 μm [3], as in the case in MCPs micro-channels. Well-established continuum laws may then not be valid. In particular, a regime classification is done in terms of the ratio between the molecular mean free path λ and the characteristic length L of the control volume, that is taken for MCPs as the diameter of the perforations. This quantity is called the Knudsen number, $\mathrm{Kn} = \lambda / L$: it characterizes rarefaction effects within the micro-channels [3]. In particular, when $\mathrm{Kn} < 10^{-3}$, the flow is in the continuum regime and classical continuity boundary conditions at the channel walls are fulfilled. On the other hand, when $10^{-3} \le \mathrm{Kn} \le 10^{-1}$, the flow is in the slip-flow regime: a velocity and temperature jump have to be considered at the wall surface. Typically, most of the microsystems that work with gases are in the slip flow regime. Assuming straight cylindrical channels with longitudinal axis in harmonic regime ($\mathrm{e}^{\mathrm{j}\omega t}$), linearized momentum and energy conservation lead to the viscous transfer impedance of a micro-channel, given per unit length by

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

where $k_v = \sqrt{-\mathrm{j}\omega\rho_0/\mu}$ 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. From Eq. (1), one can simulate the acoustic performances of MCP samples in slip-flow regime, which leads to an overall design chart of the MCP dissipation performance as a function of both the Knudsen number and the Shear number.

3 Experimental study

The validation of the simulated absorption results [4] is performed using a small Kundt tube with inner radius 1.5 cm. It is positioned vertically and connected on one side to a loudspeaker driven by a white noise signal up to 7 kHz. If unbacked, the MCP sample radiates on the other side into a semi-anechoic room. Measured absorption results are presented in Figure 1 in red for the unbacked and backed configurations. They are compared against predictions assuming different loads. As it can be appreciated, a good agreement is achieved for the unbacked configuration when assuming an unflanged radiation load. This load radiation impedance has been determined experimentally using a miniature pressure-velocity probe. Since the load behind the MCP significantly influences its acoustical performance, a discussion is provided of the sensitivity of the MCP dissipation performance to variations in the load impedance.

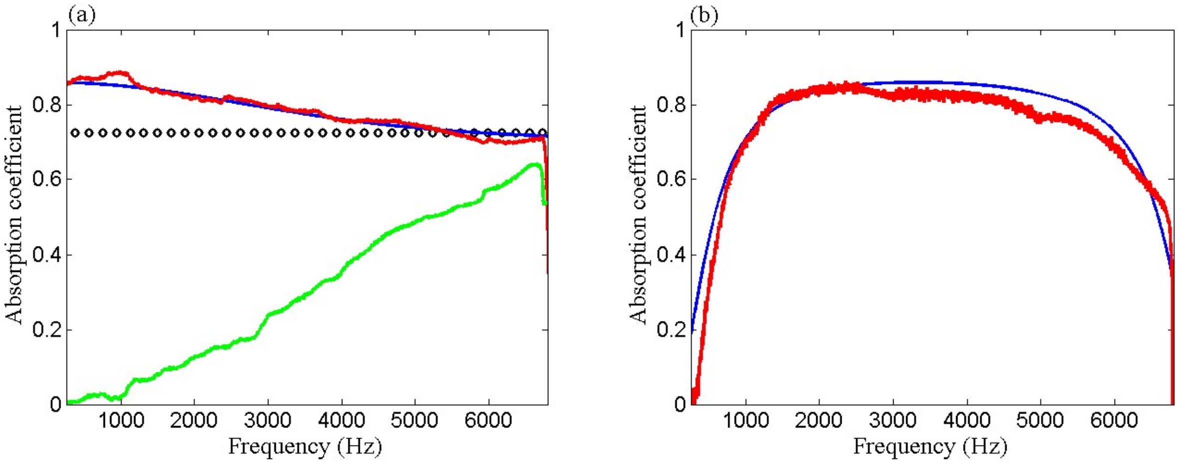

Figure 1 : (a) Normal incidence absorption coefficients of an unbacked optimized MCP: measured (red) and calculated assuming unflanged (blue) and anechoic (black circle) radiation loads, and that measured of an open termination without MCP (green); (b) Normal incidence absorption coefficient of an optimized MCP rigidly-backed by a cavity of depth 24 mm: measured (red) and calculated (blue).

4 Comparison with other absorbers performances

Many acoustic materials used in demanding environments in the fields of aeronautics or ventilating systems are covered with a resistive layer, initially used for protection, but whose parameters can be selected to maximize the normal sound absorption of such rigidly-backed porous layers [5]. The performance of MCPs backed by a downstream porous media will be compared against wire-mesh or textile screens in order to show their advantages and weaknesses in relation to other sound controlling devices.

References

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