Noise Attenuation
for
Chimney Engineers
presented by
Steven Reid
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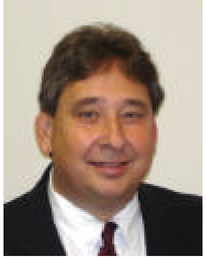
Noise attenuation for Chimney Engineers



Steven Reid

Steven Reid is the President and owner of Industrial Environmental Systems, Inc. USA. He has thirty years of design and application experience in air pollution control, and steel and fiberglass chimneys. Steven was deeply involved in the Damper technology in the United States.

Steven has been a CICIND member since 1990 and is chairman of the GRP Liner Committee. He is also a member of the ASME STS-1 Steel Stack Committee and the ASCE FRP Stack Standard Committee. He is also a member of the National Society of Professional Engineers, American Boiler Manufacturer's Association and holds Professional Engineering Licenses in fifteen US states and Puerto Rico.

Introduction

Chimney engineers regularly encounter noise from powered sources such as combustion turbines, engines and fans. Although chimneys usually have little to do with generating noise, they do transmit noise. Noise attenuation devices and treatments are frequently housed by or attached to chimneys. As such, it is beneficial for a good chimney engineer to be aware of the acoustical factors affecting chimneys.

Abstract

In order to understand noise attenuation, we must first understand some characteristics of sound. Typical sound problems faced by chimney engineers involve meeting a specified noise limit at a given distance from the chimney. Sound power, source directivity, break-out noise, pressure drop, flow velocity, self generated noise and attenuation techniques all play a part in the total problem solution.

It is not the intent of this paper to teach one to design silencers. It is assumed that the chimney engineer will work with an experienced silencer manufacturer who will supply the necessary hardware and expertise to properly meet the specified noise limits. This paper simply attempts to familiarize the chimney engineer with the terms and concepts necessary to confidently engage the acoustic engineer by allowing him to evaluate the feasibility of silencer applications in broad terms.

Sound

Sound is an alteration in an elastic medium, such as air, that is capable of being detected by the human ear. Noise is non-beneficial sound. Acoustical energy is periodic in nature and varies in amplitude and frequency. The magnitude or level is a measure of the intensity of acoustical energy and is measured in decibels (dB).

A decibel is defined as ten times the logarithm to the base ten of the ratio of a sound level under consideration (S_2) to a reference sound level (S_1).

$$dB = 10\ Log_{10}\ (S_2 / S_1)$$

In acoustics, the decibel level is used to quantify sound power levels radiated by sound sources and sound pressure levels that people hear. It is very important to distinguish between sound power levels, indicated herein by PWL and sound pressure levels indicated by SPL.

For the remainder of this paper, the term Log is intended to mean the base ten log unless noted otherwise.

Decibel Addition

Decibels are logarithmic quantities and do not follow normal algebraic rules. Instead, decibels are first converted to energy equivalents, the energy equivalents are added algebraically, and then the total energy equivalent is converted to its decibel value.

The decibel sum Ls of several sound levels, L_1 L_2 L_3 etc. can be obtained from the following equation:

$$Ls = 10\ Log\ (\ 10^{L_1/10} + 10^{L_2/10} + 10^{L_3/10} + \dots\ )$$

Although cumbersome to do by hand, this procedure is easily programmed into a spreadsheet program.

Sound Radiation

In free air, an elevated point sound source will radiate into a full sphere. The sound pressure created by the source is a function of the distance from the source.

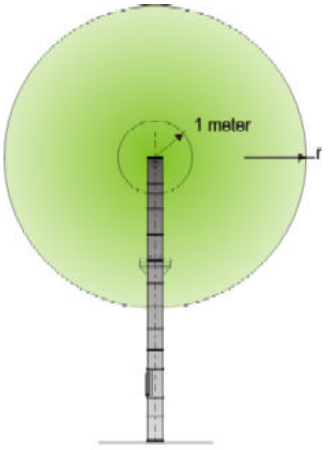


Figure 1

Since the sound pressures are equal on the surface of the sphere, the sound pressure is actually a function of the area of that sphere. This is an important computation and is performed frequently. See Figure 1.

SPL = PWL – 10 Log (A / A_o) where A_o is equal to 1 square meter.

For a sphere, A = 4 x pi x R^2

$$SPL = PWL - 10 \text{ Log } (4 \text{ pi } R^2 / 1)$$

$$SPL = PWL - 10 \text{ Log } (4 \text{ pi}) - 20 \text{ Log } (R)$$

$$SPL = PWL - 11 - 20 \text{ Log } R \quad \text{dB}$$

This means that the sound pressure level of a given spherically propagated sound source will be 11 dB less than the sources sound power level at one meter.

