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Revision Memo

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SCOPE

This introduction to noise control provides background information on how to solve noise problems in refineries and chemical plants. Details can be found in other Design Practice sections that follow this introduction, ER&E reports, and technical / professional society, vendor and other, third party literature sources.

BACKGROUND

Noise is defined as any undesired sound. The major objectives of plant noise control are to comply with Exxon guidelines and government noise regulations at workplace and nearby community locations. This is to protect hearing of plant employees and to maintain good plant-community relationships. In addition, noise control is required for avoidance of in-plant speech interference inside control rooms, offices, and other plant areas frequented by personnel.

The need for noise control can also be stated in economic terms, such as avoidance of the need to pay worker's compensation claims, avoidance of citations, fines, lawsuits, and unfavorable publicity. Prolonged in-plant personnel exposure to high noise levels results in permanent hearing damage. The permanent hearing damage cannot be corrected by medical treatments.

A noise problem, in general, involves a system composed of three basic elements: a source, a path, and a receiver. In order to generate a cost-effective solution to a complex noise problem, the dominant source of the noise must be known, the characteristics of the significant transmission paths must be understood, and the noise criteria at the receiver locations must be defined. Consequently, plant noise control involves control at the noise source, transmission path, and receiver.

The most economical and effective approach to noise control is to evaluate expected noise emission and incorporate attenuation treatments during the initial design stage of a plant or in equipment selection. It is the plant owner's responsibility to develop noise criteria for the protection of the workers from hearing loss and for the prevention of community annoyance. The owner must present the contractor or equipment vendor with specifications covering hearing conservation and community noise criteria and finally decide upon the adequacy of the contractor's noise analysis and vendor's equipment noise data.

REFERENCES

INTERNATIONAL PRACTICES

- ▶ [IP 2-1-1](#) Plant Noise Design Criteria

OTHER REFERENCES

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2. Beranek, L. L. and Ver, I. L., *Noise and Vibration Control Engineering, Principles, and Applications*, published by John Wiley & Sons, Inc., 1992.
- ▶ 3. American National Standards Institute, *Acoustical Terminology*, ANSI S1.1-1994.
4. Rice, S. C., *Revision To Process Plant Noise Analytical Program 3565*, User's Manual EE.75E.80, 1980.

DEFINITIONS

Noise – Noise is undesired sound.

Sound – Sound is caused by vibrations in air, water, or other media that stimulate auditory nerves and produce the sensation of hearing. The sound vibrations are periodic pressure variations and are transmitted through the media by waves.

Sound Intensity, I (W/m²) – Sound intensity is the amount of sound power radiating through a unit area. It is the average rate of sound energy transmitted in a specified direction at a point through a unit area normal to this direction at the point considered.

Sound Power, W (watt) – Sound power is the sound energy radiated by a source per unit of time.

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DEFINITIONS (Cont)

Sound Pressure, p (pascals, Pa) – Sound pressure is a periodic fluctuation of pressure produced by an acoustic wave. The relationship among the above three terms is:

$$I = \frac{p^2}{\rho c} = \frac{W}{A} \quad \text{Eq. (1)}$$

where: I = Intensity, W/m²
p = Pressure, Pa
W = Power, W
A = Area through which the sound waves pass, m²
ρ = Density of the medium through which the sound passes, kg/m³
c = Sound velocity in the medium, m/s

The relationship $I = \frac{p^2}{\rho c}$ is strictly correct only for a sound wave in the free field produced by a single source.

- ♦ **Level, L_x (decibel, dB)** – Level is the magnitude of an acoustic quantity expressed in decibels. The subscripts, x of L, are used to indicate the type of quantity. The decibel is defined as 10 times the logarithm to the base 10 of the ratio of two like quantities, both proportional to power, e.g., $L_W = 10 \log W/W_0$. L_W is the sound power level in decibels for a radiated power, W. W_0 is the reference power.
- ♦ **Sound Pressure Level, L_p (dB)** – Sound pressure level is the relationship of a measured sound pressure to an arbitrary reference.

$$L_p = 10 \log \left(\frac{p_1}{p_0} \right)^2 \quad \text{Eq. (2)}$$

The reference quantity, p_0 , accepted internationally is 20 micropascals (20 μ Pa).

- ♦ **Sound Power Level, L_w (dB)** – Sound power level is the relationship of the sound power to an arbitrary reference. Often, L_W is used to express the acoustical power produced by equipment.

$$L_w = 10 \log \left(\frac{W_1}{W_0} \right) \quad \text{Eq. (3)}$$

The reference quantity, W_0 , is 10⁻¹² watts.

