PSV noise – criteria, limits and prediction

By Eur Ing MDG Randall, Foster Wheeler Energy Limited

In an earlier article, the author concentrated on noise at close range from pipes and vents of PSVs (Pressure Safety Valves). Three criteria were mentioned there. This article reviews in general terms those three criteria, then discusses associated engineering practice and ends with an appreciation of the numbers that may be met when working with PSV noise.

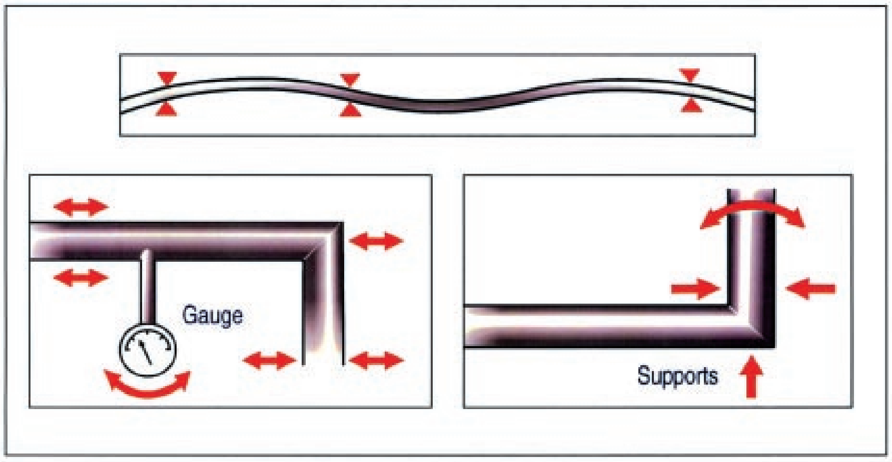


Figure 1A Whole body modes of vibration (partially supported pipe systems)

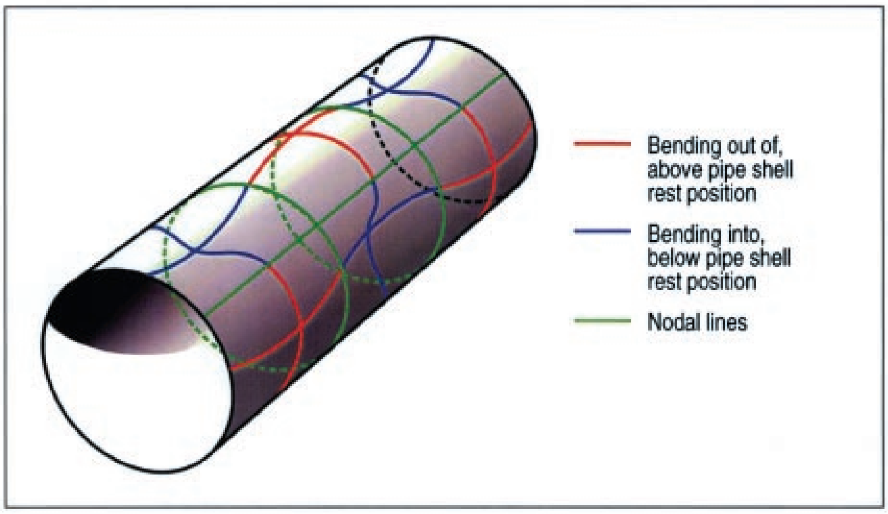


Figure 1B Standing waves on a shell (formed by a pipe wall)

The noise engineer has some twenty or so criteria by which to judge noise and reduce its effect. For the general purposes of power and gas plants, petrochemical and pharmaceutical engineering we will only consider the most important three here. These are:

- Acoustic fatigue
- Risk of hearing damage
- Reaction from local communities

Acoustic fatigue

Some while ago the author asked a valve vendor's representative whether his company had any cases of acoustic fatigue? "No," he said "but we've seen a few pipes break due to high noise".

Fractures sometimes occur on gas bearing pipes when there are high noise levels inside them. They appear when the vibration of the pipe shell surface, or branch body, cannot be supported by the materials of construction. The important forms of vibration appear to be:

- Whole body modes of vibration
- Pipe shell vibrational modes
- Where shell vibration modes occur on a pipe, but the end or edge conditions do not match the modes, thus increasing the modal density and probably the vibrational stress in the pipe shell at the ends or edges of the vibrational field.
- Forced vibration of the pipe body or shell

Figures 1A and 1B show the first two types of vibration referred to.

The properties of the gas in the pipe or branch that appear to be associated with the onset of fatigue appear to be:

- high noise level
- matching of frequencies in the gas space with modes of vibration on the pipe shell, or of the whole pipe.

