SOUND ATTENUATION IN DUCTS LINED WITH GRANULAR MATERIAL

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Abstract

Attenuation of acoustic waves in rigid ducts lined on two sides with granular material has been investigated. An experimental apparatus, set-up according to ISO standards, was used to measure sound attenuation along lined ducts: the lining characteristics were varied and the influence of the material and lining thickness on sound attenuation was analysed. Experimental data reveal that innovative selective mufflers can be designed in order to exploit the selective sound-absorbing properties of granular materials.

Introduction

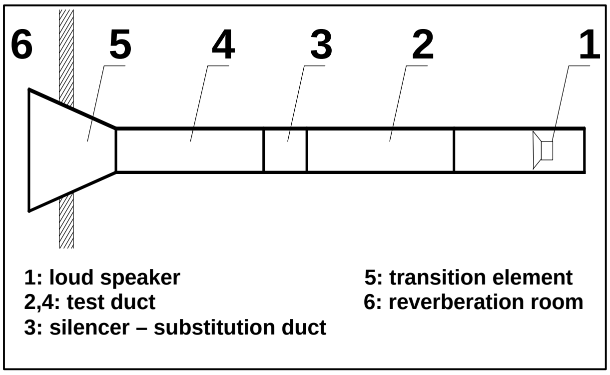
Increasingly strict standards regulating sound emissions in outdoor environments and the demand for indoor noise abatement have led to the use of lined ducts with the aim of reducing the transmission of sound along the ducts. Applications range from those of a more traditional kind, as seen in air conditioning plants, to sectors such as the control of noise emitted by the induction and exhaust ducts of boilers or power plants.
While the sound-absorbing materials most commonly used as lining are glass and mineral wool, alternative absorbing materials, as granular clay, have recently been proposed [1]; these are considered to be more acceptable from the health point of view and better suited to operating in chemically aggressive environments. Moreover inert granular materials exhibit good resistance to noise-induced fatigue, that is the disintegration of the sound-absorbing material as a result of prolonged exposure to pressure waves. In particular, granular clay has been picked out as suitable for sound absorption inside lined ducts, in that it is endowed with great chemical and physical stability and possesses very interesting acoustic properties. Experimental studies [2] have demonstrated the advantageous narrow-band noise reduction characteristics of granular materials, and have suggested that this feature can be exploited in order to enhance the attenuation of noise along lined ducts.
The present paper describes an experimental study aimed at testing this hypothesis. An experimental apparatus based on standards ISO 11691 [3] and ISO 7235 [4] was constructed in order to measure the transmission loss in lined ducts. After validating its behaviour, the apparatus was used to measure the insertion loss in ducts lined with granular material of assigned characteristics, for different thicknesses of the lining. These experimental results were then compared with those obtained for the same ducts with linings of mineral wool.

Acoustic characteristics of granular materials

Bulk granular materials generally display good sound-absorbing efficiency, with an acoustic behaviour typical of rigid porous materials. The absorption mechanism is based on viscous effects in the air contained inside the interconnecting pores which separate the granules; the solid structure can generally be regarded as ideally rigid and stationary, and the acoustic absorption as produced by the viscosity of the air, which is subjected to a process of alternate compression and rarefaction as a sound wave passes through it. Unlike what happens in the case of a free gas, this process can be regarded as adiabatic only at high frequencies; indeed, at low and middle frequencies, the solid structure interacts with the bulk of the gas through a heat transfer process thus giving rise to isothermal or polytropic processes.
Various models have been proposed to interpret the acoustic behaviour of granular materials. Such models generally enable us to determine the characteristic impedance and the propagation constant of porous rigid materials as functions of non-acoustic properties such as porosity, flow resistance and structure factor. The models proposed fall into three categories: empirical models, microstructural models and phenomenological models. The first category includes the model of Delaney and Bazley [5], which is based solely on flow resistance. The microstructural approach, which is based on the detailed description of the sound field inside a single cell of simple geometry, was introduced by Rayleigh [6] and developed completely by Zwikker and Kosten [7] and subsequently by other authors [8, 9, 10]. The phenomenological model, which considers the material in its entirety, was put forward by Morse and Ingard [11] and extended by Hamet [12] to encompass thermal processes.
Recent experimental studies have demonstrated the features of selectivity of normal incidence sound-absorption in granular materials [2], revealing a noticeable variation in the absorption coefficient as a function of frequency. Moreover, it has been shown that acoustic behaviour depends on both the mean grain diameter and the thickness of the specimen of sound-absorbing material. These experimental findings proved to be in agreement with what had been predicted by Hamet’s theory. This aspect assumes particular importance when bulk granular materials are used as absorbing linings inside the ducts, since sound attenuation depends on the normal acoustic impedance of the lining. This suggests that selective dissipative mufflers can be created by appropriately adjusting the granulometry and thickness of the sound-absorbing material to the spectrum of noise.

