WHY ULTRASONIC GAS LEAK DETECTION?

Fecarotta, C.[1] **and Janowski, A.**[2]
[1] **MSA Italiana S.p.A., Via Po 13/17, Rozzano, 20089, Italy, email:**
Claudio.Fecarotta@MSAsafety.com
[2] **MSA Polska Sp. z o.o. Al. Jana Pawła II 27, Warsaw, 00-867, Poland, email:**
Andrzej.Janowski@MSAsafety.com

ABSTRACT

Technologies that have traditionally been used in fixed installations to detect hydrogen gas leaks, such as Catalytic and Electrochemical Point Sensors have one limitation: in order for a leak to be detected, the gas itself must either be in close proximity to the detector or within a pre-defined area. Unfortunately, outdoor environmental conditions such as changing wind directions and quick dispersion of the gas cloud from a leaking outdoor installation often cause that traditional gas detection systems may not alert to the presence of gas simply because the gas never reaches the detector. These traditional gas detection systems need to wait for the gas to form a vapor cloud, which may or may not ignite, and which may or may not allow loss prevention by enabling shutting down the gas facility in time. Ultrasonic Gas Leak Detectors (UGLD) respond at the speed of sound at gas leak initiation, unaffected by changing wind directions and dilution of the gas. Ultrasonic Gas Leak Detectors are based on robust microphone technology; they detect outdoor leaks by sensing the distinct high frequency ultrasound emitted by all high pressure gas leaks. With the ultrasonic sensing technology, leaking gas itself does not have to reach the sensor – just the sound of the gas leaking. By adding Ultrasonic Gas Leak Detectors for Hydrogen leak detection faster response times and lower operation costs can be obtained.

1.0 INTRODUCTION

Ultrasonic gas leak detection is a comparatively recent detection technique and has emerged as an effective means of establishing the presence of gas leaks. It works especially well in open, ventilated areas where other methods of gas detection may not be independent of ventilation. Because UGLDs respond to the source of the leak, rather than the gas itself, they complement sensors that measure gas concentration.

2.0 HOW DOES UGLD WORK?

Fixed gas detection in open ventilated areas like offshore or onshore facilities is generally considered problematic because the gas easily dilutes and drifts away from conventional gas sensors. Ultrasonic gas leak detectors solve this problem by detecting the airborne acoustic ultrasound generated when pressurized gas escapes from a leak. When a gas leak occurs, the ultrasound generated by the leak travels at the speed of sound, through the air, from the source to the detector. Ultrasonic gas leak detectors are non-concentration based detectors. They send a signal to the control system indicating the onset of a leak.

The importance of speed of detection can be visualized using an event tree for gas releases. An ultrasonic gas leak detector alarms as soon as a pressurized gas leak occurs. After the gas leak begins, the gas can either be ignited or accumulate. If a gas cloud builds up, conventional gas sensors can detect the gas and produce an alarm. Similarly, a well-placed flame detector can respond to leaking gas in the event it ignites and creates flames.

The timeframe for the evolution of different scenarios varies according to the location of the installation (offshore or onshore), ambient condition (wind direction and speed), gas and leak properties (leak rate and gas type), and other factors. If the gas leak takes place inside a building, the gas can quickly accumulate and prompt a point or open path detector to alarm. However, if the gas leak is outdoors or where the air current is strong, it may go undetected for hours or days before the concentration becomes sufficiently high to raise an alarm.

UGLD should be considered a first layer of protection in pressurized gas installations and used together with conventional gas detection methods to secure optimal protection in outdoor or well ventilated areas. The total response time for UGLD and conventional gas detectors is further described on the next pages.

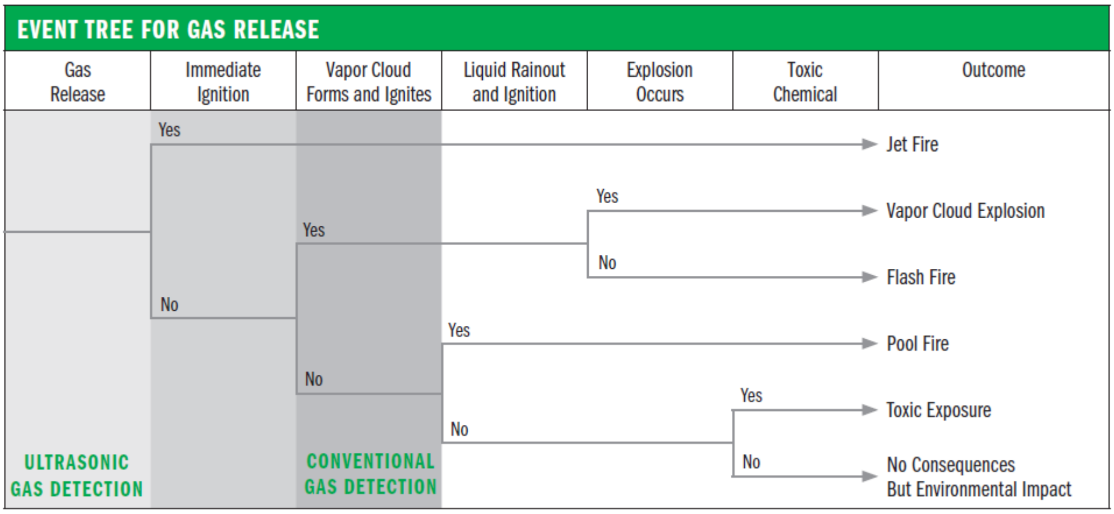


Figure 1. The gas release event tree illustrates the sequence of events that can take place in the event of a gas release. The figure shows that UGLD responds at gas leak initiation whereas conventional detectors only respond when the gas has accumulated and formed a vapour cloud

3.0 TOTAL SPEED OF RESPONSE

Response time for conventional gas detectors is often measured in seconds. Nevertheless, this response is based on gas coming directly in contact with the sensor element. This can be difficult to define in open, well ventilated areas where dilution and the direction of the plume can carry the gas away from the sensor.