The Mach number of the gas in the pipe is also associated with acoustic fatigue but this appears to be based on empiricism rather than theory. Where a high fractional Mach number in a pipe (Mach No. = v/C, $\rho = \dot{M}/Av$, $\therefore$ Mach No $= \dot{M}/\rho CA$) system could result in a Mach 1 region of flow further downstream there is the possibility of that Mach 1 region being another noise source. The noise from this downstream source is unlikely to contribute to the upstream noise. This is because it appears to be impossible for the downstream noise,

created by shock and local turbulence, to travel upstream via the Mach 1 region, i.e. at propogational speeds faster than the speed of sound. There does however appear to be the possibility of phase effects, travelling outside the fluid, creating resonance conditions across the Mach 1 region, see for example Ref. 1. How much upstream noise this would create is unknown but it is expected to be noticeably tonal in character.
The published evidence to date indicates that in the absence of welding defects, fatigue failure of the main (route or run) pipe occurs with:

- greater axial Asymmetry, A, of the pipe and reinforcing pads, where branches, supports etc, are welded to the main pipe
- greater pipe diameter, D
- thinner pipe shell.

Pipe shell thickness, t, is not a measure of pipe shell thinness, T, but its reciprocal is. (T = 1/t) Thus a measure of potential pipe failure due to pipe properties is related to D, T and A. This may be viewed as an equation $P_{fp} = k * D^l * T^m * A^n$ where the constant, k, and the indices l, m and n have to be determined.
Engineers will wish to avoid fatigue failure and thus may attempt to design with thicker, more axisymmetric, smaller diameter, run pipes. A design guide for the prediction and avoidance of acoustic fatigue in pipes can be developed from the work in Ref. 2/2a. Other design guides are both in course of development and exist as proprietary or patented methods. Rules of thumb to be found in the literature are:

- When noise outside the pipe increases to about 110 dB to 130 dB(A) there is a possibility that the pipe will crack. See Ref. 3 and Ref. 4.
- Instruments attached to the pipe will be damaged above 105 dB(A). See Ref. 5 p254.

The phrase "in the absence of welding defects" has caused some controversy. Is acoustic fatigue cracking always associated with a weld? Well if you want to disprove the statement "All swans are white!" it might be easiest to "Find a black swan". To this end the best the author can offer is Figure 8 in Ref. 6, and Prof. Richard's comments (p 674 in that Ref.) as possible evidence of black swans.