The following, derived from **Eqs. 1, 2, and 3**, are the relationships in the free field between L_p and L_W .

$$\begin{aligned} L_W &= L_p + 10 \log A_M \\ L_W &= L_p + 10 \log A_F - 10 \end{aligned} \quad \text{Eq. (4)}$$

where: A_M = The area through which the sound waves pass, m²
 A_F = The area through which the sound waves pass, ft²
 L_p = The average sound pressure level across area A, dB
 L_W = The sound power level of the sound passing through area A, dB

Sound Intensity Level, L_I (dB) – Sound intensity level is the relationship of the sound intensity to an arbitrary reference.

$$L_I = 10 \log \left(\frac{I}{I_0} \right) \quad \text{Eq. (5)}$$

The reference quantity, I_0 , is 10⁻¹² watt/m².

DEFINITIONS (Cont)

Overall Noise Level, L_{po} , L_{Wo} (dB)

A single number which expresses a total sound level, including the contributions of all frequencies. Thus, it is the logarithmic summation of the sound levels of each band in a sound spectrum.

- "A"-Weighted Sound Pressure Level, L_{pA} or dBA (dBA)** – An overall sound pressure level (in dB), in which the sound pressures of low and very high frequencies are weighted less heavily than the mid-frequencies. The weighting curve is designated in ANSI 12.4 and is termed "A" weighting. It was derived from studies of the human ear's response to different frequencies. These studies found that for noise levels below 55 dB, "A" weighting correlated with human perception of loudness. Hence dBA noise levels are well suited for, and indeed are used for, community noise regulations. In addition, it has been found that "A" weighted sound levels can be related to hearing damage and are thus used in hearing conservation regulations. Sound level meters measure this quantity directly using the "A" scale.

- Particle Velocity (m/s)** – In a sound field, the velocity caused by a sound wave, of a given infinitesimal part of the medium.

Frequency (hertz, Hz) – This is the time rate of repetition of periodic sound. One hertz equals one cycle per second.

Band – A band is a continuous group of acoustical frequencies. The width of the band is identified by the difference between the lowest and highest frequency in the group. It is designated by the geometric mean frequency.

- Octave Band** – An octave is a band in which the upper frequency is twice the lower frequency. The most often used eight octave bands are with center frequencies at 63; 125; 250; 500; 1,000; 2,000; 4,000; and 8,000 Hz.

OCTAVE BAND (Hz)	FREQUENCY RANGE (Hz)	
63	44.5	89
125	89	177
250	177	354
500	354	707
1,000	707	1,414
2,000	1,414	2,828
4,000	2,828	5,656
8,000	5,656	11,312

Third Octave Band – A third octave band is a band in which the upper frequency is 1.26 times ($2^{1/3}$) the lower frequency.

- Sound Spectrum** – A sound spectrum is the distribution of sound pressure, sound power, or sound intensity over the entire audio frequency range. Usually, the levels are given for each of eight octave bands (63 to 8000 hertz) or the corresponding twenty four 1/3 octave bands. In some situations, the octave bands or three 1/3 octave bands above and below these eight octave bands are also reported. These are the 31 and 16,000 hertz octave bands.

Community Noise Levels

- L_{10} (dB) The statistical sound pressure level ("A" weighted or octave band) that is exceeded 10 percent of the time.
- L_{50} (dB) The statistical sound pressure level ("A" weighted or octave band) that is exceeded 50 percent of the time.
- L_{90} (dB) The statistical sound pressure level ("A" weighted or octave band) that is exceeded 90 percent of the time.
- L_{eq} (dBA) The equivalent sound pressure level ("A" weighted) over a time period. The equivalence meaning equal energy, i.e.:

$$L_{eq} \text{ (dBA)} = 10 \log \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} 10^{\frac{L_{pA}(t)}{10}} dt \right] \quad \text{Eq. (6)}$$

- $L_{eq(8)}$ (dBA) The equivalent sound pressure level for 8 continuous hours.
- $L_{eq(24)}$ (dBA) The equivalent sound pressure level for 24 continuous hours.
- L_d (dBA) The equivalent sound pressure level for the 15 day-time hours of 0700 to 2200.