3.1 Conventional Gas Detectors

When it comes to the response time of a conventional gas detection system, it is important to consider the total speed of response, comprising the time for diffusion to the sensor and gas accumulation: Total speed of response for conventional gas detectors can be calculated as:

Ttotal = Tdetector + Tgas

Tdetector is also referred to as T90 (and T50) and it simply tells how long it takes for the gas detector to reach 90% (or 50%) of the correct reading when 100% of full-scale gas concentration is injected directly into the sensor head of the detector. Tdetector is normally 15-30 seconds.

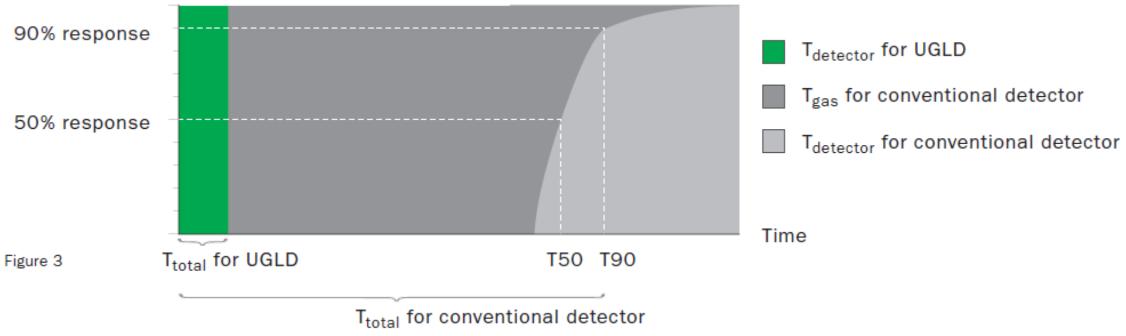


Figure 2. Ttotal for an ultrasonic gas leak detector.

Tgas tells how long it takes for a certain gas concentration to travel from the leak to the sensor. This parameter is often taken for granted simply because it is difficult to predict mainly due to changing wind directions and dilution of the gas cloud. In practice, Tgas can range from minutes to hours!

In a safety system with gas detectors, it is inadequate to use just Tdetector. One must consider the total speed of response, Ttotal, which is the only parameter that provides a true picture of the actual response time of the gas detection system.

3.2 Ultrasonic gas leak detectors

The main advantage of an UGLD compared to a conventional gas detector is that it does not need to wait for a gas concentration to accumulate and form a potentially explosive cloud before it can detect the leak. The total speed of response for an UGLD can be calculated as:

Ttotal = Tdetector + Tultrasound

Tdetector for an UGLD is the alarm delay time implemented, commonly 10-30 seconds.

Tultrasound represents the time it takes ultrasonic noise to travel from the leak source to the detector. This is typically measured in milliseconds. The response of the UGLD is not dependent on the ability of gas to travel to the detector. Figure 2 on previous page illustrates the superior Ttotal for an ultrasonic gas leak detector.

4.0 DETECTION COVERAGE

Since the sound pressure level decreases over distance at a predictable rate, operators and engineers can establish detection coverage before ultrasonic gas leak detectors are installed. The location and number of detectors can be planned based on plant drawings when the facility is in the design stage. UGLDs are used to cover both large outdoor facilities and single installations. UGLD detection coverage depends on the ultrasonic background noise level of the area and on the minimum gas leak rate to be detected. For the purposes of sensor allocation, plant environments can be divided into three types: high noise, low noise, and very low noise, as represented in the graphic below.

The image shows a detector installed on a mounting pole 2 meters (6 feet) above ground as seen from the front. Because the sensor points down when installed, the detection coverage is greater below and to the sides of the sensor than above. Notice that when not obstructed by a floor, the detection coverage is “apple shaped”. From the illustration it could be implied that the detector detects gas leaks below ground, but this is rarely the case. The only instance in which a detector responds to gas leaks below ground is when the device is installed on a grid floor, which allows ultrasound to travel through the cells in the grid with minimum impairment. An UGLD may, for example, be installed on an upper platform deck while providing coverage to lower decks as well.

As shown also, the shape of the detection coverage is the same for the three plant areas, but the maximum detection range varies according to ultrasonic background noise.

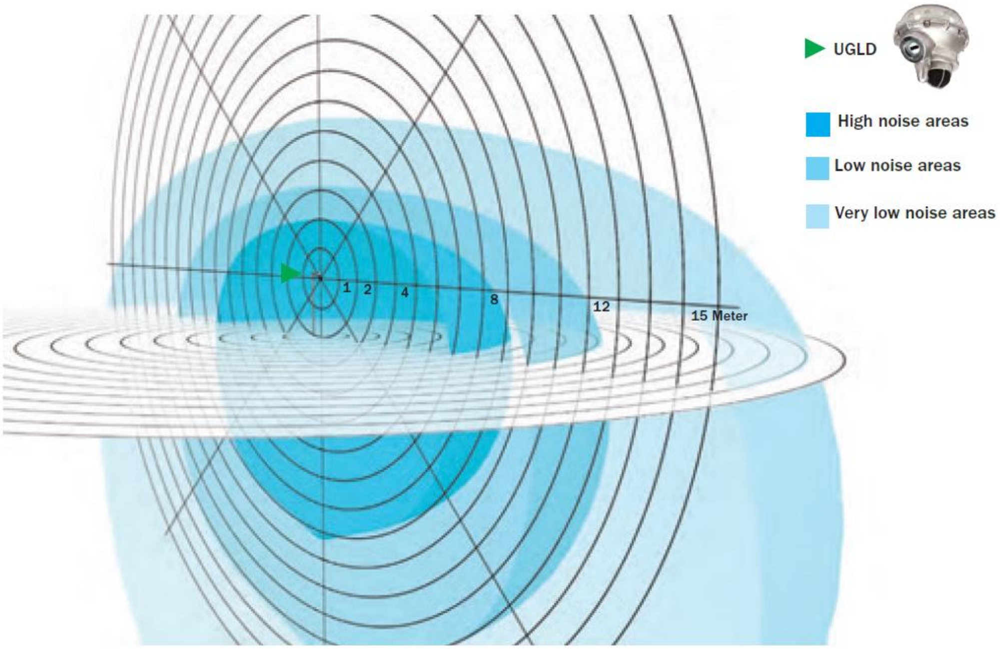


Figure 3. The graphic shows the detection coverage characteristics for UGLD. The distances are based on the detection of methane based gas leaks using a leak rate of 0.1 kg/s as the performance standard.

