Determination of Diffuse Field Sound Absorption from a Normal Incidence Impedance Measurement

David Herrin
University of Kentucky
Overview

• Normal and Diffuse Absorption Coefficient
  ✓ Normal Incidence Absorption – ASTM E1050
  ✓ Diffuse Field Absorption – ASTM C423

• Sample Size for ASTM C423

• Diffusiveness in the Chamber

• Sensitivity Studies
Normal Incident Absorption ASTM E1050

Characteristic impedance

\[ Z_n = R_n + iX_n \]

Sound source

Reflection coefficient

\[ R = \frac{B}{A} = \frac{Z_n - 1}{Z_n + 1} \]

Normal-incidence absorption

\[ \alpha_n = 1 - |R|^2 \]
Normal Incidence Absorption Variation

Reconstituted Porous Rubber

Reticulated Foam

Glass Fiber

Solid line indicates the mean sound absorption. Error bars indicate the 95% confidence limit in any one laboratory based on round robin tests.

- ASTM E1050 is very repeatable.
- $\alpha_n$ is always less than 1.0.

Cox and D’Antonio, 2017 adapted from Horoshenkov et al., 2007
Diffuse Field Absorption ASTM C423

\[ \alpha_d = 0.9210 \frac{V_d}{cS} \]

- \( V_d \): Volume of reverberation room
- \( c \): Speed of sound
- \( d \): Decay rate, dB/s

The Vibro-Acoustics Consortium
Diffuse Field Absorption

\[ T_1 = \frac{55.3V}{c(\alpha_0(S_{room} - S_{sample}) + \alpha_s S_{sample}) + 4V m_1} \]

- \( S_{sample} \): Sample area
- \( S_{room} \): Room surface area
- \( \alpha_0 \): Average absorption coefficient of empty room
- \( m_1 \): Air attenuation
- \( V \): Volume
Diffuse Field Absorption Variation

Solid line indicates the mean sound absorption. Error bars indicate the 95% confidence limit in any one laboratory measurement on round robin tests (13 laboratories).

- ASTM C423 is not as repeatable from room to room.
- May exceed 1.0.

Cox and D’Antonio, 2017 adapted from Horoshenkov et al., 2007
Absorption Greater than 1.0

For a grazing wave, sound power is absorbed but there is technically no "incident power". The absorbed power increases when the sample has a finite size.
Section 5.3 Diffraction effects usually cause the apparent area of a specimen to be greater than its geometrical area, thereby increasing the coefficients measured according to this test method. When the test specimen is highly absorptive, these values may exceed unity.

Section 5.4 Regardless of the differences and the necessity for judgment, coefficients measured by the test method have been used successfully by architects and consultants in the acoustical design of architectural spaces.
Discrepancy Edge Effect

\[ \alpha_d = \alpha_{\infty} + \beta E \]

\( E \) ratio of edges to area of sample

\( \alpha_{\infty} \) random incidence absorption coefficient of infinitely large sample \((E=0)\)

\( \beta \) constant that depends on frequency, the absorption, and the room.
Reverberation Room

Wallace Sabine at Harvard University
Discrepancy Between

\[
\alpha(\theta) = \frac{4R_n \cos \theta}{(1 + R_n \cos \theta)^2 + (X_n \cos \theta)^2}
\]

Average for diffusive incidence:

\[
\bar{\alpha} = 2 \int_{0}^{\pi} \alpha(\theta) \sin \theta \cos \theta \, d\theta
\]
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Radiation Impedance

Integral on area $S$:

$$p(x, y, 0) = \frac{Z_n}{Z_n + Z_R} 2p_i(x, y, 0)$$

$Z_R$ : Radiation Impedance

$Z_R$ is a function of the geometry of the absorber, frequency, and angle of incidence.
Radiation Impedance

Assuming a diffusive field

\[ \alpha_d \approx 8 \text{Re}(Z_n) \int_0^{\pi/2} \frac{\sin(\theta)}{|Z_n + Z_R|} d\theta \]

\[ Z_R \text{ of rectangular sample (2.44 m x 2.74 m)} \]

| \( Z_R \) | \( \theta = 0 \) | \( \theta = \pi/6 \) | \( \theta = \pi/2 \) | \( \theta = \pi/2 \) |
|---------|---------------|----------------|---------------|
| \( f = 63 \text{ Hz} \) | 0.27+0.55i | 0.27+0.55i | ... | 0.24+0.52i |
| \( f = 125 \text{ Hz} \) | 0.79+0.65i | 0.77+0.66i | ... | 0.51+0.68i |
| ... | ... | ... | ... | ... |
| \( f = 4000 \text{ Hz} \) | 1.00+0.01i | 1.04+0.02i | ... | 3.37+3.41i |
Size Correction

5 cm mineral wool sample

![Graph showing diffuse field absorption vs. frequency for different sample sizes. The graph compares measurements and predictions for sample sizes of 3.6 m, 2.4 m, and 1.2 m. The normal absorption is also shown as a reference.](image)
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Diffuse Field means

- Sound pressure is uniform inside reverberation chamber
- Sound intensity distribution is uniform over all possible directions
Sound Intensity Distribution

Simulation method by Jeong (2010) used beam tracing method.

\[ \theta : \text{Incident angle} \]
\[ \phi : \text{Azimuthal angle} \]

\[ \bullet : \text{Point source} \]
\[ \bullet : \text{Observation point} \]
Sound Intensity Distribution

The high frequency intensity is nearly independent of the room geometry, the location of the absorber and the absorption coefficient of the specimen. – Jeong, 2010
Intensity Distribution Correction

5 cm mineral wool sample

\[ e = 2.4 \text{ m} \]

![Graph showing absorption vs. frequency](chart)

- Normal Incident Absorption
- ASTM C423
- Size Corrected
- Size and Angle Corrected for Irregular Room
- Size and Angle Corrected for Rectangular Room

Jeong, 2010
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Procedure

1. Input layered sound absorber properties (thickness, flow resistivity, etc.).
2. Use empirical models and transfer matrix theory to determine normal incidence impedance ($Z_n$) and normal incidence sound absorption ($\alpha_n$) in 1/6 octave bands.
3. Use normal incidence impedance and sample size to determine diffuse field sound absorption ($\alpha_d$).
Normal Incidence vs. Diffuse Field

10 cm (4 in) plastic foam
\( \sigma = 5000 \text{ Rayls/m} \)
ASTM C423 • 6.69 m² (72 ft²) is recommended.
• Sample size 2.44 m × 2.74 m (8 ft × 9 ft).
• Area may not be less than 5.57 m² (60 ft²).

10 cm (4 in) plastic foam

\[ \sigma = 20,000 \text{ Rayls/m} \]
ASTM C423 Effect of Flow Resistivity

10 cm (4 in) plastic foam

The Vibro-Acoustics Consortium
ASTM C423 Effect of Mass Layer

Foil + Foam
Foam Thickness: 2.54 cm (1 inch)
Foam Flow Resistivity: 30000 rayls/m
Foil Surface Density: 0.05 kg/m²
References


