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Analysis of behavior of porous material used for discharge system of hermetic compressor

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Abstract: Gas pulsation is an important noise source in household refrigerators. The pulsation is generated in the compressor discharge chamber and it is transferred to the cabinet through the condenser, which is directly connected to the back of the system. The discharge has a considerable contribution of the noise refrigerator. This work proposes the use of experimental method to explore the characteristic of porous material, which is used for discharge system of hermetic compressor. The most important acoustic parameter of porous material is the airflow resistivity. Experimental setup was developed to evaluate the nonlinear behavior. The obtained parameter can feed the analytical model, such as the Johnson-Champoux-Allard (JCA) that is an equivalent fluid model for acoustic material.

Keywords: airflow resisitivity, porous material, acoustics

NOMENCLATURE

Latin symbols

i: imaginary part of complex number
D: diameter of the sample
JCA: Johnson-Champoux-Allard
Ls: thickness of the sample
SPL: Sound Power Level
C: dimensionless empirical constant
Pr: Prandtl number
V_p: mean flow velocity
Q: volumetric airflow rate
Re: Reynolds number in porous media
R^2: correlation coefficient
S: cross-sectional area of the specimen
u: airflow velocity
UFSC: Federation University of Santa Catarina
LVA: Vibration and Acoustic Laboratory
Labmat: Materials Laboratory

Greek symbols

α: absorptive coefficient
α_∞: tortuosity
δ: dimensionless empirical parameter
ϕ: porosity of porous material
γ: ratio specific heat
$\tilde{k}$: stiffness of porous material
Λ: viscous characteristic length
Λ': thermal characteristic length
μ: dynamic viscosity of fluid
Λ': thermal characteristic length
ρ: density of fluid
$\tilde{\rho}$: density of porous material
υ: kinematic viscosity
σ: airflow resistivity
σ_o: airflow resistivity tendency
σ_r: airflow resistance
ω: angular frequency vector

Subscripts

ef: effective
o: fluid thermodynamic property
p: porous flow velocity
r: resistance
1: dimensionless empirical parameter
2: dimensionless empirical parameter
∞: relative to tortuosity of porous material

INTRODUCTION

Absorbers materials are useful in exhaust system to attenuate sound which is generated from compress of the fluid. Compressor system has acoustics filter (or muffler) in suction and discharge to control the attenuation of sound pressure of the refrigerant fluid. Mainly, the sound level pressure of the atmosphere discharge filter is about 150 dB (ref. 20.10^{-6} Pa). In fact, this highly is an important characteristic for engineer's projects and the researches (P&D) about extreme conditions of porous materials.

Acoustic material is represented by five macroscopic parameters: airflow resistivity, porosity, tortuosity and characteristic length: viscous and thermal. An equivalent fluid model needs these parameters for the analytical expression, like the effective dynamic density (e.g. inertial and viscous effects of porous material on fluid) and the bulk modulus (e.g. interaction between fluid and structure of porous material).

Airflow resistivity is the most important parameter, due to consider the nonlinear effect. According to ISO 9053 standard there are two methods to obtain the airflow resistivity: the alternating and the continuous airflow methods. This was used and developed in LVA (Laboratory of Acoustic and Vibration – UFSC – Florianópolis) for experimental test of the porous metallic material. The samples are made by sintering process (metallurgy powder) through the space holder technique.

LITERATURE

Equivalent fluid model

Zwikker and Kosten (1949) used the wave propagation model for rigid porous material to represent it like an equivalent fluid. In other words the porous medium is considered a fluid. The inertial and viscous effects of porous material on fluid, according to Eq. (1), e.g. the effective dynamic density. While Eq. (2) represents the interaction between fluid and structure of porous material, e.g. the effective bulk modulus. These equations are valid for Johnson-Champoux-Allard model which depends of five macro-acoustic parameters of the material (Champoux and Allard, 1991)

$$\tilde{\rho}_{ef}(\omega) = \rho_o\alpha_\infty\left(1+\frac{\phi\sigma}{\mathrm{i}\omega\rho_o\alpha_\infty}\left(1+\frac{4\omega\rho_o\mu\alpha_\infty^2}{\sigma^2\phi^2\Lambda^2}\right)^{1/2}\right), \tag{1}$$

$$\tilde{k}_{ef}(\omega) = \frac{\gamma P_o}{\gamma-(\gamma-1)\left(1+\frac{8\mu}{\mathrm{i}\omega\rho_o Pr\Lambda'^2}\left(1+\frac{\mathrm{i}\omega\rho_o Pr\Lambda'^2}{16\mu}\right)^{1/2}\right)^{-1}}. \tag{2}$$