Detection coverage for high, low, and very low noise levels is illustrated in the figure below.

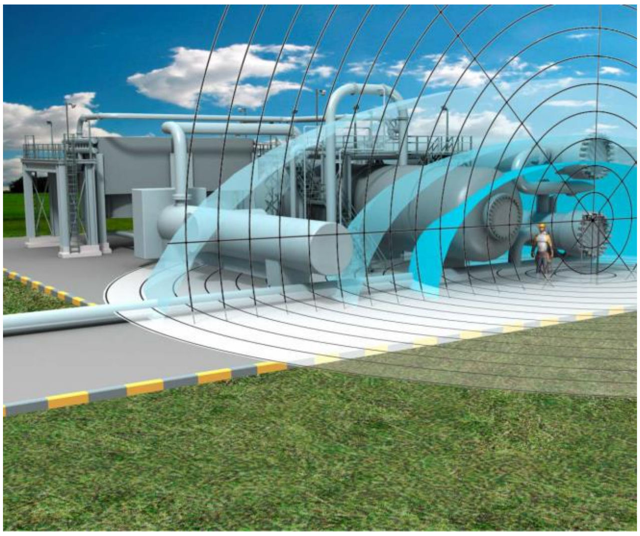


Figure 4. Detection coverage

High noise areas (eg compressor area)
Audible noise: 90-100 dBa
Ultrasonic background noise < 78 dB
Alarm trigger level = 84 dB
Detection coverage = 5-8 meter (16-26 ft)

Low noise areas (eg normal process area)
Audible noise: 60-90 dBa
Ultrasonic background noise < 68 dB
Alarm trigger level = 74 dB
Detection coverage = 9-12 meter (30-39 ft)

Very low noise areas
Audible noise: 40-55 dBa
Ultrasonic background noise < 58 dB
Alarm trigger level = 64 dB
Detection coverage = 13-20 meter (43-66 ft)

5.0 LEL VS LEAK RATE

Whereas conventional gas detectors measure gas concentrations as a percentage of the lower explosive limit (LEL) or in parts per million (ppm), the performance of ultrasonic gas leak detectors is based on the leak rate, usually measured in kilograms per second.

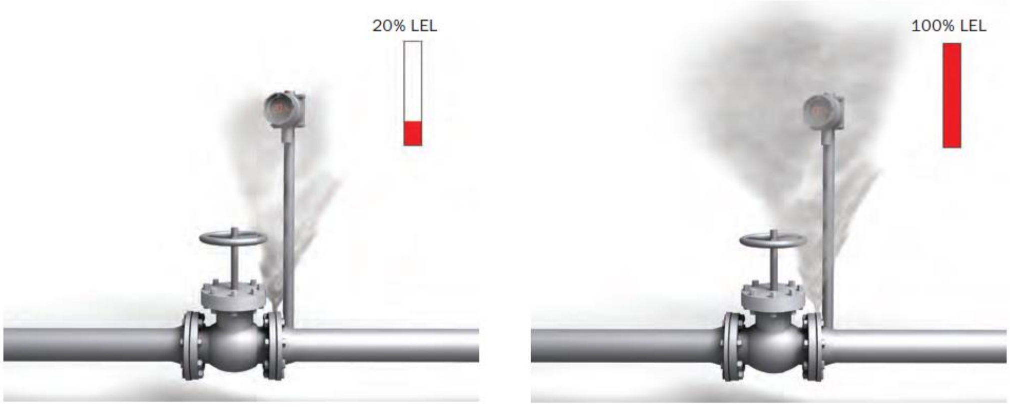


Figure 5: The conventional gas detector above measures gas concentration in the lower explosive limit (LEL). The LEL level measured by the sensor depends on the leak rate (mass flow rate), leak directionality, and where the sensor is positioned relative to the leak

5.1 LEL

For conventional gas detection, gas concentration is measured in either LEL or ppm. The term LEL is used for combustible gases and is measured as a percentage. When the concentration of combustible gas in air reaches 100% LEL, an ignition of the gas causes an explosion.

5.2 Leak rate

The term leak rate describes the amount of gas escaping from a leak per unit time. A leak can be considered large, for instance, if a large quantity of gas escapes every hour or every second. Conversely, a leak can be said to be small if a small amount of gas jets out from the pressurized system over a given period.

The leak rate, which defines how fast a potential dangerous gas cloud accumulates, can be divided into three categories according to hazard severity:

- Minor gas leak < 0.1 kg/s
- Significant gas leak 0.1 - 1.0 kg/s
- Major gas leak > 1.0 kg/s

The categories developed by the body HSE are used to define the guidelines for UGLD[1]. For methane based leaks then UGLD must respond to small leaks of minimum 0.1 kg/s.
Notice an UGLD does not measure the leak rate. The leak rate is used to set the performance criteria, and in effect define, which leaks the UGLD must pick up. The UGLD provides a measure of the ultrasonic sound measured in decibels (dB). When there is a gas leak with a leak rate of 0.1 kg/s inside the detector's coverage area, the sound level will exceed the trigger level of the UGLD and cause an alarm. As a result, in order to prevent injury or loss of life, UGLDs must detect methane leaks of at least 0.1 kg/s.