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DEFINITIONS (Cont)

- L_n (dBA) The equivalent sound pressure level for the 9 night-time hours of 2200 to 0700.
- L_{dn} (dBA) Day-night average sound level. The 24-hour "A" weighted equivalent sound pressure level with a 10 dB penalty applied to the 9 night-time hours.

$$L_{dn} = 10 \log \left[\frac{1}{24} \left[15 \times 10^{\left(\frac{L_d}{10}\right)} + 9 \times 10^{\left(\frac{L_n+10}{10}\right)} \right] \right] \text{ dB} \quad \text{Eq. (7)}$$

- L_{den} (dBA) The community noise equivalent level. It is 24-hour average A-weighted sound level for a given day, after addition of five decibels to sound levels from 1900 hours to 2200 hours, and after addition of ten decibels to sound levels from 2200 hours to midnight and from midnight to 0700 hours.

Free Field – This is a sound field in a homogeneous, isotropic medium, free of all boundaries. It is characterized by the particle velocity being primarily in the direction of propagation of the sound wave and the sound intensity being proportional to p^2 . In a free field, sound pressure levels decrease at a rate of 6 dB for each doubling of the distance from the source.

Near Field – This is the area close to a sound source. It is characterized by appreciable variations of sound pressure with position. Particle velocity is not necessarily in the direction of propagation of the sound wave. Moreover, sound intensity is not simply proportional to p^2 . Reduction in sound pressure is usually other than (i.e., more or less than) 6 dB for each doubling of distance.

Far Field – This is a sound field sufficiently remote to mask the size effects of large, irregularly shaped sound sources. Therefore, the field resembles a free field, particularly regarding the rate of sound pressure reduction with distance (6 dB for each doubling of distance).

- ◆ **Directivity Factor (Q)** – This is the ratio of the intensity on a designated axis of the sound radiation at a distance from the source center to the intensity that would be produced at the same position by a point source radiating the same total acoustical power uniformly in all directions.

- ◆ **Directivity Index, DI (dB)** – The DI is 10 times the logarithm to the base 10 of the directivity factor:

$$DI = 10 \log Q$$

Insertion Loss, L_i (dB) – Insertion loss is the difference between two sound pressure levels measured at the same point in space before and after noise abatement measures. Insertion loss can also be measured in terms of sound power levels or intensity levels.

Transmission Loss, L_T (dB) – Transmission loss of a noise control device is the difference between sound power incident on the device and the sound power transmitted by the device.

Noise Reduction, L_{NR} (dB) – The noise reduction of a control device is the difference in sound pressure levels measured at the device input and output.

CHARACTERISTICS OF NOISE

Noise is rarely a pure tone. It covers the entire audible range of about 20 to 20,000 hertz, but most of the noise energy is concentrated in the range of about 50 to 10,000 hertz. We react to noise in different ways, depending on both the overall levels and the frequency composition. The noise spectrum is a measure of both, since it shows how the sound energy is distributed over the audible range of frequencies.

L_{pA} (or dBA) is a good measure of how loud a noise appears to be. A difference of one decibel is virtually indistinguishable by the human ear. A three-decibel difference is detectable, but a ten-decibel difference stands out. In normal conversation, voice sound pressure level is about 50 to 60 dBA and 10 to 20 dB above the background level.

The intensity of sound waves traveling through the atmosphere decreases with distance. Two major factors are considered in most design calculations: dispersion and molecular air absorption. Other attenuation factors include structure shielding, wind effects, and ground absorption. Sound waves travel outward from a source, usually spherically (if the source is high above the ground) or hemi-spherically (if the source is near the ground). Accordingly, the sound energy is distributed over greater areas as the distance from the source increases; therefore, the sound level decreases. Reduction of the sound level for spherical or hemi-spherical dispersion is proportional to the logarithm of the square of the distance from the sound source. Noise reduction (dB) due to spherical or hemi-spherical dispersion is 6 dB for each doubling of the distance from the source. Sound waves in the atmosphere excite the air molecules, and this results in a conversion of sound energy into heat (molecular air absorption). Noise reduction (dB) due to molecular air absorption is linear with the distance and frequency.

CHARACTERISTICS OF NOISE (Cont)

Often sound waves in confined areas (reverberation) are reflected from walls or other surfaces before reaching the observer. If sound waves are reflected many times before they die out, the area is called reverberant, and the sound level is higher than in the absence of reflection. Where reverberation should be considered in plant design, it will be covered in other sections related to the particular type of equipment. Examples where reverberation affects plant noise levels are under furnaces or inside compressor houses.

Major changes in sound energy are necessary to significantly affect loudness. This is implied by the logarithmic relationship between sound pressure or power and the respective levels. A few examples will illustrate this: Doubling the sound power, regardless of the power level, results in an increase of three decibels in sound level. Thus, two identical sound sources produce sound three dB greater than either by itself. Regarding noise treatment, a muffler that achieves a 20 dB reduction in noise level eliminates 99 percent of the sound energy. **Figure 1** shows corresponding sound pressure and sound pressure levels for typical sounds. **Figure 2** shows corresponding sound power and sound power levels for typical noise sources.