The macroscopic parameters of the porous material are: ϕ is the porosity, α_∞ is the tortuosity, Λ is the viscous characteristic length, Λ' is the thermal characteristic length. Thermal properties of the fluid are: γ is the ratio specific heat, μ is the dynamic viscosity, Pr is the Prandtl number, ρ_o is the density, P_o is the static pressure.

Barbosa and Lenzi (2015) analysed muffler prototypes with absorbing material in chamber of its. The metallic porous material was modeled using equivalent fluid model, have been noted the improving attenuation for some range frequency.

Airflow resistivity

Cox and D'Antonio (2009) define the airflow resistivity as a measure of how easily air can enter a porous absorber and the resistance that air flow meets through a structure. It therefore gives some sense of how much sound energy may be lost due to boundary layer effects within the material. Equation (3) express this parameter and Eq. (4) is the airflow resistance,

$$\sigma = \frac{\Delta p}{Q}\frac{S}{L}, \tag{3}$$

$$\sigma_r = \frac{\Delta p}{Q}, \tag{4}$$

where Δp is the air pressure difference (Pa) across the sample, Q is the volumetric airflow rate (m^3/s), S is the cross-sectional area (m^2) and L is the thickness (m) of the test specimen.

According to Aurégan and Pachebat (1999) porous material could be used in several applications, mainly at high intense sound. In this context, the nonlinear behavior occurs in the sound propagation of the material due to nonlinearities in the flow field in the case of rigidly framed material. The research was developed with comparison between analytical model (i.e. equivalent fluid) and experimental measurement at high SPL. In fact, the behavior of airflow resistivity, linear and nonlinear, depends the Reynolds number calculated in porous media. Besides, the increase in resistivity describes most of the nonlinear effects appearing in rigidly framed porous media when the sound level increases. Equation (5) is known as Forchheimer's law (empirical behavior), which is valid for Re $>>$ 1 and the Equation (6) is valid for Re $<<$ 1. Reynolds number is defined in porous media through the Equation (7).

$$\sigma = \sigma_o((1-\delta)+C_1\mathrm{Re}), \tag{5}$$

$$\sigma = \sigma_o(1+C_2\mathrm{Re}^2), \tag{6}$$

$$\mathrm{Re} = \frac{2\Lambda V_p}{\upsilon}, \tag{7}$$

where $V_p = (Q/S)/\phi$ is the mean flow velocity and υ is the kinematic viscosity of the fluid. The dimensionless variables C_1, C_2 and δ are empirical parameters of the material. Figure 1 shows the behavior of the airflow resistivity for agglomerated rubber. It is noted for Re is much smaller than unity, when Re=Re$_c$ (i.e. critical Reynolds number) the behavior of the resistivity is quadratic which a deviation exits from the Forchheimer's law.

Umnova et al. (2003) evaluate a model for the propagation of high amplitude continuous sound for rigid porous layers. It is measured the flow resistivity on flow velocity as linear approximation for porous aluminum. This tendency could obtained the macro-acoustic (i.e. airflow resistivity) parameter to feed analytical model, such as the analysis the acoustic impedance and reflection coefficient.

The use of porous material in the chamber of the discharge muffler is an effective method for the attenuation of noise that control the performance of compressor (Soedel, 2006). Mareze (2009) noted that acoustics properties of the porous material like airflow resistivity, porosity and tortuosity are highly important input data of the analytic and numerical models. Also, Berger (2004) emphasizes the importance of flow resistivity for the characteristic of material at low frequencies.