6.0 GAS PRESSURE, LEAK SIZE AND DETECTION COVERAGE

6.1 Gas pressure and influence on UGLD

The detection coverage illustrated in earlier section is based on a gas pressure of at least 10 bar (145 psi). There is no upper limit. Nonetheless, ultrasonic gas leak detectors can detect gas leaks from pressurized systems kept at much lower pressures. For methane, for instance, a minimum pressure of 2 bar (30 psi) is required to generate ultrasound. Use of the technology in such cases, however, results in reduced detection coverage. For allocation of UGLDs in low pressure systems the manufacturer should be consulted.

6.2 Leak size and influence on UGLD

The leak size influences the performance of the UGLD in the following way: the greater the leak size, the bigger the leak rate and thus the greater the detector's coverage (assuming the gas pressure is kept constant). Some of the most frequently asked questions pertain to the leak size and whether the opening can be too small or too large to create adequate levels of ultrasound.

The most important thing to understand is that the leak rate can derive from an infinite number of combinations of leak size and gas pressure (gas properties also have some influence). As the hole becomes larger, the leak rate increases. However, with extremely large leaks it becomes more and more difficult to sustain the system's pressure. When the system pressure starts dropping it causes a reduction of the leak rate and thereby decrease the ultrasonic sound level.

In theory, there is no limitation to the rule when the leak becomes small. However, to achieve the commonly used leak rate for methane of 0.1 kg/s for a leak with a small hole size like 0.5 mm (0.02 in), the system's pressure must be almost 3,000 bar (or around 43,500 psi). Since tiny pinhole leaks are found in fittings especially on offshore facilities, UGLDs are neither designed for pinhole leaks nor for big pipe ruptures. Pinhole leaks increase in size over time and become easier to detect while pipe ruptures can be identified by the pressure drop. Instead of considering specific hole sizes or pressures, UGLD should be related to the leak rate.

7.0 FREQUENCY AND AMPLITUDE

Ultrasonic gas leak detection differs from conventional gas detection mainly because it responds to the airborne acoustic sound from the gas leak, and not by sensing the gas molecules. Two new parameters are fundamental to understand ultrasonic technology – amplitude and frequency, where amplitude is measured in decibels [dB] and frequency is measured in Hertz [Hz].

7.1 Amplitude (dB)

The term amplitude is the parameter that describes the sound level or volume of the acoustic sound. Imagine that you sit in front of the radio and turn up the volume, the sound level increases and in the world of acoustics, we say the dB level increases.

7.2 Frequency (Hz)

The term frequency is the parameter that describes the high and low pitches in acoustic sound. To illustrate this, low frequencies can be heard from the bass drums in music, whereas high frequencies can be heard from for example cymbals. This means there are low frequencies and high frequencies.

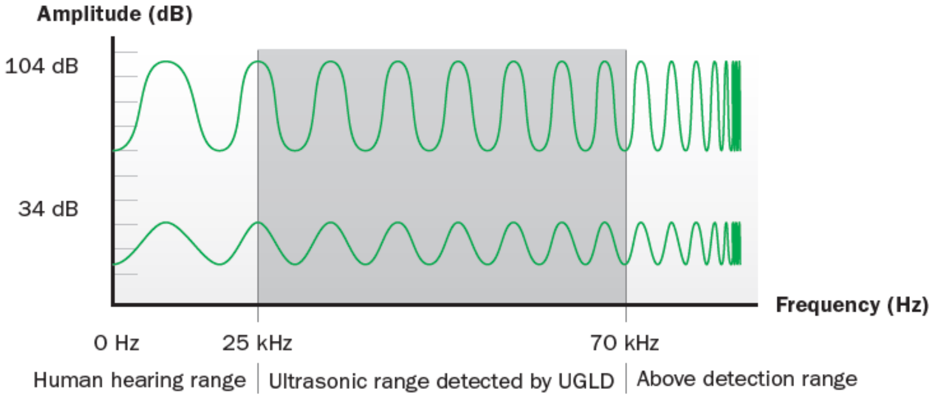


Figure 6. Relation between amplitude (dB) and frequency (Hz).

The human ear can hear both high and low frequencies, but only within a certain frequency range, typically from 20 Hz to 20000 Hz (20 kHz). This frequency range is also called the audible frequency range. Frequencies above 20 kHz up to 100 kHz are called ultrasonic frequencies. The human ear cannot hear acoustic sound in this frequency range. The UGLD is designed to ignore audible and lower ultrasonic frequencies and only sense ultrasonic frequencies in the range 25 kHz to 70 kHz. An example of the relation between amplitude (dB) and frequency (Hz) is shown in Figure 6.

The latest generation of UGLD with real-time broadband acoustic sound processing technology, allow to fully analyse the sound spectrum as low as 12 kHz since common high pass filters are not used. This provides a broader leak detection range which also increases sensitivity to smaller gas leaks, without interference from unwanted background noise.

7.3 Frequencies in plant environments

In normal industrial plant environments there can be a wide variety of acoustic sound frequencies present or there may be only a limited number. Basically it depends on the process equipment installed in various parts of the plant. In some areas there is a complex mixture of sound frequencies at high amplitude (high dB level); for example, in spaces with turbines, compressors, and other high speed rotating machines. In other areas there is a simple mix of sound frequencies at low decibel levels. This is the case in process areas with no rotating equipment or in remote installations in outdoor locations.

In very noisy plant locations where the audible noise level may be around 95 dB (very loud), the ultrasonic sound level will, as a rule of thumb, be 20-30 dB lower (65- 75 dB) simply because the machine made noise does not generate a lot of ultrasonic frequencies - only a lot of audible sound frequencies. For this reason UGLDs can be installed in very noisy locations without interference from the normal audible background noise.

8.0 UGLD BENEFITS

Ultrasonic gas leak detection is used for pressurized gas leak detection. Its detection principle is different from that of concentration-based detectors, and consequently, shares few of the conventional devices' vulnerabilities. Making UGLD part of the plant fire and gas detection system adds an alternative or complementary layer of protection, which may increase detection efficiency while reducing the need for a high point sensor count.

As the UGLD technology is based on sound propagation instead of transport of gas molecules, detectors respond to hazards at a significantly faster rate than concentration based sensors. The detectors are unaffected by environmental conditions like wind, leak dilution, and the direction of the leak, which indicate that they have high detection reliability.