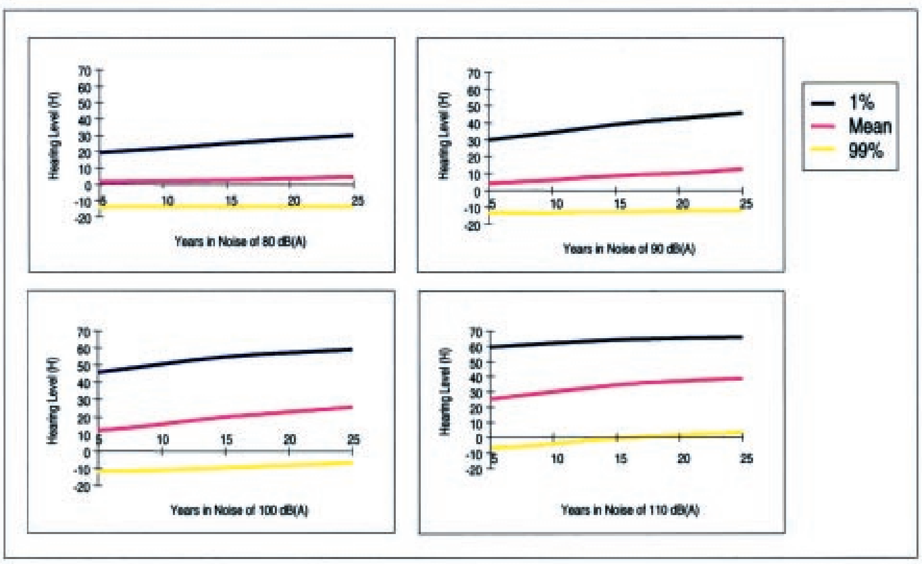
Risk of Damage to Hearing

Noise may cause hearing damage by reason of one very loud event, a series of loud events, or days, weeks and years of loud noise in a work or recreational environment. Fig 2, based on Ref. 7, shows how selected percentages of a male population are gradually affected by continuous noise for 8 hours a day over a number of years of work.
Figures 2a, b, c and d show the effect of noise on hearing level, for a population of males during part of a working lifetime after starting at age 20. Some social impact may be said to start at 30 dB hearing level. Compensation may be payable at 50 dB and above.
It will be seen that an average of 80 dB(A) for 8 hours of work each day results after 25 years (age 45) in a male population average (mean) of about 5 dB hearing level. In an average level of 110 dB(A) the male population mean reaches a hearing level of 30 dB in 10 years.
Consider the unfortunates whose ears are more sensitive to damage. 1% of a male population reach a hearing level of 30 dB after 25 years in 80 dB(A). 1% of a male population working in a daily average level of 110 dB(A) reach 65 dB hearing level after 25 years.
The basis of these charts is the discovery that hearing loss is a function of both the "noise level" and the "cumulative time of exposure". The unit of noise measurement is seen to be the dB(A). In modern methods of hearing damage risk assessment there is no link to frequency content except via the "A" weighting. See Ref. 8. Note, however, that the dB(A) unit may not effectively predict damage done by tonal components. For this the work of Ref. 9 is suggested.
In the late 1900's, the normal limit of exposure to continuous noise was 90 dB(A) for 8 hours or its equivalent. Now we see companies and governments seeking 85 dB(A) for 8 hours. Tables of duration and continuous noise level, equivalent to 8 hours of 90 or 85 dB(A) are published.
Remember that the calculation of noise energy or "dose", in normal continuous conditions, is related to both the person's time in an area and the noise level in that area, not just to the noise in the area. Thus one might expect to keep a tally of each person's cumulative noise dose or the sum of all the different noise levels and times for each day, week etc. Indeed, "noise dose meters" are available for employees to wear. This may well be thought better than the alternative of:

- calculating individual noise doses
- monitoring hearing levels of employees
- watching for the onset of noise-induced hearing loss.

Some employers want to have some surety that employees will not receive noise doses that would lead to hearing damage. This will relieve them of various tasks, such as:

- supplying ear protection and maintaining it in good effective condition
- provision of training to employees on the effects of noise
- defining and marking perimeters of HDR (Hearing Damage Risk) areas



Figures 2a, b, c and d. Hearing Level after working for years in noise.

• mounting notices and machine labels, which warn of noise.

That surety can be achieved by a knowledge that noise levels, in the factory or on site, are all below 90 dB(A), or 85 dB(A) if that is the chosen limit. This enables employees to go anywhere on the site during an 8 hour shift and not meet a level of 90 dB(A) and thus know their daily noise dose cannot equal 90 dB(A) for 8 hours. Then the only task remaining is to monitor noise and confirm it remains below the selected limit of 90 or 85 dB(A).

Where a 12 hour shift pattern is in force the 90 (85) dB(A) limit is reduced to 88 (83) dB(A), because 10log(8/12) = -2dB. See Ref. 7.

Damage to hearing caused by one very loud event (a single intense sudden sound) may be different in onset and character to the observed noise induced hearing loss from lower but more continuous levels. In this situation, damage in the inner ear is caused to a whole organ rather than to certain cells.

How does one characterise the noise from a PSV release? Tonal? Impulsive? Continuous? Or, more than one of these? There are many versions of rules forbidding exposure to unprotected single event noise, and to high level continuous noise. For example 135dB, 150 dB (see Ref. 10) and 130dB(AI), 200mPa (see Ref. 11) and today as low as 115 dB(A) (see Ref. 12). See also the Box "Hearing protection"

Annoyance to a Local Community

Years ago, in the "wait and see" era, plants and factories were built, noise was generated, local residents complained, and then some noise control might be installed. It was always in that order. The likelihood of assembly, riot, and bloody insurrection was thought to be low, especially if complaints were treated urgently. When no urgency was attached to the complaints the author has known residents of some village streets angry enough to require a joint visit from a representative of the local authority and a representative of the noisy plant. This was to display an agreed policy, explain what caused the noise and say that unfortunately it would be some weeks before any worthwhile remedial measures could be designed, engineered, installed, tested and commissioned. People have been killed in noise disputes so one treats angry residents with care. See Ref. 13.

In the second half of the 20th century methods were developed by which to predict the "annoyance" to be expected, or more exactly, the "likelihood of complaints" due to noise in the vicinity of industrial plant. Two systems of rating the reaction of a local community are based on:

• differences in dB(A) between pre-existing levels and the level of noise complained of, or noise to be introduced. See for example Ref. 14/14a.
• maximum noise levels set by local or government authorities in relation to a description of the surrounding environment. See for example Ref 15, Table on p10 and Ref 15a, Annex 5. These dB(A) levels may be measured in L_{10}, L_{90}, or Leq terms. The levels can vary from about 20 to about 70 dB(A).