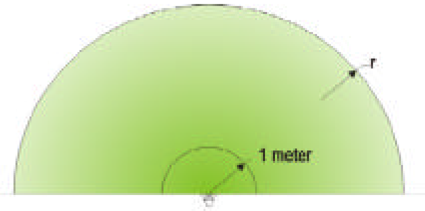


Figure 2

If the source was not elevated and reflections from the ground were considered, the sound pressure radiates into a hemisphere and the equation becomes: See Figure 2.

For a hemisphere, $A = 2pR^2$

$$SPL = PWL - 10Log(4pR^2/1)$$
$$SPL + PWL - 10Log(4p) - 20Log(R)$$
$$SPL = PWL - 11 - 20LogR \text{ db}$$

Therefore, the sound pressure level resulting from a given power source at a given distance will always be 3 dB greater for hemispherical propagation than for spherical propagation. This is logical since in hemispherical propagation, the given amount of power is distributed over half the area for spherical propagation.

Frequency (Pitch)

The frequency or pitch of sound is a measure of the number of times the alteration repeats in a unit of time. Frequency is measured in Hertz (Hz) or cycles per second (cps).

The audible frequency range of human hearing for most people ranges from about 20 to 50 Hz up to around 10,000 to 12,000 Hz. Generally people hear better in the 500 to 5000 Hz range. Therefore, noise in this range is more problematic.

Different types of equipment produce varying levels of low, medium and high frequency sounds. The sound level and frequency distribution of the total noise is determined by measurement with a frequency analyzer. An octave band analyzer has a set of contiguous filters covering essentially the full frequency range of human hearing. Each filter has a bandwidth of one octave and nine such filter cover the range of interest for most noise problems.

The bandwidth and geometric mean frequency of standard octave frequency bands used in analysis procedures are shown in Table 1. Be advised that much of the literature in acoustics ignores the 31 Hz band.

Octave Frequency Range, Hz	Geometric Mean Frequency of Band, Hz
22-44	31
44-88	63
88-175	125
175-350	250
350-700	500
700-1400	1000
1400-2800	2000
2800-5600	4000
5600-11200	8000

Table 1: Standard Frequency Bands

Sound data is presented as a sound level in each of nine frequency bands. The individual sound levels can be added and an overall sound level reported. When sound levels are relatively consistent among each frequency band, the sound is said to be broadband. Most machinery noise is broadband in nature.

When one or more frequencies have sound levels much greater than the rest, the sound is said to have tones at those frequencies. For example, a fan can produce a tone based upon its number of blades and shaft speed. This is referred to as the fan's blade pass frequency. A nine blade fan rotating at 1800 rpm may produce a tone at 9 x 1800 / 60 = 270 Hz.

Sound Power

Sound power level is a measure of the acoustical energy radiated by a source. The abbreviation PWL is used to refer to sound power levels. The sound power level of a source is:

$$PWL = 10 \text{ Log}_{10} (W / W_{ref})$$

Where W is the sound power of a source in watts, and Wref is the reference power in watts. Unless stated otherwise the power, W, is the effective root mean square (rms) sound power. The reference power (Wref) is 10^{-12} watts. Therefore, a sound source with a sound power of 1500 watts would have a sound power level as follows:

PWL = 10 Log (1500 / 10^{-12}) = 142 dB

Table 2 provides typical sound power levels for various sources.

Sound Power Watts	SPL dB re 1 pW	Sound Source
10^2	140	Threshold of Pain
10	130	Threshold of Feeling
1	120	Jet Engine
10^{-1}	110	Elevated Train
10^{-2}	100	Pneumatic Hammer
10^{-3}	90	OSHA 8-Hr Limit
10^{-4}	80	Police Whistle
10^{-5}	70	Shouting
10^{-6}	60	Typical Factory
10^{-7}	50	Average Conversation
10^{-8}	40	Living Room
10^{-9}	30	Average Auditorium
10^{-10}	20	Whisper
10^{-11}	10	Soundproof Room
10^{-12}	0	Reference Power

Table 2: Sound Power Levels of Various Sources

It is important to realize that sound power levels cannot be measured directly but are calculated from sound pressure level data.

Sound Pressure

Sound pressure level, in dB, is a measure of the acoustical energy imparted upon a receiver. Sound waves produce small oscillations of pressure just above and below atmospheric pressure. These pressure oscillations impinge on the ear drum and create the sensation of sound. A sound level meter with its microphone measures sound pressure.