Experiments

An experimental apparatus (in line with the above-mentioned standards) was constructed to assess the insertion loss in straight ducts with a square cross section (30x30 cm). The apparatus comprised the following elements: a loudspeaker, test ducts, a silencer or a substitution duct, a transition element and a reverberation room (Fig. 1).
A pink noise was generated at the closed end of the channel by means of a broad-band loudspeaker. The signal generated by the sound source was picked up by a microphone positioned at various points inside the reverberation room. By means of an appropriate software program, the signal was elaborated in order to determine the spectrum of the sound pressure level inside the reverberation room, which constituted the reference environment for the



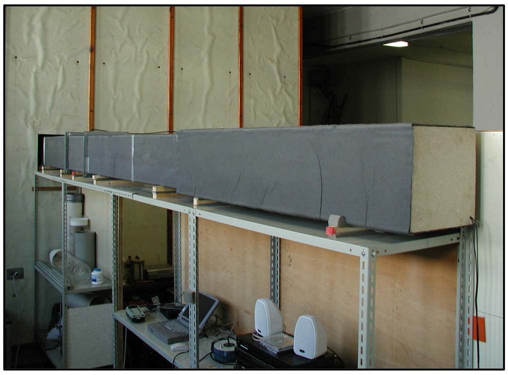


Figure 1 Test facility.

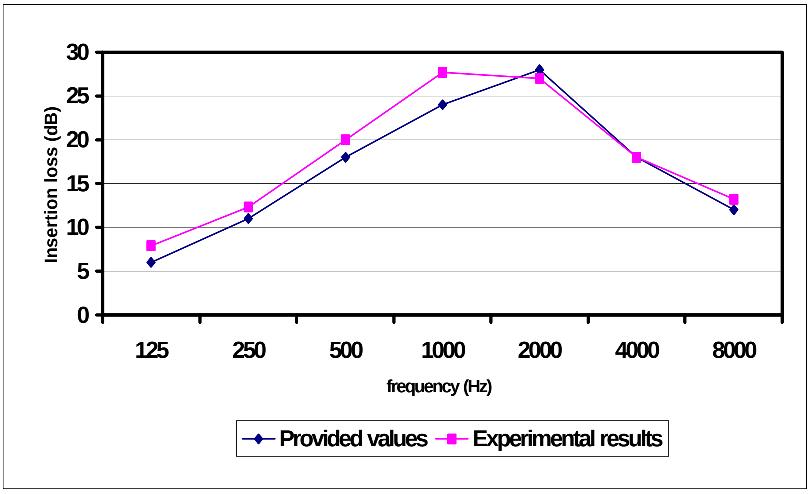


Figure 2 FCR silencer: comparison between provided and experimental results.

measurements. To determine the insertion loss in one-third-octave-band provided by the silencer under examination, measurements were taken by alternatively mounting on the duct either the silencer itself or the substitution duct. The difference, in decibels, between the mean sound pressure level inside the reverberation room before and after insertion of the dissipative silencer along the duct returned insertion loss values.

