High Temperature Effects on the Insertion Loss of Absorptive Duct Silencers

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1 INTRODUCTION

Conventional passive rectangular duct silencers, which are in widespread use in commercial and industrial applications, employ a bulk absorptive material such as fibreglass, mineral wool or foam to attenuate noise. The majority of test data and calculation schemes [1], [2], [3], used to predict silencer attenuation consider only the acoustic performance at or near room temperature. While such predictions are useful for silencers used in heating and ventilating duct systems, many industrial applications require an estimate of the acoustical performance of the silencer at high temperatures. The use of absorptive silencers to control noise from gas turbine generators is an example of an application in which the extreme operating temperatures (250 to 700 °C) can have a significant effect upon silencer insertion loss (IL) performance.

2 THEORETICAL BACKGROUND

The IL of an absorptive silencer is affected by two temperature dependant phenomena. First, the flow resistivity of the porous material changes with temperature. This occurs because the resistance to gas flow through the pores of the fibrous material varies with the dynamic viscosity of the gas in the pores (which is usually primarily air). The dynamic viscosity is temperature dependant. Furthermore, the speed of sound in the gas and the gas density vary with temperature. This means that the ratios of silencer dimensions to wavelength, d/λ and $2h/\lambda$, (refer to Figure 1) change, as does the ratio of the acoustic resistance of the porous fill to the characteristic acoustic impedance of the gas, $Rd/\rho c$.

The change in gas properties with temperature can be modelled using well established thermodynamic/fluid-dynamic relationships:

$$c = c_0(T/T_0)^{1/2} \tag{1}$$

$$\rho = \rho_0(T_0/T) \tag{2}$$

$$\mu = \mu_0(T/T_0)^{0.7} \tag{3}$$

where, c, ρ, μ are the speed of sound, density and viscosity of the gas, respectively and T is the absolute temperature. The '0' subscript denotes normal room temperature values.

The flow resistivity, R, of the porous silencer fill varies with the dynamic viscosity [4], [5]. Hence,

$$R = R_0(\mu/\mu_0)$$

$$= R_0(T/T_0)^{0.7} \tag{4}$$

For the present study, silencer IL predictions were made using a finite element code based on a cubic Galerkin formulation [6]. The algorithm inherently addresses the changes in d/λ, $2h/\lambda$ and $Rd/\rho c$, since ρ, c, R, d and 2h are entered as parameters into the program at runtime. The algorithm calculates the characteristic acoustic impedance, Z_C and the complex propagation constant, k_C, using regression equations by Mechel [5], at any number of desired frequencies. For the purposes of the present analysis, IL predictions were made for six silencer geometries at the standard 24 one-third octave band centre frequencies ranging from 50 Hz to 10 kHz, for each of five operating temperatures.

3 RESULTS AND DISCUSSION

Figures 2 and 3 show the variation in IL with temperature for two of the six silencer geometries modelled. Several trends are readily apparent.

First, the frequency at which peak attenuation occurs increases with increasing temperature. This effect is accompanied by a corresponding decrease in attenuation in the lower frequencies as temperature rises. Additionally the bandwidth of the attenuation peak changes as T varies, although a definite trend is not obvious. Table I presents a summary of the frequencies at which peak attenuation occurs and the maximum insertion loss per unit length achieved at this peak.

The observed changes in silencer IL spectrum are consistent with an intuitive examination of the changes in fluid properties and flow resistance quantified in equations (1) through (4). As temperature increases, the wavelength, λ for any given frequency, f, also increases (i.e., since $\lambda = c/f$). Thus, the critical silencer dimensions, d and 2h are, in effect, becoming smaller with respect to wavelength as temperature increases. The frequency of peak attenuation depends on d and 2h, so it is no surprising that longer wavelengths result in higher peak IL frequencies.

The reduction in low frequency attenuation observed with increasing T, also can be explained in part by the fact that the frequency of peak attenuation is shifting upward. As well, the increased resistivity of the porous fill, R, at higher T contributes to decreased low frequency attenuation. This occurs because an increase in R results in an increase in the magnitude of the reactive part of the characteristic impedance ($X_C = \mathrm{Im}\{Z_C\}$) of the fill material at low frequencies [5], [7]; greater reactivity implies a more reflective (i.e., less absorptive) fill.