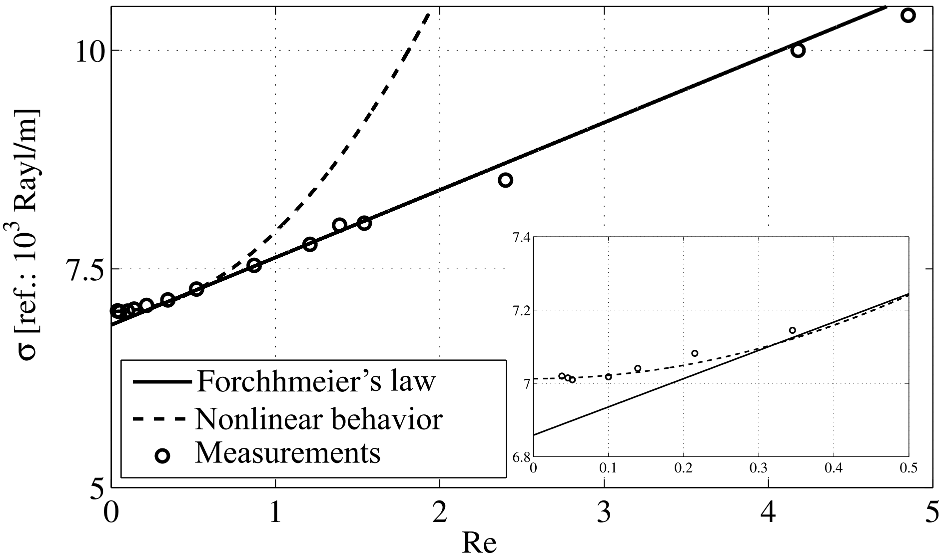

Figure 1 – Airflow resistivity as a function of Reynolds number. Ref.: Aurégan and Pachebat (1999).

ACOUSTICS MEASUREMENTS

The samples (see Fig. 2) are made of Niquel with Carbamida (space holder) on the LabMat, in the process was choose the grain size of 250 μm and the porosity ϕ=0.67. The geometric characteristics are: D = 25.5 mm and Ls = 6.5 mm. The instruments of the setup are depicted in Fig. 3, which are: measured flow range air (type 316L-0.25-2.5 L/min-Swagelok), two low pressure transmitter (type MBS 9200-40-250 mbar-Danfoss) and one signal acquisition (National Instruments with Labview software). Air compressed is used in the line tubing with control of a regulator microvalve.

Figure 2 – Samples of the measurements.

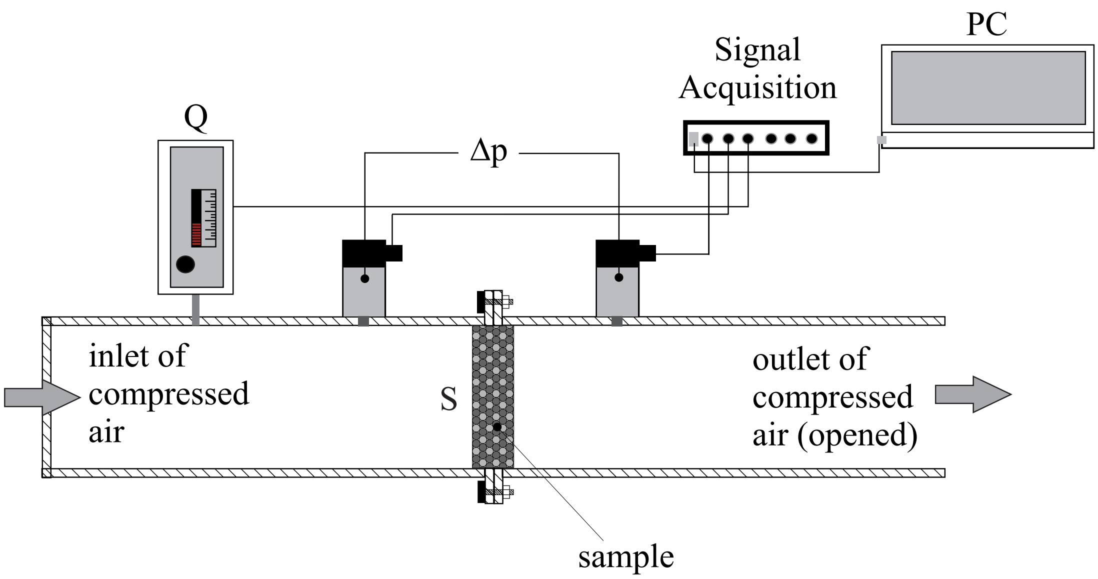

Figure 3 – Setup of the measurement of airflow resistivity.