The sound source consisted of a random noise generator, an amplifier and a loudspeaker; the power of the sound produced must be sufficient to ensure that the sound pressure level is at least 10 dB greater than the background noise. The loudspeaker is fitted inside a duct (30x30x170 cm) made of 2 cm thick chipboard panels, and is enclosed in a sealed cabinet filled with mineral wool.

The ducts and the transition element were made up by 1 mm thick galvanised steel sheets. The length of the test duct must be at least half of the wavelength corresponding to the minimum frequency in the test range and not less than four times the duct cross-section diagonal. The dimensions of the test duct enable the apparatus to measure the insertion loss produced by lined ducts in the 100 Hz - 8000 Hz frequency range.

The substitution duct, which was designed and built in the same way as the test ducts, was used in the measurement procedure to define a reference condition.

The transition element, which enables the apparatus to be connected to the reverberation room, must have a low reflection coefficient and dissipative losses close to zero; moreover, it must not produce any endogenous noise that might influence measurements in the test room. The transition element constructed for the present apparatus is shaped like a truncated pyramid with an internal angle of 30° between the walls, terminating in the reverberation room.

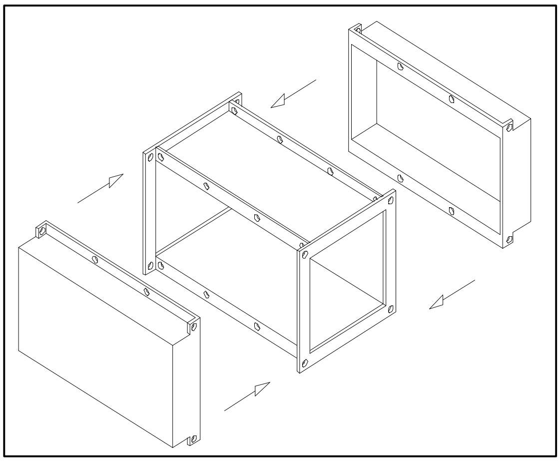


Figure 3 Substitution duct with replaceable symmetrical side pockets.

Table 1 Characteristics of lining materials.

	Density (kg/m^3)	Flow resistivity ISO 9053 (rayl/m)	Porosity
Granular clay	458	3440	0.40
Mineral wool	50	25073	-

In order to limit flanking transmissions as far as possible, particular steps were taken. With regard to transmission paths through solid media, rubber washers were inserted between flanges; to limit transmission through air, the entire test section was enclosed in sound-proofing panels made of expanded polyurethane with a 1 mm thick lead sheath inserted in between.
Proper functioning of the apparatus was ascertained by comparing the insertion loss values obtained with those provided for a commercial silencer. FCR silencer model SQ-A-110-600 was used; this has a 30x30 cm cross section, a length of 60 cm and a single 20 cm wide sound-absorbing buffer lined with mineral wool. Comparison between experimental data and catalogue values revealed very good agreement, as shown in Fig. 2.
In order to analyse the behaviour of ducts lined with materials other than mineral wool, a duct was constructed which was equipped
with two replaceable symmetrical side pockets of various thickness (5-10-15-20 cm) (FIG. 3). Sound transparent layers were used for confining the lining materials. In this way, it was possible to vary both the thickness of the lining and the absorbing material, and therefore to analyse the effect that thickness and absorbing material have on insertion losses, that is to say, on the efficacy of the dissipative silencer.
Side pockets were filled with bulk granular clay, with a granule diameter in the range of 2-3 mm, or, alternatively, with mineral wool. The characteristics of these materials are reported in Table 1. The flow resistance values are the result of a series of measurements carried out in the DITEC laboratories and described in detail in [13].

