ACOUSTIC DECIBEL CALCULATIONS FOR AIR AND WATER

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December 15, 1999

Introduction

There are several methods for characterizing sound energy. Two examples are the sound pressure level and the sound intensity level. These levels are represented in terms of decibels (dB), which represent a logarithmic scale. In order to calculate a decibel value, a reference value is needed.

Surprisingly, a 100 dB level in air does not equal 100 dB in water. The reason for this inequality is that the conventional reference values depend on whether the medium is air or water.

The purpose of this tutorial is to outline the conventions for air and water.

Acoustic Impedance

The acoustic or characteristic impedance Z is defined as

$$Z = \rho c \tag{1}$$

where

ρ is the density of the medium
c is the speed of sound in the medium

Impedance, density, and speed of sound values for water and air are shown in Table 1.

Table 1. Characteristic Impedance Values for Air and Water

Medium	Density (kg/m^3)	Speed of Sound (m/sec)	Impedance (Pa • sec/m)
Air (dry at 20 °C)	1.204	345	415
Water	1000	1500	$1.5(10^6)$

The characteristic impedance of water is about 3600 times that of air.

As an aside, note that the instantaneous pressure p(t) is

$$p(t) = \rho c u \tag{2}$$

where u is the particle velocity.

Sound Pressure

Sound pressure is sound force per unit area. The sound pressure level SPL is calculated as

$$SPL = 20 \log\left[\frac{P_{rms}}{P_{ref}}\right],$$

where

$$P_{ref} = \begin{cases} 20\,\mu Pa \ \text{rms for air} \\ 1\,\mu Pa \ \text{rms for water} \end{cases} \tag{3}$$

P_{rms} is the root-mean-square sound pressure in equation (1).

The reference values have been established by convention. Note that $20\,\mu Pa$ is roughly the threshold of human hearing at 1000 Hz. The basis for the reference value in water is not immediately clear, however.

Algebraic manipulation shows that for a constant pressure value,

$$\text{SPL(dB) in water} = \text{SPL(dB) in air} + 26.0 \text{ dB} \tag{3}$$

Sound Intensity

Sound intensity is the acoustic power per unit area in the direction of propagation. The sound intensity I for free field radiation is

$$I = \frac{(P_{rms})^2}{\rho c} \tag{4}$$

The intensity reference values for air and water can be calculated from the pressure reference values and from equation 4 as shown in Table 2.

Table 2. Intensity Reference Value Calculation			
Medium	Reference Pressure (μPa rms)	Impedance (Pa • sec/m)	Intensity Reference (W/m^2)
Air (dry at 20 °C)	20	415	10^{-12}
Water	1	$1.5(10^6)$	$6.7(10^{-19})$

The sound intensity level SIL is defined as

$$SIL = 10 \log\left[\frac{I}{I_{ref}}\right],$$

where

$$I_{ref} = \begin{cases} 1\left(10^{-12}\right) \text{ W/m}^2 & \text{for air} \\ 6.7\left(10^{-19}\right) \text{ W/m}^2 & \text{for water} \end{cases} \qquad (5)$$

Again, the intensity reference values are taken from Table 2.

Algebraic manipulation shows that for a constant intensity value,

$$\text{SIL(dB) in water} = \text{SIL(dB) in air} + 61.8 \text{ dB} \qquad (6)$$

Conclusion

For clarity, the reference value should be stated along the decibel level in a report. For example, a microphone recorded the following level in a noisy restaurant:

SPL = 82 dBA, reference 20 μPa

Note that the "A" in dBA refers to the weighting network, as explained in Reference 1.

Reference

1. T. Irvine, Weighting Levels for Sound Level Meters, Vibrationdata.com Publications, 1999.