Note the use, once again, of the dB(A) unit. The most significant advantage of the dB(A) unit is that it is about the best unit found to date, by which to measure community reaction to many different noises, and as we saw in the earlier paragraphs it is used for hearing damage risk assessment too. Rating methods can be improved by adjusting the dB(A) value to take account of other factors associated with the noise. See Ref. 16. For example tonal components, which might be annoying, and rapid onset of noise that might cause a startle reaction in some persons.

Long term measurement surveys of "background sound" confirm the self-evident fact that people are awake and cause noise during the day and are generally asleep, and thus quiet and more susceptible to noise, during the night. Fundamental to the various noise rating systems is the recognition that days are noisier than nights, and industrial areas are noisier than country villages. This simple separation of activities is the stuff of planning authorities, but there have been cases where planners have allowed a mixture of residential and factory development in close proximity, and with the expected unfortunate consequences.

When a new plant or factory is being planned the existing background sound or existing type of area in which the factory is to be built is considered. This is so that a limit to industrial noise can be set, and thus community reaction may be avoided. So as to make best possible use of the capital invested, the modern factory will probably be in continuous (i.e. 24 hour) operation. Night-time background levels are less than day and evening levels. This implies that the night-time limit is the factor that will determine the degree of noise reduction and control to be used during design of the plant.

In addition to a limit on continuous noise from factories there may be additional requirements which limit transient noises. For example, "no noise shall be in excess of 10 dB greater than the limit for continuous noise" or, "during the day and night-time as

Hearing protection

An acceptable level of noise, for 8 hours a day over a working lifetime, or for a once-off exposure to high level noise, is best set by competent authorities. Where noise from some source exists and cannot by practicable means be reduced to acceptable levels, hearing protection should be worn where and when the noise occurs. For some sources, like the PSV, noise is expected but the event of operation can only be estimated as a probability not as a specific time, or perhaps not even as a specific level and duration. For such events hearing protection should be worn in the expectation that the noise will occur while operators / maintenance personnel are close to the noise source.

The type of hearing protection is likely to be chosen from the range of devices (ear "plugs" and "muffs") that are on the market. Selection of an appropriate type will take note of the "assumed protection" of the device and the frequency content of the noise. This presents something of a challenge to the Health and Safety Engineer because although the assumed protection data is available by frequency for all the better protection devices, there is little or no frequency data available for PSVs. Not all PSV vendors provide even dB(A) figures for their equipment and thus it should not be expected that all will be able to compute and provide the frequency content and level of noise. These will vary with pressure and mass flow passing during a relief event. Pressure and mass flow rate will themselves vary with time during an event.

The future still holds its secrets, but there might come a time when in addition to today's requirement of frequency domain analysis, the noise from the pop action PSVs will have to be analyzed in the time domain for both initial pop noise and then flow noise.

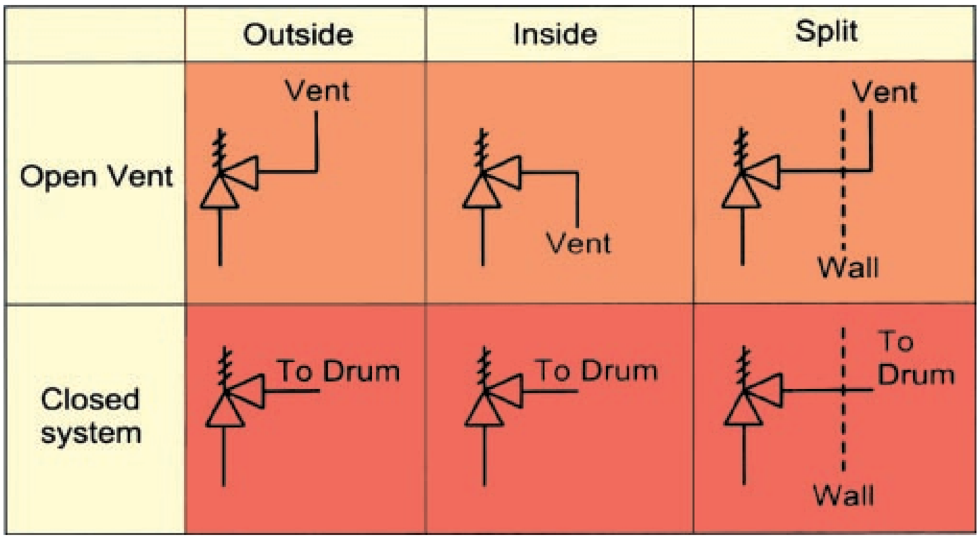


Figure 3. "Closed Systems" and "Open Vent" systems at a factory.

appropriate no Leq (15 min) shall be greater than 10 dB above the daytime limit and 5 dB above the night-time limit".