FIGURE 1
TYPICAL "A" WEIGHTED SOUND PRESSURE LEVELS

Sound Pressure Levels "A" Weighted dB L_{pA} or dBA		Sound Pressure Adjusted For "A" Weighted Pascals	Typical Sound
140	— —	20×10^1	50 HP Siren 100 ft (30 m)
130	— —		Jet at Take-Off 200 ft (60 m)
120	— —	20	Jet Overhead 500 ft (150 m)
110	— —		Under Untreated Furnace
100	— —	20×10^{-1}	Heavy City Traffic
90	— —		
80	— —	20×10^{-2}	Inside Sports Car at 50 mph
70	— —		Busy Restaurant
60	— —	20×10^{-3}	Conversational Speech
50	— —		Average Residential Area
40	— —	20×10^{-4}	Quiet Residential Area
30	— —		Soft Whisper 5 ft (1.5 m)
20	— —	20×10^{-5}	Studio For Sound Pictures
10	— —		
0	— —	20×10^{-6}	Threshold of Hearing

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CHARACTERISTICS OF NOISE (Cont)

FIGURE 2
TYPICAL SOUND POWER LEVELS

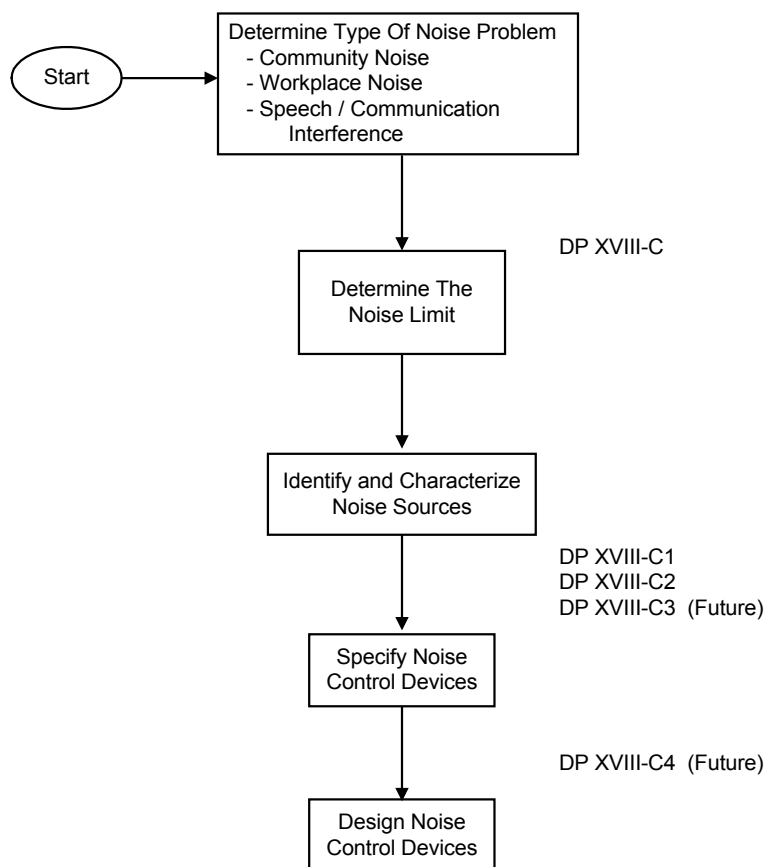
Sound Pressure Level dB – re 10^{-12} watts		Sound Power (watts)	Sound Source
160		10^4	Turbo Jet Engine
150		10^3	10,000 HP Centerfugal Compressor
140		10^2	10,000 HP Gas Turbine
130		10	Refinery Flare
120		1	10-Fan Air Fin Cooler
110		10^{-1}	200-400 HP Induction Motor
100		10^{-2}	SO-SA Burner Radiating Under Furnace
90		10^{-3}	
80		10^{-4}	
70		10^{-5}	Voice – Normal Conversation
60		10^{-6}	
50		10^{-7}	
40		10^{-8}	
30		10^{-9}	Voice – Very Soft Whisper

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DECISION TREES FOR PLANT NOISE CONTROL

This section consists of decision trees that will give general guidance to proceed with a noise control effort. The decision tree is presented in **Figures 3** and **4**. **Figure 3** is for trouble shooting for the existing facilities. **Figure 4** is for purchasing new or replacement equipment. For those situations that do not fit into the general decision trees, such as for major capital projects, contact ER&E noise control specialists for assistance.