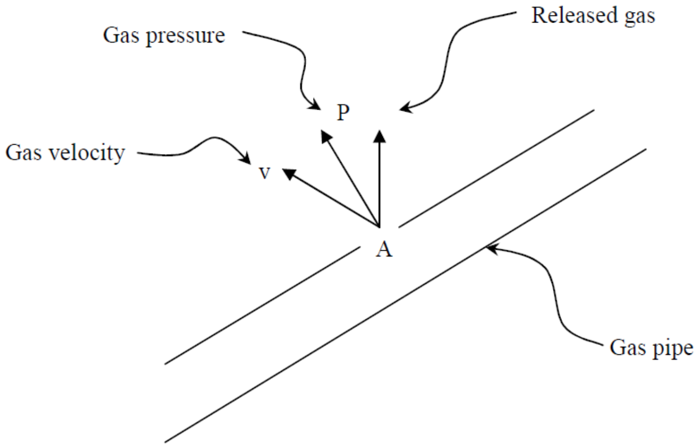
9.0 ARE THERE ANY INSTALLATIONS WHERE UGLD CANNOT BE USED?

Ultrasonic gas leak detection is only applicable when the gas is under pressure because it is the drop to atmospheric pressure that makes the leak generate ultrasound. In addition, UGLDs cannot be used to detect liquid leaks [2] or in locations with extreme levels of ultrasonic background noise (>95 dB).

10.0 TEST REPORT: acoustic fundamentals - sound pressure level investigation

10.1 Background

This report is to study the ultrasonic sound pressure generated by a gas release from a controlled orifice with high pressure gas. The gas mass flow rate, the gas molecular weight, number of leaking molecules per second, and the temperature are considered. The result is applied to an acoustic model that estimates sound pressure level (SPL) at a distance from where the gas is leaking.



10.2 Theory

The rate of the work done by the released gas shown in the figure is:

$$\begin{aligned} \dot{W}_g &= \bar{F} \cdot \bar{v} \\ &= P \cdot \bar{A} \cdot \bar{v} \\ &= P \cdot \bar{A} \cdot \frac{d\bar{s}}{dt} \\ &= P \cdot \frac{dV}{dt} = P \cdot \dot{V} \end{aligned} \tag{1}$$

Where,

P = gas pressure, $[Pa]$.
$\bar{F}$ = the force pushing gas out, $[N]$.
$\bar{v}$ = gas velocity at opening, $[\frac{m}{s}]$.
$\bar{s}$ = traveling distance of the gas particles, $[m]$.
$\bar{A}$ = area of the opening, $[m^2]$.
$\dot{V}$ = gas volumetric flow rate, $[\frac{m^3}{s}]$.

We employed the ideal gas equation, $P\mathrm{M} = \rho\Re T$ to Eq.(1) and the rate of the work, $\dot{W}_g$ in Eq.(1) can be written in terms of gas properties,

$$\begin{aligned}\dot{W}_g &= P\cdot\frac{dV}{dt}\\ &= P\cdot\frac{dM}{dt}\cdot\frac{1}{\rho}\\ &= \frac{\Re T}{\mathrm{M}}\cdot\frac{dM}{dt} = \frac{\Re T}{\mathrm{M}}\cdot\dot{M}\end{aligned} \tag{2}$$

Where,

M = molecular weight, $[\frac{g}{mole}]$.

ρ = gas density, $[\frac{kg}{m^3}]$.

$\Re$ = 8.314472, gas constant $[\frac{Joule}{mole.K}]$.

T = gas temperature, $[K]$.

$\dot{M}$ = gas mass flow rate, $[\frac{kg}{s}]$.

The sound pressure level, SPL, due to a sound power source, $\dot{W}_s$, in an environment with sound absorption can be estimated by [3] [4]

$$SPL = 10\log\left(\frac{\dot{W}_s}{10^{-12}}\right) + 10\log\left(\frac{1}{2\pi r^2} + \frac{4}{R}\right) \tag{3}$$

Where,

r = microphone distance, [m].
R = ambient room constant (sound absorption property), $[m^2]$.

For further development, we introduce an efficiency function, η , that relates sound power, $\dot{W}_s$ to gas power, $\dot{W}_g$, which is:

$$\dot{W}_s = \eta\cdot\dot{W}_g\,, \quad \text{and} \quad 0 \le \eta \le 1 \tag{4}$$

Therefore Eq.(3) can be written as:

$$\begin{aligned}SPL &= 10\log\left(\eta\cdot\dot{W}_g\cdot\left(\frac{1}{2\pi r^2} + \frac{4}{R}\right)\right) + 120\\ &= 10\log\left(\frac{\eta\Re T}{\mathrm{M}}\dot{M}\cdot\left(\frac{1}{2\pi r^2} + \frac{4}{R}\right)\right) + 120\end{aligned} \tag{5}$$

To continue, $\frac{\dot{M}}{\mathrm{M}}$ in Eq.(5) is replaced by the rate of the molecule numbers,

$$
\begin{aligned}
SPL &= 10\log\left(\eta\Re T\,\frac{\dot{M}}{\mathrm{M}}\cdot\frac{6.02\times10^{23}}{6.02\times10^{23}}\cdot\left(\frac{1}{2\pi r^{2}}+\frac{4}{R}\right)\right)+120\\
&= 10\log\left(\mu T\,\frac{\dot{\mathrm{N}}}{6.02\times10^{23}}\cdot\left(\frac{1}{2\pi r^{2}}+\frac{4}{R}\right)\right)+120\\
&= 10\log\left(\mu T\dot{\mathrm{N}}\cdot\left(\frac{1}{2\pi r^{2}}+\frac{4}{R}\right)\right)-117.796
\end{aligned}
\tag{6}
$$