The variation of pressure drop was analyzed for flow velocity range of 20-100 mm/s. Garai and Pompoli (2003) have been suggested the method of analysis consists in a linear regression on the pressure drop/velocity graph. Also this suggestion is valid to coefficient correlation $R^2 \geq 0.95$ as a quality criterion. In this context, it is noted for the measurements (see Fig. 4) the behavior of the linear regression which R^2 has tendency to unity. Figure 5 shows the linear fitting of the airflow resistivity average of the samples. The important value is the angular coefficient of the curve, i.e. σ=1.742.10^6 Pa.s/m^2.

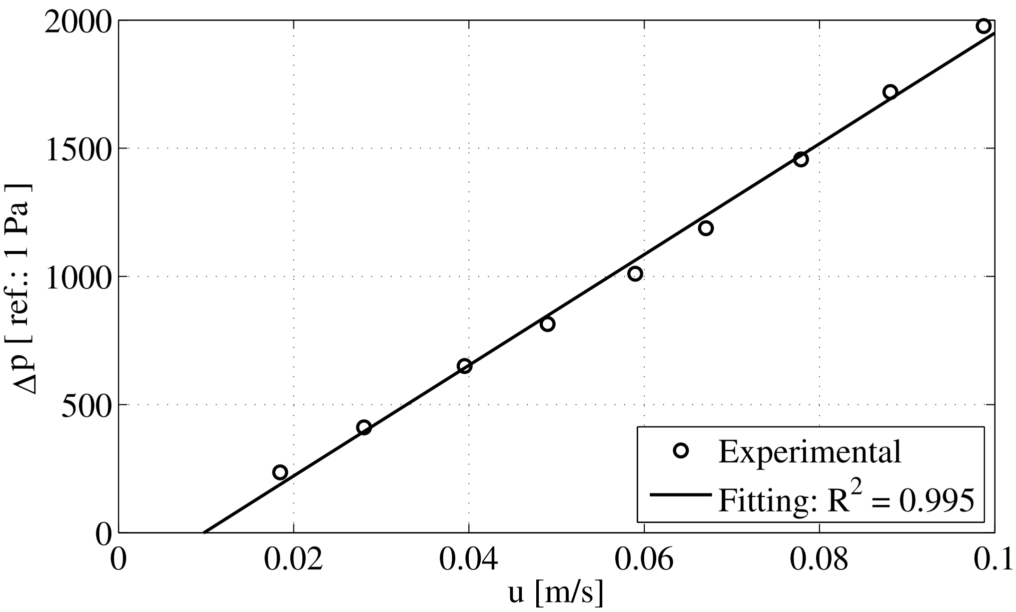

Figure 4 – Pressure difference as function of airflow velocity.