Results

Insertion loss, defined as the difference between pressure levels in a reference environment measured before and after a silencer is inserted into the test duct, was determined for 4 different elements characterised by a thickness of the absorbing lining equal to 5, 10, 15 and 20 cm.
Fig. 4 reports the insertion loss values obtained for discrete values corresponding to one-third-octave-band in the 160-2560 Hz frequency range. The figure reveals the selective acoustic absorption of the granular material; the maximum absorption frequency diminishes steadily as

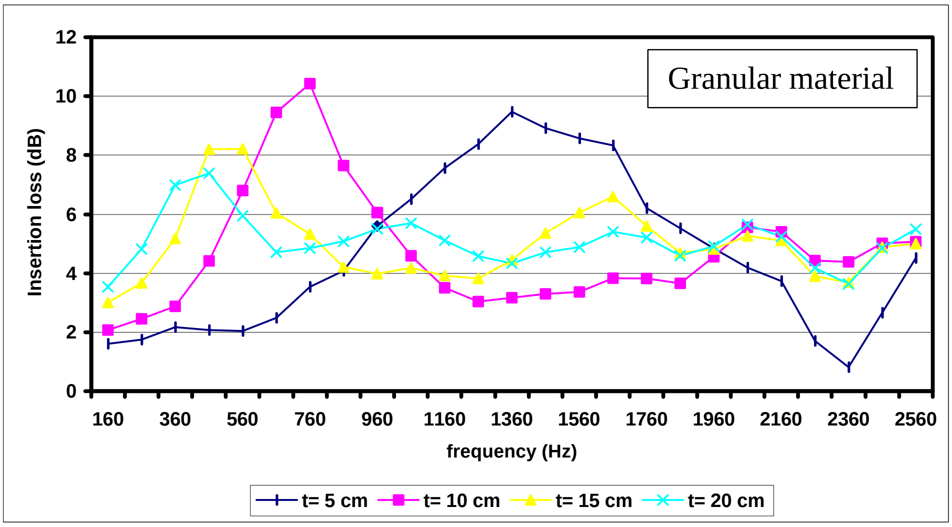


Figure 4 Spectral insertion loss for rectangular ducts lined with granular material of different thickness.

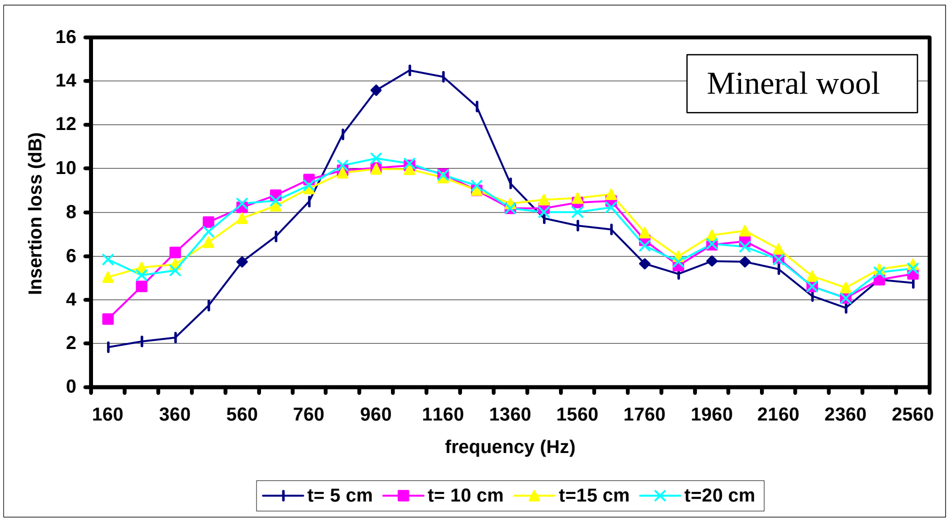


Figure 5 Spectral insertion loss for rectangular ducts lined with mineral wool of different thickness.

the thickness of the material increases.

Insertion losses were also determined for the same elements when lined with bulk mineral wool (density 50 kg/m^3), again at thicknesses of 5, 10, 15 and 20 cm. Fig. 5 shows the results obtained, which were practically independent of the thickness, in the frequency range examined, for thicknesses grater than 5 cm.