Where $\dot{\mathrm{N}}$ is the rate of the number of molecules and the weighting gas constant (compared to $\frac{\Re T}{\mathrm{M}}\dot{M}$ in Eq.(2)), are defined by:

$$\mu = \eta\cdot\Re\ \left[\frac{Joule}{mole.K}\right],$$

Note: $\dot{M}$ is obtained from following equation:

$$\dot{M} = A\cdot P\cdot\sqrt{\frac{\gamma\cdot\mathrm{M}}{\Re\cdot T}\cdot\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} \tag{7}$$

It should be noted that the use of the sound field, $\left(\frac{1}{2\pi r^{2}}+\frac{4}{R}\right)$ in Eq. (6) may lead to a negative room constant, *R*, when we attempt to use it in ultrasonic fields. Numerical investigation with measured SPL should lead to more accurate estimates of the sound field. To accomplish, we first separate the sound field in Eq. (6) from other known variables and replace it with a generalized sound field, *f (r)* , where the room absorption and the air damping are considered as an important factor. Therefore Eq. (6) becomes

$$\frac{10^{\left(\frac{SPL}{10}+11.7796\right)}}{T\dot{\mathrm{N}}} = \mu\cdot f(r) \tag{8}$$

Note, for lower frequency applications the generalized sound field, $f(r)=\left(\frac{1}{2\pi r^{2}}+\frac{4}{R}\right)$

From Eq.(6) the ratio of the efficiency function, η , in Eq.(4) between two gases can be estimated by:

$$\frac{\eta_{gas1}}{\eta_{gas2}} = 10^{\left(\frac{SPL_{gas1}-SPL_{gas2}}{10}\right)}\frac{\left(\dot{\mathrm{N}}\right)_{gas2}}{\left(\dot{\mathrm{N}}\right)_{gas1}} \tag{9}$$

Where $\dot{\mathrm{N}}$ is the rate of the number of molecules,

$$\dot{\mathrm{N}} = \frac{\dot{M}}{\mathrm{M}}\cdot 6.02\times10^{23} \tag{10}$$

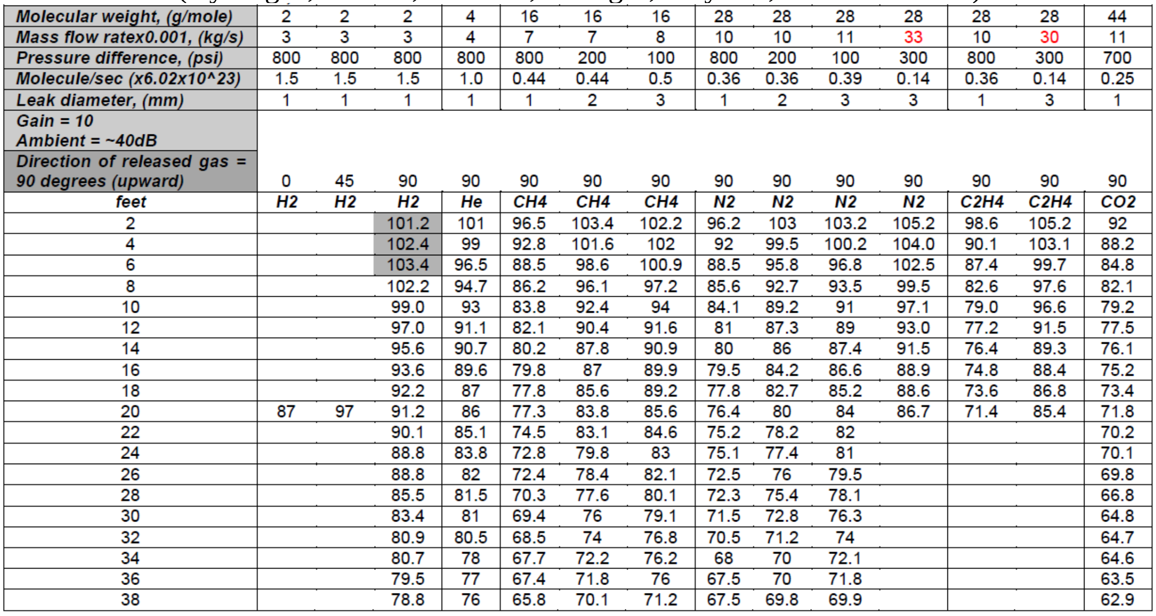
10.3 Test setup

The test setup was conducted using a PC based data acquisition system, as well as a Gassonic Observer. The following is a list of the test apparatus and the tested gases:

1) TopWard: DC power supply, model 3303A.
2) High pressure hose with regulator + orifice.
3) AC400 with Memstech microphone (MSM2RM-S3035) + screen.
4) Gassonic Observer, calibrated with 1701.
5) PC-based DAS (NI6122 DAQ+BNC-2110 connector block) running LabVIEW 8.5
6) Gases: Hydrogen, Helium, Methane, Nitrogen, Ethane, Carbon Dioxide, Propane, Propylene Ethylene
7) O'Keefe orifices with 1, 2 and 3 mm diameter.

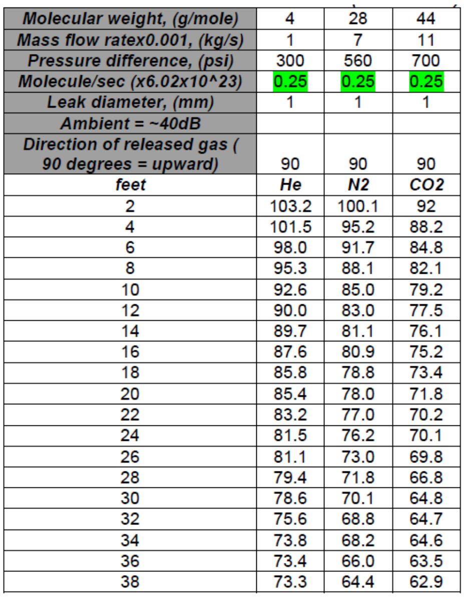
10.4 Experimental Results

Table 1: SPL vs. distance for different leak conditions and gases (Hydrogen, Helium, Methane, Nitrogen, Ethylene, Carbon Dioxide)