On planning an accident

Here is an issue for discussion, which is raised by the nature and use of PSVs. How much planning and design time should be given to noise which is an accidental by-product of accidents and emergencies? It may be argued that fire and like cases are emergency or accidental situations and, are-not/cannot, be avoided by legislation or planning guidelines. Where noise occurs as a result of an accident (say an explosion) it is accepted as part of that accident. Where noise occurs as a result of an emergency it is generally accepted as "accidental" and thus not subject to the planning measures referred to above. See p. 4b of Ref. 17. The author is not aware of any published planning legislation, regulation, or guidance that specifically requires control of noise in accident or emergency situations.

Thus the question that arises is, should noise resulting from foreseen actions, undertaken to avoid emergencies, be subject to planning rules? In such cases it might be expected that noise reduction would be employed as research yields results, but should noise control be required? The possibility of increased risk of accident by addition of noise control features has been foreseen, and both statutory authorities and engineers should be aware of the possible deleterious consequences of such additions.

Noise from the PSV, open vent, and associated pipe

PSVs are sited in the open air on power, gas and petrochemical plants, and both inside and outside buildings on pharmaceutical plants. Remember that most of the noise will come from an open vent, the next most important source will be the downstream pipe. Less obvious areas of noise radiation are the upstream pipe if it is of any length, and finally the body of the valve. This is because the ear is drawn to the downstream pipe or vent as the area from which the noise is radiated. Measurements are required to find the relationship between upstream and downstream pipe SPL, but a rule of thumb (Ref. 18) is a 10dB decrease across a valve downstream to upstream. These four different "sources" (see Box "BY and FROM") play different parts dependent upon whether the PSV is outside or inside, whether the open vent is inside or outside and how much upstream and downstream pipe is inside or outside. The major variations are shown in Figure 3.

It is most important, when silencers or pipe insulation are suggested, that attention be paid to the sources that will remain after the treatment is applied. The noise of a dominant source only masks lesser sources while it is dominant. The application of noise control may leave some other component to be the source of hearing damage risk or an annoyance situation. With the latest development in the Foster Wheeler PDS reporting system we can immediately find exact locations of both valves and, if there are any, terminations of their open vent lines. No longer do we have to trace through electronic ISOs or a Model to find where the pipe leads, but this is part of another story.

Calculations by the PSV vendor

Foster Wheeler expects the responsibility for equipment noise to remain with the equipment vendor. No concession is made where equipment noise is radiated from connecting pipework. PSV vendors are expected to provide data on the noise produced by their equipment, the noise radiated through associated pipework (not in the vendors supply) and the suggested means of reducing or controlling noise to an agreed level at a specified distance.

The vendor's calculations, made to determine how much noise radiates from the various parts of the system, may be of the four types noted above, namely:

- Noise from valve. This is usually given by vendors as SPL 1m from the downstream pipe and 1m downstream of the valve.
- Noise from the downstream pipe. This is basically the same number as in 1 but more accurately there will be some loss down long lengths of pipe. Two apparently conflicting rules of thumb are given here: 1) There is a 3 dB loss for each 50 diame-

BY and FROM

Only when attempting to hunt for noise sources and describe them, prior to instituting noise reduction or noise control, will the engineer distinguish between noise caused BY sources and noise radiated FROM an item or area. The obvious PSV example is where the noise from the PSV is known to be caused BY and AT the valve. Although vent noise comes FROM the open vent it is not, for the most part, created there. But see p515 and 528 of Ref. 23. Thus we do not say caused BY the open vent. When we have understood what the noise is caused BY and where the noise is radiated FROM we can introduce noise reduction and control by the most effective means. "Noise reduction" can be produced on noise sources and along the route "source to radiation point". "Noise control" can be installed along the route, "radiation point to receiver" Although this BY and FROM convention can be used all the time, the word "source" is often used to cover both BY and FROM situations.

ters of gas filled pipe away from the source. See Ref. 19.

2) Acoustic insulation to the valve body and the first 5 pipe diameters downstream is an effective method of noise treatment. See p 64 of Ref. 20.

- Noise from the open vent. Few vendors currently provide this data but where an open vent is present it is the loudest source.
- Noise from the upstream pipe.

Foster Wheeler now regularly asks potential vendors to provide data on the first three issues, and it has become commonplace for potential vendors to provide a sizing service within our offices. This is so that the sizing can encompass prediction of the noise levels, which are to some extent dependent on the pipe size and thickness selected by others. Where control valves are used as vent valves the same questions are asked as for "Open Vent" PSVs.