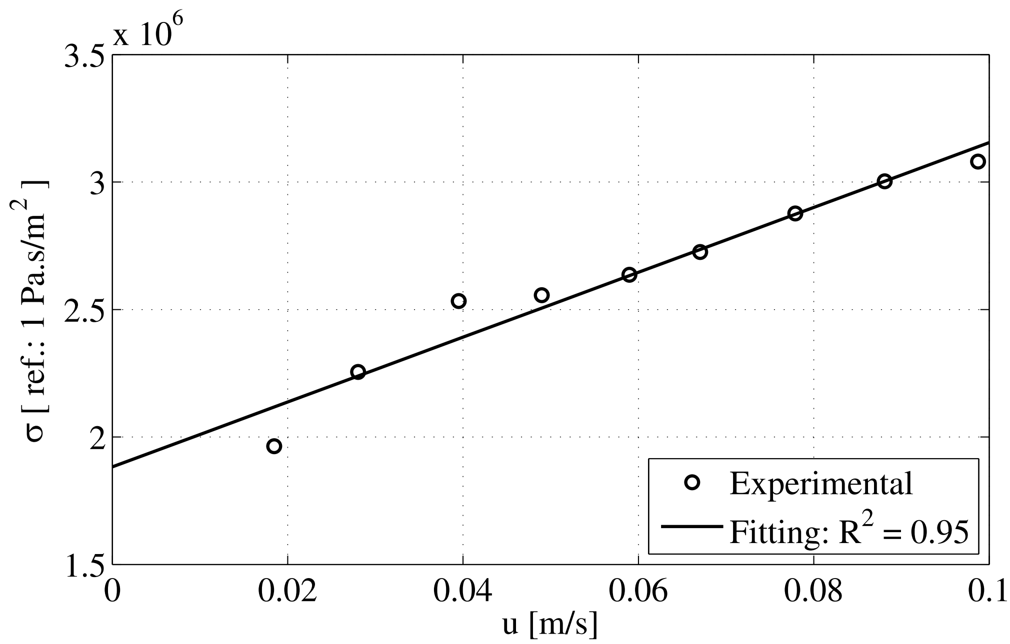

Figure 5 – Airflow resistivity as function of airflow velocity.

RESULTS

The final validation is to compare the absorptive coefficient of the material with the analytical model (JCA). The experimental curve is obtained from impedance tube (diameter 26 mm-frequency range: 500-6400 Hz) and the remaining acoustic parameters (α_∞=2.24, Λ=13.11μm and Λ'=20.67μm) was from experimental data. The experimental proceding is according to ISO 10534-2 (1998). It is possible to note a good agreement between the curves, especially until 5 kHz.

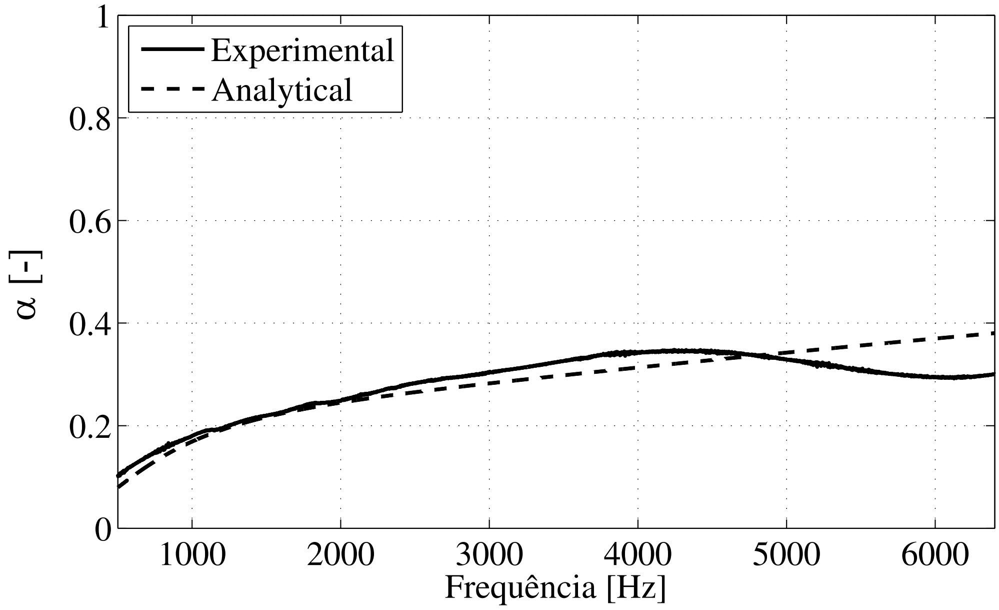

Figure 6 – Setup of the measurement of airflow resistivity.

CONCLUSIONS

The setup adopted for the characterization of the samples was validate with success. The instrumentation used has a good accuracy and it is enough to obtain satisfactory results.

Good agreement between analytical and experimental results was obtained. The analytical model using the Johnson-Cahmpoux-Allard (equivalent fluid model) are appropriate for representing porous media.

Further analyses will use the acoustic parameters of the material in muffler prototypes. In this context, the main idea of using porous material for discharge mufflers of reciprocal compressors is improving attenuation for some range frequency.

The proposed study is only the beginning of the main author PhD thesis. Many others prototype design have been explored through an optimization tool and implementation code with MatLab.

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