The abbreviation SPL is used to refer to sound pressure levels. The sound pressure is:

$$SPL = 10 \operatorname{Log}_{10} (p / p_{ref})^2 = 20 \operatorname{Log}_{10} (p / p_{ref})$$

Where p is the sound pressure in dB, and p_{ref} is the reference pressure. The reference pressure (p_{ref}) is 20 micropascals (Newton per square meter). A sound technician in the field would measure p and then perform the above calculation to experimentally determine the SPL.

Sound pressure can be determined from a given sound power level. Machinery manufacturers normally acoustically rate their equipment in terms or sound power.

Sound Transmission in Air

The sound power levels at two points will be related as follows:

$$SPL_2 = SPL_1 - 20 \operatorname{Log} (R_2/R_1)$$

where R2 and R1 are distances in like units. See Figure 3.

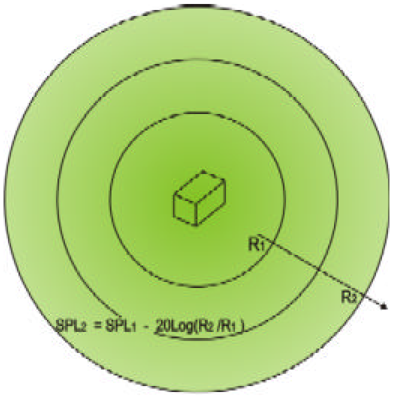


Figure 3

It is convenient to remember that doubling the distance from noise results in a six decibel reduction.

We can show this by setting R2 / R1 equal to 2 and solving for SPL2.

SPL2 = SPL1 – 20 Log (2)

SPL2 = SPL1 – 6.02 dB

Directivity and Receiver location

It is important to consider the type of noise source and the location of the receiver when evaluating sound pressure. Point sources radiate noise in a 360° sphere. In practice, noise sources will be either point sources or directed sources.

Acoustical engineers speak of receivers at positions one, two or three. Position one is one meter downstream of the source. Position two is one meter from the source but perpendicular to the sound direction. Position three is at the ground and 135° from the source. Credit can be taken from directed sources when the receiver is at one of these positions. See Figure 4.

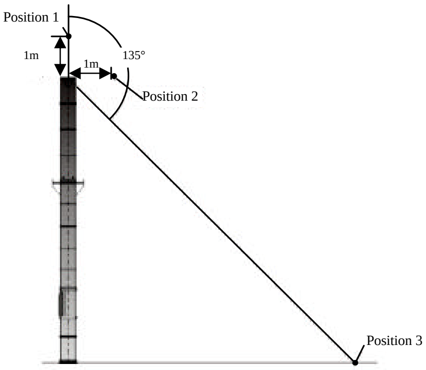


Figure 4

Angle to Direction of Flow (Degrees)		0				45				90 & 135			
Silencer Outlet Diameter (Meters)		**0.5**	**1**	**2**	**>3**	**0.5**	**1**	**2**	**>3**	**0.5**	**1**	**2**	**>3**
Octave Band Center Frequency, Hz	**31**	0	0	0	0	0	0	0	0	0	0	0	0
	63	0	+2	+3	+4	0	0	+1	+2	0	0	0	-1
	125	0	+3	+4	+5	0	+1	+2	+3	0	0	-1	-2
	250	+1	+3	+4	+5	0	+1	+2	+3	0	-1	-2	-5
	500	+1	+4	+5	+6	0	+2	+3	+4	0	-3	-5	-7
	1k	+1	+4	+5	+6	0	+2	+3	+4	-1	-6	-8	-10
	2k	+1	+4	+5	+7	0	+2	+3	+5	-3	-7	-10	-12
	4k	+1	+4	+5	+7	0	+2	+3	+5	-7	-11	-13	-15
	8k	+1	+4	+5	+7	0	+2	+3	+5	-13	-15	-13	-17

Table 3: Directivity Based Upon Angle to Direction of Flow and Silencer Outlet Size

Table 3 gives the sound loss due to directivity. Tables such as these are derived from experimental data and will vary for different sources. Some manufacturers introduce conservatism into their designs by ignoring or severely limiting directivity.

Many specifications will specify a noise level three feet from the base of the stack and five feet above the ground. This is actually not a very good specification since that point is actually in the acoustical shadow of the stack.

Weighted Sound Levels

Sound level meters usually have "weighting networks" that are designed to represent the frequency characteristics of the average human ear for various sound intensities. The frequency characteristics of the A-, B- and C-weighting networks are shown in Table 4.