The noise engineer takes the vendor's data and creates a model in which the total noise, from a PSV (valve, pipes and vent) or PSV group (where more than one PSV is expected to vent simultaneously), is calculated for the appropriate room or open air condition. When noise reduction and control have to be employed the vendor may be required to take responsibility for the entire package of valve and noise engineering, so that there is no division of responsibility. This can include calculation of noise at some point near the valve or vent, such as on a nearby platform, or at a point farther away, such as on a road at the local community. For this aspect some small amount of noise modeling is required, but it is little more than arithmetic (see Box "A Little Arithmetic").

Noise from a PSV – an appreciation

A quick method of evaluating the sound power from a PSV has been given (see Ref 21) where the suggestion that η could be taken as a global figure (of say, 0.004) was revisited.

To gain an insight into the noise from a PSV we can explore the range of PWLs to be expected when the process fluid (remember it must be gaseous) in the valve exists in a range of between:

10	to	60	in	MW
200	to	1200	in	°K
0.01	to	300	in	kg/s

MW (-) \ T(°K)	200	400	600	800	1000	1200
10	464.5	657	804.6	929.1	1038.7	1137.9
20	328.5	464.5	568.9	657	734.5	804.6
30	268.2	379.3	464.5	536.4	599.7	657
40	232.3	328.5	402.3	464.5	519.4	468.9
50	207.7	293.8	359.8	415.5	464.5	508.9
60	189.6	268.2	328.5	379.3	424.1	464.5

R = 8300
γ = 1.3

Table 1. Speed of sound in a gas

(Kg/Hr)	$\dot{M}$ (Kg/s)	Speed of Sound, C.(m/s) 315	400	500	630	800	1000
36	0.01	123	125.1	127	129	131.1	133
113.76	0.0316	128	130	132	134	136.1	138
360	0.1	133	135.1	137	139	141.1	143
1137.6	0.316	138	140	142	144	146.1	148
3600	1	143	145.1	147	149	151.1	153
11376	3.16	148	150	152	154	156.1	158
36000	10	153	155.1	157	159	161.1	163
113760	31.6	158	160	162	164	166.1	168
360000	100	163	165.1	167	169	171.1	173
1137600	316	168	170	172	174	176.1	178

η = 0.004

Table 2. Valve's sound power level

VENT PWL (say dB(A)) \ Limit SPL (say dB(A))	55	70	85	100	115	130	145
180	709431	126157	22434	3989	709	126	22
160	70943	12616	2243	399	71	13	
140	7094	1262	224	40			
120	709	126	22				
100	71						

r (metres)

Q = 2 i.e. Hemispherical
Formula r = (10^(pwl-spl)/10)/(2*π))^ 0.5

Table 3. Hemispherical distance from PWL source to an SPL point

η = 0.004
γ = 1.3

This is illustrated by Table 1 (to determine speed of sound, from knowledge of temperature and molecular weight) together with Table 2 (to determine PWL, from knowledge of speed of sound and mass flow rate). The range selected is only for discussion purposes. The position of a phase change line, gas to liquid may have to be determined where this is critical. The calculated speed of sound in the gas can be thought of as that at the valve (i.e. its choke point).

The calculated PWL of the valve can be thought of as that part which goes down the tail pipe.

Where the exit pipe leads to an open vent, e.g. on air, steam or nitrogen systems, we may need to evaluate a "safe distance" or a distance before a "community limit" is reached. Tables 3 and 5 provide approximate answers but should not be regarded as tools for final design.

Table 3 indicates how far one has to be, away from a PSV vent, if one is to be at or below some set value of SPL. This may be for "hearing damage risk" calculations at close range or "community reaction" avoidance at long range. Hemispherical spreading, is assumed, e.g. over the ground. At long ranges there is of course the advantage of at least atmospheric attenuation to add to the geometric spreading and maybe some form of shielding or other attenuation mechanism. See Ref 22.

Table 4 is provided only to demonstrate that where air absorption is of importance, e.g. 1000 Hz or higher, distance out to some noise limit is much shorter. Compare Tables 3 and 4.

In Table 5 one can see how far one has to be, away from a PSV vent, if one is to be below say 130 or 115 dB(A). The table is for spherical radiation but includes no other attenuation mechanisms.

Table 5 can be used to provide a first estimate of the vertical length of vent pipe that will be required where "stack height" is to be used as the main method of noise reduction. That takes us full circle to the questions asked by the author's last article, in Valve World (December 1998, p 52).