Fig. 6 reports the comparison between the insertion loss obtained with a lining made up of bulk mineral wool and a lining of granular material for the same lining thicknesses. On the whole, the mineral wool clearly displayed greater absorption. However, the granular material presented

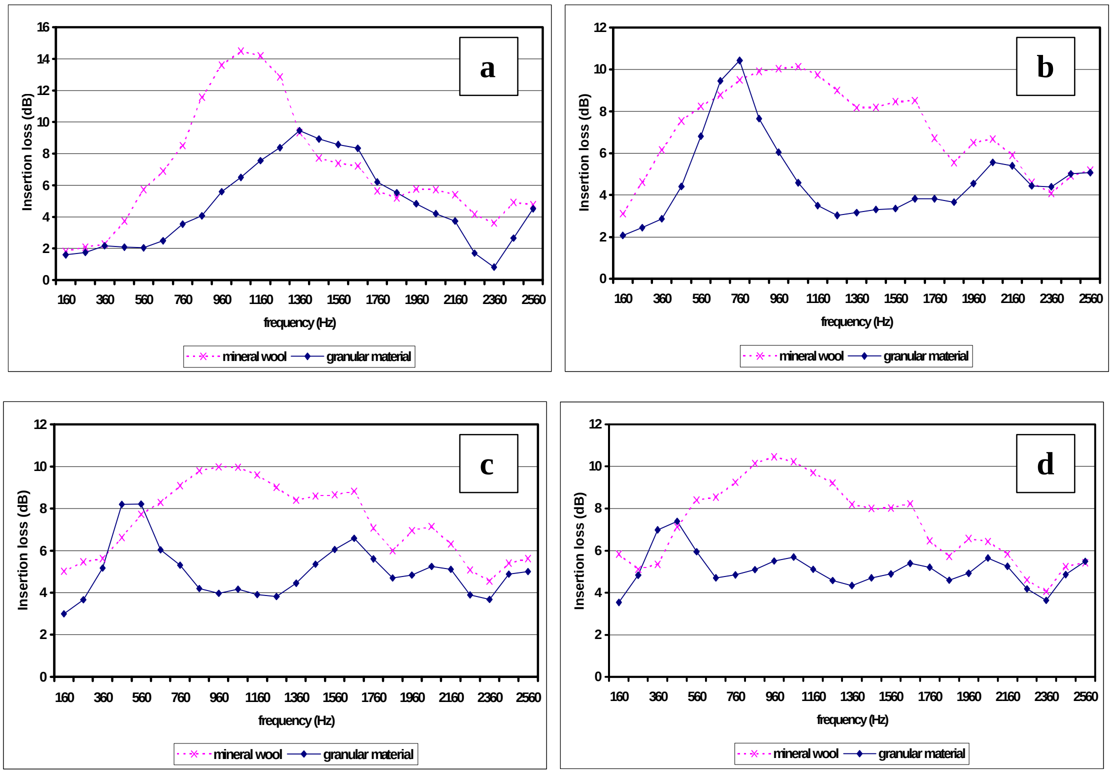


Figure 6 Comparison between the spectral insertion loss for absorbing lining of granular material and mineral wool: (a) thickness 5 cm; (b) thickness 10 cm; (c) thickness 15 cm; (d) thickness 20 cm.

higher local values at characteristic frequencies.
The insertion loss achieved through the use of granular material is, in any case, high enough to enable this material to be used in particular applications, such as in cases involving high temperature or corrosive gases.

Conclusions

Materials such as mineral wool are traditionally used for sound absorption in lined ducts or dissipative mufflers. However, in cases in which health concerns or resistance to environmental aggression have to be taken into account, granular materials, such as granular clay, which is endowed with particular sound-absorbing features, appear to constitute a valid alternative.
The selective acoustic absorption achieved through the use of different thicknesses of the material means that an innovative technique can be adopted for the design and construction of sound mufflers. Indeed, absorption can be adjusted to suit specific spectral characteristics of the acoustic signal to be attenuated.

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