The relative frequency response of the average ear approximates the A- curve when sound pressure levels of 20 to 30 dB are heard. The ear approximates the B- curve for sounds of 60 –to 70 dB and the C- curve for sounds of 90 to 100 dB. Annoyance usually occurs when noise intrudes into an otherwise generally low level sound environment. Therefore, the A-weighting scale is used for most sound engineering problems.

Frequency, Hz	Weighting, dB		
	A-	B-	C-
31	-39	-17	-3
63	-26	-9	-1
125	-16	-4	0
250	-9	-1	0
500	-3	0	0
1K	0	0	0
2K	+1	0	0
4K	+1	-1	-1
8K	-1	-3	-3

Table 4: Weighting Networks

Noise Limits

Local ordinances and OSHA requirements will usually dictate the desired overall sound levels in terms of a near field sound limit and a far field sound limit. See Figure 5.

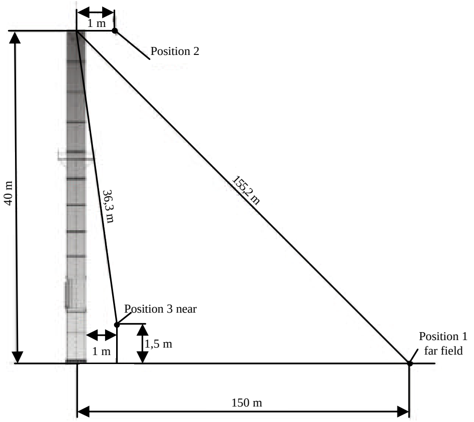


Figure 5

The near field sound limit is usually considered at a distance of one meter from the sound source. 85 dBA is a typical near field sound limit. The far field sound limit is usually considered several hundred meters from the sound source such as at a property boundary.

When beginning a sound problem, the designer will usually have source sound levels for each of nine frequency ranges given by equipment manufacturers or field data. He will also have either near field and far field sound limits, or both.

Attenuation

The purpose of incorporating a silencer into an exhaust system is to absorb noise. The insertion loss is the measure of the amount of noise absorption that the silencer is capable of. Table 5 gives representative insertion losses provided by typical industrial silencers. Most industrial applications will fall between the median and high attenuation curves. The low attenuation curve will apply when the system is restricted by space or pressure drop limitations.

Frequency, Hz	Attenuation, dB		
	Low	Medium	High
31	0	1	2
63	5	8	12
125	8	15	23
250	11	22	32
500	15	29	44
1K	18	34	50
2K	16	36	49
4K	15	30	38
8K	9	16	24

Table 5: Representative Attenuation Profiles

Absorptive silencers are a broad band approach to noise attenuation. The size of the baffles is chosen to maximize absorption of the most objectionable sound levels in the frequency spectrum. Generally low frequency noise is the hardest to control. For low frequency, high wavelength noise, the baffles must be thicker and longer. For high frequency, low wavelength noise the baffles may be thinner and shorter. A combination of low and high frequency baffles could be used in a single chimney.

As is evident from the typical attenuation curves herein, low frequency sound is the most difficult to attenuate. For that reason, most baffle and passage widths in our field of interest are fairly wide (200 – 600 mm) in order to target the lower frequencies. Occasionally the need may arise to install a set of baffles with lesser widths and spacing in series with another set in order to achieve the desired overall attenuation.

Silencers

Any device used downstream of a noise source for the purpose of lessening or attenuating noise is referred to as a silencer. The key design parameters of silencers are acoustical insertion loss, pressure drop, flow-generated noise, size, cost and life expectancy. The challenge of silencer design is to obtain the needed insertion loss without exceeding the allowable pressure drop and size for a minimum cost. These are frequently opposing requirements, and the optimal design represents a balanced compromise between them.

Silencers may be active or passive. Active silencers use noise canceling techniques using microphones, loudspeakers and signal processing to generate sound waves out of phase with the objectionable noise. The most common type of passive silencer is absorptive. Absorptive silencers are the most widely used devices to attenuate the noise in ducts and chimneys. Minimally, a fibrous lining on the inside of a chimney or duct wall constitutes a silencer. See Figure 6

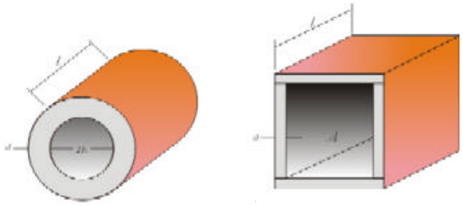


Figure 6

The silencers most often encountered by chimney engineers involve baffles (also referred to as splitters or batts) installed in a gas stream parallel to the gas flow. See Figure 7.