In conclusion

Whereas in an earlier article this author considered PSV noise at close range to the valve, pipe and vent; this review has outlined the engineering practice associated with the three criteria: acoustic fatigue, hearing damage risk and annoyance of a community; and developed some thoughts so as to provide an appreciation of the numbers that may be encountered when working with PSV noise. ■

References

1. On the mechanism of choked jet noise. A Powell. Proceedings of the Physical Society. Vol. 66 1954 pp1039 – 1056.
2. Acoustically Induced Piping Vibration in High Capacity Pressure Reducing Systems. V A Carucci and R T Mueller. ASME 82-WA/PVP-8

2a. Acoustic Fatigue in Pipes, Marsh, Van de Loo, Spallanzani, and Temple. Concawe Report 85/52. Info@concawe.be

3. Recommended Maximum Valve Noise Levels, A C Fagerlund. Proceedings of the ISA/86 International Conference and Exhibition, Houston, Texas, Oct, 1986
4. Solve valve noise and cavitation problems. H D Baumann. Hydrocarbon Processing, March 1997, pp 45 – 50.
5. Universal valve sizing prediction method. in ISA Handbook of control valves, J W Hutchinson (Ed) (2nd Edn.) pp245 – 254
6. Investigations into the failure of gas circulators and circuit components at Hinkley Point nuclear power station. W Rizk and D F Seymour. Proc Instn Mech Engrs Vol. 179 Pt 1 No 21
7. Tables for the Estimation of Noise Induced Hearing Loss. D W Robinson and M S Shipton NPL Acoustics Report Ac 61, (2nd Edition) June 1977
8. Hearing and Noise in Industry. W Burns and D W Robinson HMSO, 1970
9. Hazardous exposure to intermittent and steady-state noise. K D Kryter, W Dixon Ward, J D Miller and D H Eldredge. JASA Vol. 39 No 3 (1966) pp451 – 464.
10. Code of Practice for reducing the exposure of employed persons to noise. DoEmp HMSO 1972
11. 86/188/EEC Council Directive on the protection of workers from the risks related to exposure to noise at work. 12 May 1986.
12. Guidelines on Noise, API Medical Research Report EA 7301. 1973
13. Man who killed after months of TV noise is freed. Daily Telegraph June 25, 1992
14. BS 4142 1967 Method of Rating Industrial Noise Affecting Mixed Residential and Industrial Areas.

14a BS 4142 1997 Method for Rating Industrial Noise Affecting Mixed Residential and Industrial Areas.

15. Planning and noise, DoEnv. Circular 10/73, HMSO

15a PPG 24 Planning and noise. DoEnv. Plan-

PWL (say dB(A))	SPL Limit 55	70	85	100	115	130	145
180	7800	5500	3300	1600	540	120	22
160	4700	2700	1150	320	70	13	
140	2100	800	200	40	7		
120	540	120	22	r (metres)			
100	70	13					

f = 1000Hz

Table 4. Hemispherical distance from PWL source to an SPL point (with 1000 Hz air attenuation)

VENT PWL (say dB(A))	Limit SPL (say dB(A)) 55	70	85	100	115	130	145
180						89	16
160					50	9	2
140				28	5	1	
120		89	16	3	1	r (metres)	
100		9	2				

Q = 1 i.e. Spherical

Formula r = (10^(pwl-spl)/10)/(4π))^ 0.5

Table 5. Spherical distance from PWL source to an SPL point

A little arithmetic

Open air work

For point sources in open air the noise field can be represented by rays travelling outwards from source to all directions, and can be thought of as the same energy at any radius spread over a sphere the area of which increases with distance. (See Figure 4.)
For point sources in open air the situation can be described by the equation:

1) $SPL_{Dir} = PWL + 10Log(DI/4\pi r^2)$ Note: curved area of a sphere is $4\pi r^2$

For line sources in open air the equation is:

2) $SPL_{Dir} = PWL + 10Log(DI/2\pi rL)$ Note: curved area of a cylinder is $2\pi rL$

These equations describe the noise decreasing with distance away from the source. As a rule of thumb when the observer is more than two major dimensions away from of the valve, pipe, or vent it can be treated as a point source. See p172 of Ref. 24.
As an example let us take an open vent at the end of 30m of 8" pipe downstream of a 6" valve, Let dimension of valve body be ½m. Then at any distance over 1m from the valve body it can be treated as a point source and the noise decreases as $1/r^2$. Also at any point more than 2*(8"/40"), say ½m, from the open vent, the vent can be treated as a point source. At any distance over twice the pipe length (60 m) the pipe can be treated as a point source. At any distance closer than this to the pipe it appears to be a line source and the noise only decreases as 1/r.
References 22 (Section 3.2.2.3), 25 and 26 (Sections 3.4 and 4.2) are provided for a more classical explanation of the point, line and area sources of radiation.