Molecular weight, (g/mole)	2	2	2	4	16	16	16	28	28	28	28	28	28	44
Mass flow ratex0.001, (kg/s)	3	3	3	4	7	7	8	10	10	11	33	10	30	11
Pressure difference, (psi)	800	800	800	800	800	200	100	800	200	100	300	800	300	700
Molecule/sec (x6.02x10^23)	1.5	1.5	1.5	1.0	0.44	0.44	0.5	0.36	0.36	0.39	0.14	0.36	0.14	0.25
Leak diameter, (mm)	1	1	1	1	1	2	3	1	2	3	3	1	3	1
Gain = 10 **Ambient = ~40dB**														
Direction of released gas = 90 degrees (upward)	0	45	90	90	90	90	90	90	90	90	90	90	90	90
feet	***H2***	***H2***	***H2***	***He***	***CH4***	***CH4***	***CH4***	***N2***	***N2***	***N2***	***N2***	***C2H4***	***C2H4***	***CO2***
2			101.2	101	96.5	103.4	102.2	96.2	103	103.2	105.2	98.6	105.2	92
4			102.4	99	92.8	101.6	102	92	99.5	100.2	104.0	90.1	103.1	88.2
6			103.4	96.5	88.5	98.6	100.9	88.5	95.8	96.8	102.5	87.4	99.7	84.8
8			102.2	94.7	86.2	96.1	97.2	85.6	92.7	93.5	99.5	82.6	97.6	82.1
10			99.0	93	83.8	92.4	94	84.1	89.2	91	97.1	79.0	96.6	79.2
12			97.0	91.1	82.1	90.4	91.6	81	87.3	89	93.0	77.2	91.5	77.5
14			95.6	90.7	80.2	87.8	90.9	80	86	87.4	91.5	76.4	89.3	76.1
16			93.6	89.6	79.8	87	89.9	79.5	84.2	86.6	88.9	74.8	88.4	75.2
18			92.2	87	77.8	85.6	89.2	77.8	82.7	85.2	88.6	73.6	86.8	73.4
20	87	97	91.2	86	77.3	83.8	85.6	76.4	80	84	86.7	71.4	85.4	71.8
22			90.1	85.1	74.5	83.1	84.6	75.2	78.2	82				70.2
24			88.8	83.8	72.8	79.8	83	75.1	77.4	81				70.1
26			88.8	82	72.4	78.4	82.1	72.5	76	79.5				69.8
28			85.5	81.5	70.3	77.6	80.1	72.3	75.4	78.1				66.8
30			83.4	81	69.4	76	79.1	71.5	72.8	76.3				64.8
32			80.9	80.5	68.5	74	76.8	70.5	71.2	74				64.7
34			80.7	78	67.7	72.2	76.2	68	70	72.1				64.6
36			79.5	77	67.4	71.8	76	67.5	70	71.8				63.5
38			78.8	76	65.8	70.1	71.2	67.5	69.8	69.9				62.9

Table 2: SPL for Fixed Molecules/sec



Molecular weight, (g/mole)	4	28	44
Mass flow ratex0.001, (kg/s)	1	7	11
Pressure difference, (psi)	300	560	700
Molecule/sec (x6.02x10^23)	0.25	0.25	0.25
Leak diameter, (mm)	1	1	1
Ambient = ~40dB			
Direction of released gas (90 degrees = upward)	90	90	90
feet	***He***	***N2***	***CO2***
2	103.2	100.1	92
4	101.5	95.2	88.2
6	98.0	91.7	84.8
8	95.3	88.1	82.1
10	92.6	85.0	79.2
12	90.0	83.0	77.5
14	89.7	81.1	76.1
16	87.6	80.9	75.2
18	85.8	78.8	73.4
20	85.4	78.0	71.8
22	83.2	77.0	70.2
24	81.5	76.2	70.1
26	81.1	73.0	69.8
28	79.4	71.8	66.8
30	78.6	70.1	64.8
32	75.6	68.8	64.7
34	73.8	68.2	64.6
36	73.4	66.0	63.5
38	73.3	64.4	62.9