4 CONCLUSION

Based on the six absorptive silencer models analyzed thus far, it is apparent that an increase in temperature causes an increase in the frequency at which peak attenuation occurs, and a decrease in low frequency attenuation. The results of this preliminary study suggest that scaling factors can be derived through a regression analysis to predict the high or low temperature performance of an absorptive silencer knowing its room temperature performance and the anticipated operating temperature. An investigation to this end is ongoing, in order to generate sufficient data to develop such scaling factors.

5 REFERENCES

1. L.L. Beranek, *Noise and Vibration Control*, Ch. 10, 15 (McGraw-Hill, New York, 1971).
2. L.L. Beranek and I.L. Vér, *Noise and Vibration Control Engineering*, Ch. 10, (John Wiley & Sons, Inc., 1992).
3. D.A. Bies and C.H. Hansen, *Engineering Noise Control*, Ch. 9, (Unwin Hyman Ltd., 1988).
4. R.B. Tatge and D. Ozgur, "Gas Turbine Exhaust System Silencing Design", Proceedings Noise-Con 91, 223-30 (1991).
5. Beranek and Vér, Ch. 8.
6. R. Ramakrishnan and W.R. Watson, "Design Curves for Rectangular Splitter Silencers", Applied Acoustics Journal, V.35, 1-24 (1992).
7. Bies and Hansen, Appendix 3.

Table I

	Temperature °C				
	-100	20	120	250	500
Silencer #1: d = 0.06 m, 2h = 0.183 m, R0 = 20000 Rayl/m					
f_{PEAK} [Hz]	800	1250	1600	2500	3150
IL_{PEAK} [dB/m]	47	36	34	35	35
Silencer #2: d = 0.299 m, 2h = .152 m, R0 = 15000 Rayl/m					
f_{PEAK} [Hz]	800	1250	2000	2500	3150
IL_{PEAK} [dB/m]	39	41	41	42	42

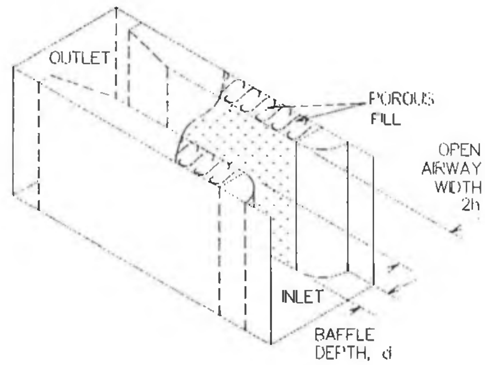

Figure 1

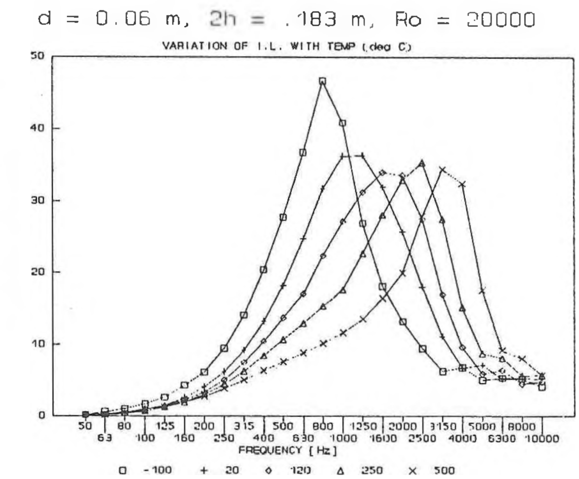

Figure 2

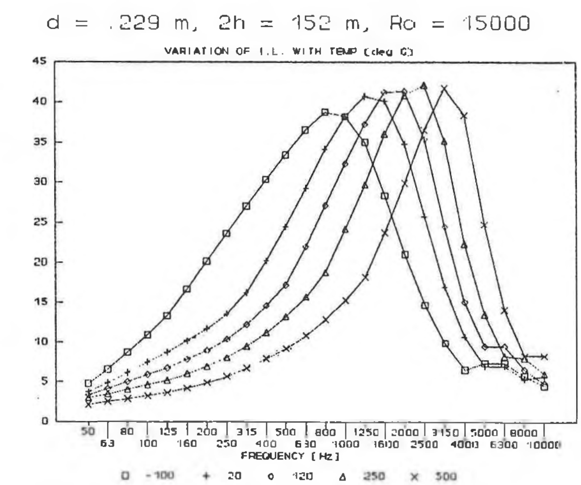

Figure 3