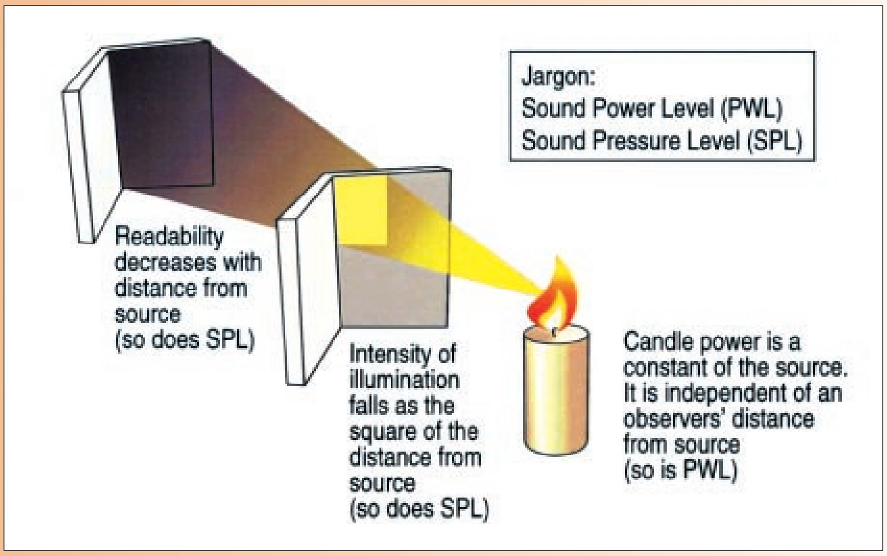


Figure 4. Relationship between PWL and SPL

Room work

In a room with a noisy piece of kit there are two noise fields superposed one on the other. A direct field of rays radiated from the source, directly to the receiver. A reverberant field of rays radiated from the source but having bounced one or more times, reverberated, from the walls and contents within the room before reaching the receiver.
For point sources in a room the situation can be described by a set of equations:

1) $SPL_{Dir} = PWL + 10Log(DI/4\pi r^2)$

3) $SPL_{Rev} = PWL + 10Log(4/R)$

4) $SPL_{Tot} = SPL_{Rev}$ L+ SPL_{Dir}

Where

L+ = Logarithmic addition

SPL_{Rev} = Reverberant sound pressure level

SPL_{Dir} = Direct sound pressure level

SPL_{Tot} = Total sound pressure level

PWL = Sound power level

DI = Directivity index

R = Room constant = $S\alpha/(1-\alpha)$

S = Total wall floor and ceiling area

α = Average sound absorption co-efficient

Equation 1 is substituted by Equation 2 when the pipe source has to be treated as a line source.

ning Policy Guidance, PPG 24 September 1994, HMSO
16 Community Reaction Criteria for External Noises, C W Kosten and G J van Os in: National Physical Laboratory Symposium No 12, The Control of Noise (June 1961) HMSO
17 Noise and other environmental considerations in the design and planning of Gas Compressor Stations in the UK. A. Cleveland, ASME Paper 72-GT-110 from Meeting 26-30 March1972
18 Analysing and controlling noise in process plants, T N Stein, Chemical Engineering, March 10 1980.
19 Process plant noise control at the design engineering stage. Trans. of the ASME, Nov 1970, pp779 - 783
20 API recommended practice 521, Fourth Edn. March 1997
21 Safety valve noise; limits, reduction and control. M D G Randall, Valve World Vol. 3 Iss 6 Dec 1998
22 Noise Procedure Specification EEMUA Pub. No. 140 E-mail INFO@EEMUA.CO.UK
23 H H Heller and P A Franken, Chap. 16 in Noise and Vibration Control, L L Beranek (Ed), McGraw- Hill, 1971.
24 Noise Reduction, L L Beranek. McGraw-Hill, 1960.
25 Note on two common problems of sound propagation. E J Rathe. J. Sound Vib. (1969) Vol. 10(3) pp 472 - 479
26 Determination of sound power levels of industrial equipment, particularly oil industry plant. P Sutton, D Audoynaud, L A Bijl, K J Marsh, W C van't Sant. Concawe Report No. 2/76. Info@concawe.be

About the author

Eur. Ing. Mervyn Randall is both a Chartered Physicist and Chartered Engineer. He holds a B.Sc. from University of Wales and a M.Sc. from University of Southampton (ISVR). He has worked as a consultant and for contractors in the Oil, Gas, Power, Petrochemical, and Pharmaceutical Industries. He has worked for Foster Wheeler for the past ten years and now is a senior engineer in the Technology and Vessel Group at Foster Wheeler Energy Limited's headquarters in Reading, England. His interest in sound and noise was developed while at University and he still retains a passion for the subject.