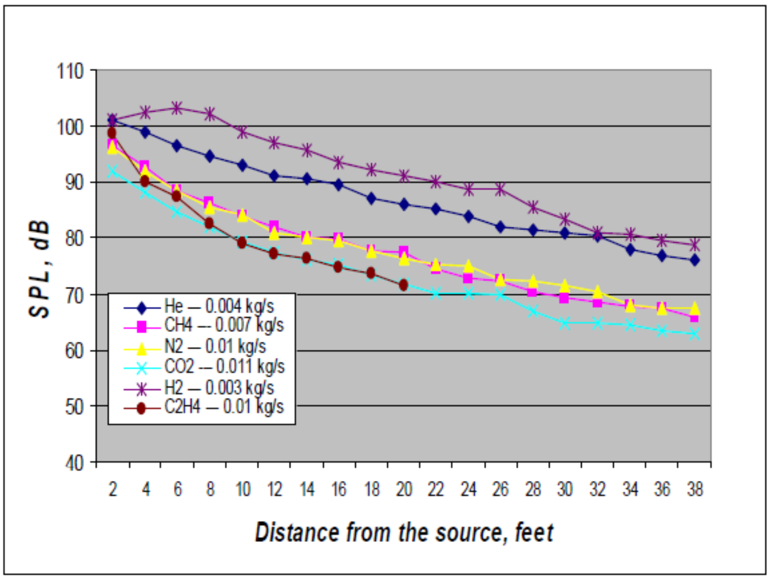


Figure 7: SPL vs. molecule type for 1mm leak diameter

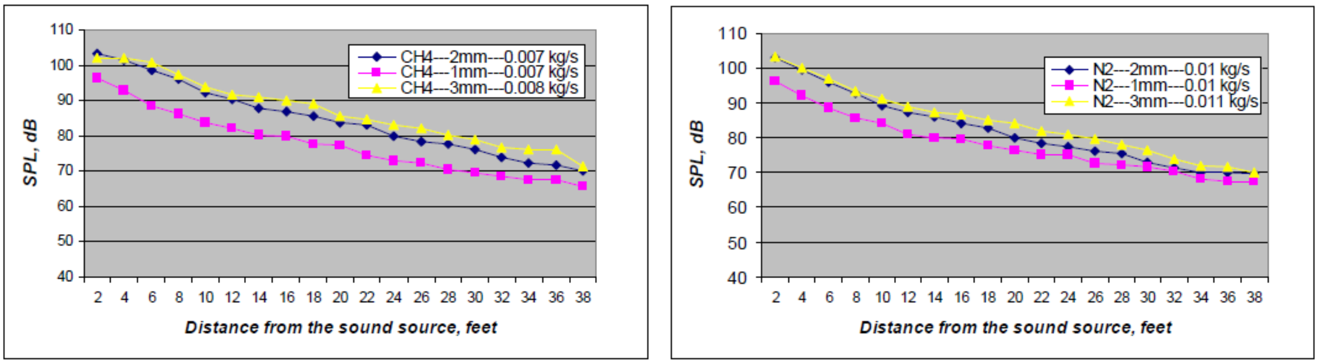


Figure 8: SPL vs. gas leak diameters (Methane and Nitrogen)

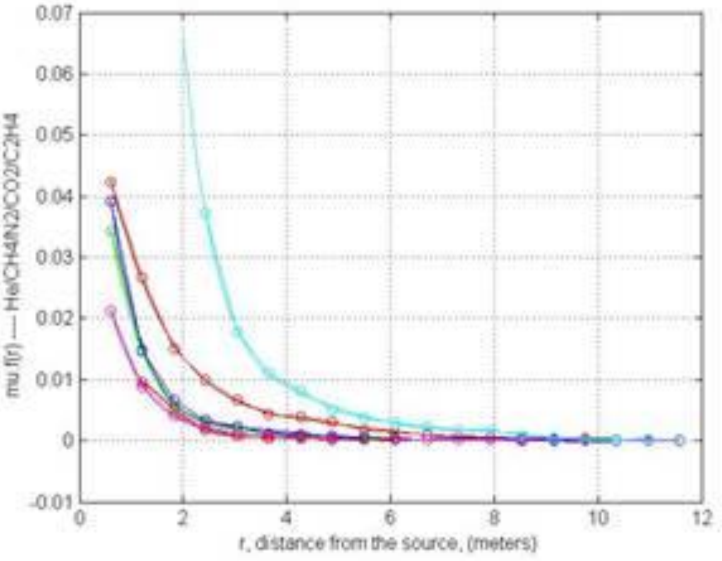


Figure. 9: Acoustic energy efficiency vs. type of gases. (cyan = H_2, red (upper) = He, blue = CH_4, green = N_2, pink = CO_2, red (lower) = C_2H_4)

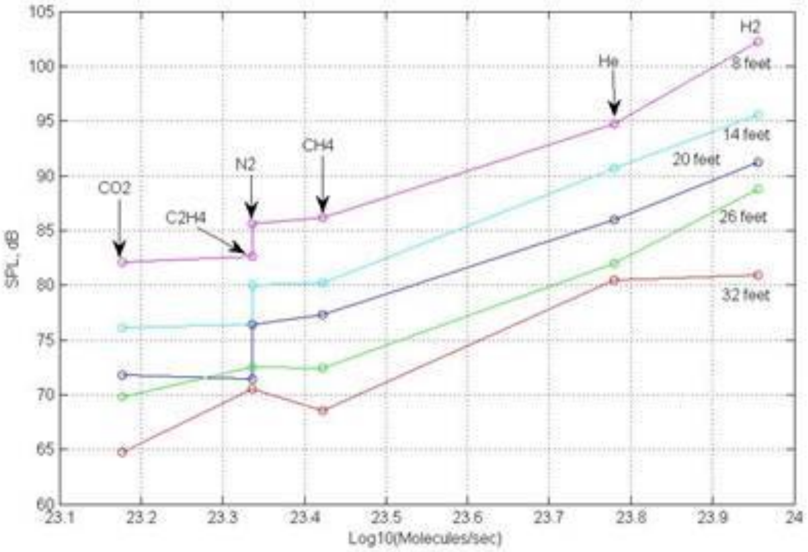


Figure 10: SPL vs. rate of the molecule flow (log)

10.5 Conclusions

The physical properties such as molecular weight, mass flow rate and energy transfer efficiency are three major acoustic parameters in the field of the high pressure gas leak that generates ultrasound. Among these parameters, molecular weight of the gas is the most important factor. Our measurements show that gas with smaller molecular weight can generate much higher SPL (see Figure 7 and Eq. 5).

In spite of the complexity of the mechanism of the energy transfer efficiency, the influence of the diameter of the gas leak was examined. Our measurement show that larger leak diameter causes higher acoustic energy transfer efficiency (see Figure 8). The influence of non-geometric properties, such as the type of the gas, was also examined. Our results show that **Hydrogen** is the most efficient gas (see Figure 9 and Eq. 6) among the tested gases.

The influence of the leak rate of the number of molecules per second $(\dot{N})$ in Eq. (6) was examined. Figure 10 shows a linear relationship between measured SPL and log of $(\dot{N})$ per Eq. (6). However, the results shown in Table 2 indicate that SPL also depends on the energy transfer efficiency, μ, since $\dot{N}$ is the same for all tested gases. The conclusion is that μ is a function of the leak diameter and the type of the gases, and $(\dot{N})$ by itself is not sufficient to describe the measured SPL values.

11.0 REFERENCES

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2. HSE website. Research Report RR568 - Measurement of acoustic spectra from liquid leaks: https://www.hse.gov.uk/research/rrpdf/rr568.pdf
3. Refer to “The SCIENCE and APPLICATIONS of ACOUSTICS” second edition, Daniel R. Raichel, 2006 Springer, pp.259-260.
4. Please note that Eq.(3) is one of the candidates. Further evaluations on other acoustic models should be considered.