FIGURE 3
TROUBLE SHOOTING FOR EXISTING NOISE PROBLEMS



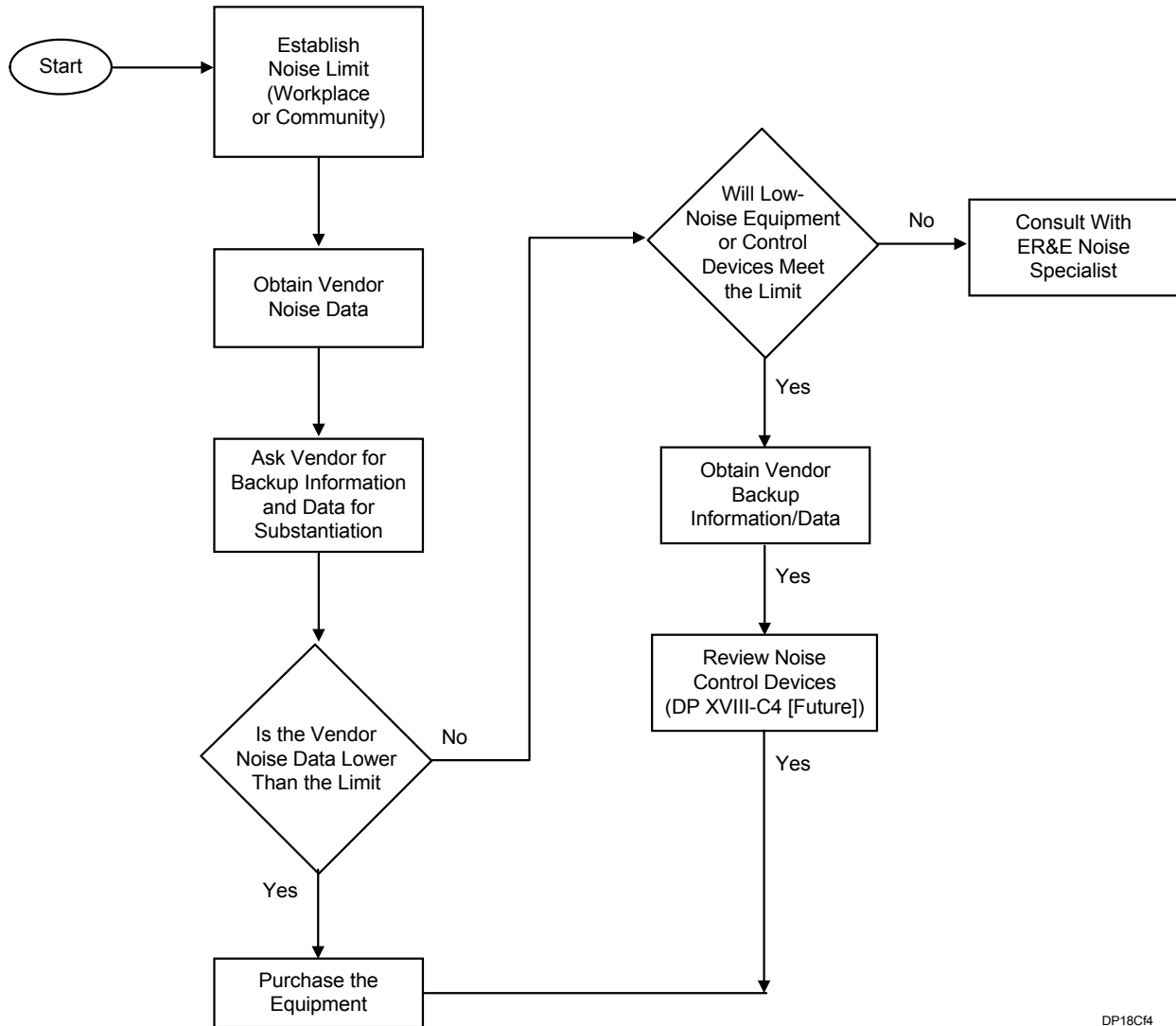
Notes:

- (1) Noise control devices can be applied to the equipment (i.e., low-noise equipment), or transmission paths (i.e., silencer or enclosure), or receiving (i.e., quiet room for worker).
- (2) Administrative noise control (e.g., restricted access) should also be considered on a case-by-case basis.

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DECISION TREES FOR PLANT NOISE CONTROL (Cont)

FIGURE 4
PURCHASE NEW OR REPLACEMENT EQUIPMENT



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