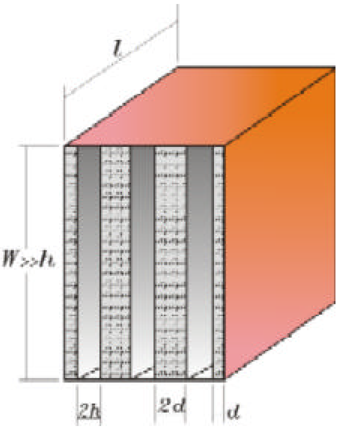


Figure 7

The baffles contain a light weight acoustic fill and are protected from abrasion by a fabric coating and perforated metal cover. The acoustic fill dissipates the sound energy as the waves pass through the media. See Figure 8.

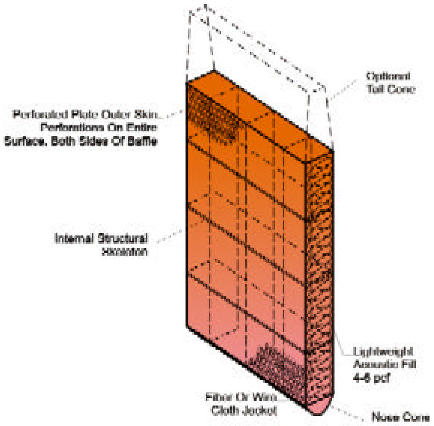


Figure 8

Pressure Drop

The pressure drop of a well designed silencer is proportional to the amount of attenuation provided. Formulae for pressure drop calculations include experimentally determined factors for various configurations. Accordingly, each silencer manufacturer may calculate slightly different pressure drops for a given application. Baranek and Ver offer the following:

$D_{PT} = ½ \, d \, V_P^2 \, (K_{ENT} + K_F + K_{EXIT}) \; N/M^2$

Where:

D_{PT} is the total pressure drop in N/M^2

D is the actual gas density in kg/m^3

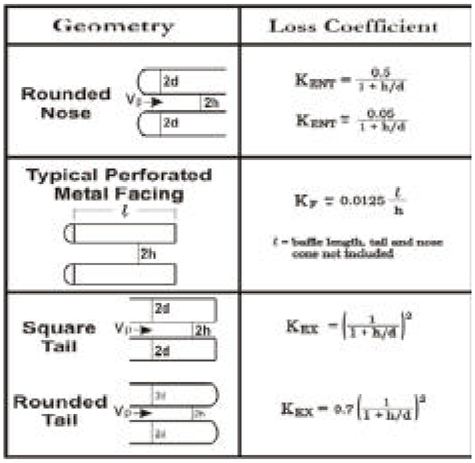
V_P is the velocity pressure in m/s

K_{ENT} is the entrance loss factor

K_F is the friction loss factor

K_{EXIT} is the exit loss factor

See Table 6 for loss factors.



Geometry	Loss Coefficient
Rounded Nose	$K_{ENT} = \frac{0.5}{1 + h/d}$ $K_{ENT} = \frac{0.05}{1 + h/d}$
Typical Perforated Metal Facing	$K_F = 0.0125 \frac{\ell}{h}$ ℓ = baffle length, tail and nose cone not included
Square Tail	$K_{EX} = \left(\frac{1}{1 + h/d}\right)^2$
Rounded Tail	$K_{EX} = 0.7\left(\frac{1}{1 + h/d}\right)^2$

Table 6: Pressure Loss Coefficients for Parallel Baffle Silencers

Breakout Noise

Steel chimneys do not generate noise but the chimney though can pass acoustical energy through its shell, especially at low frequencies. This is called breakout noise. Commonly, breakout noise is controlled by placing acoustical treatment on the chimney or duct wall.

When chimneys and ductwork is about 10 mm or thicker, breakout noise generally does not require treatment. This is because there is a limit to the mass that a sound wave can penetrate.

Self generated Noise

When the passage velocity through a silencer is too high, self or flow generated noise can be created. Empirical predictive schemes based upon experimental data have been published by I.L. Ver. His predictions give the octave-band sound power level of the flow-generated noise as a function of the face velocity, face area percent open area and absolute temperature.

$$L_{Woct} = 8.4 + 55 \text{ Log } V_F + 10 \text{ Log } A_F - 45 \text{ Log } P_{OA} - 25 \text{ Log } (T_{ABS} / 294) \text{ dB re } 10^{-12} \text{ W}$$

Once the power level is known, it is treated as a separate sound source. Exactly where the sound is generated is a subject of debate. That debate is important because the self generated noise may or may not be attenuated by the silencer that causes the noise. It is obviously conservative to assume that the self noise is not attenuated.

Acknowledgement

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