THE MODELING AND CALCULATION OF SOUND RADIATION FROM FACILITIES WITH GAS FLOWED PIPES

INTRODUCTION

Analysis of the emission caused by industrial facilities like chemical plants, refineries or other production areas is the first and most important step while calculating the noise pollution of the environment. Pipework with gas or fluid flows are often contributing relevant to the sound radiation of a complete facility. This radiation can be determined applying the methods described in technical papers like VDI 3733 and ISO 15664.

![Gas pipes inside industrial facility](image)

**FIGURE 1:** Gas pipes inside industrial facility

In all cases where measurements are not possible or during a planning and optimization process, a practical technique is to derive the sound power level from significant parameters which do have influence on the noise emission. After the definition and modeling of an emitting system, all contributing system parameters influencing the emission can be altered according to different operating scenarios. As a result the spectrum of the noise emission of a gas pipe can be calculated for the real conditions.

ACOUSTICAL ASPECTS OF GAS FILLED PIPES

Pipes are used to transport solid, liquid and gaseous media. The following only deals with round pipes for gaseous media without a solid content, e.g. granulates etc., up to a diameter of 800 mm. For pipes with rectangular cross-sections and pipes for liquid media, different considerations must be taken into account. From the acoustical point of view, pipes with large diameters are to be viewed as even plates.

Significant for the emission of a pipe is the contribution of sound power via the outer walls of the pipe introduced into the pipe from external sources such as fans, compressors etc. As a rule, this external sound power is significantly higher than the natural noise generated by the flow.

**Noise absorption in Gas filled Round Pipes**

Compared to flat plates, pipe noise absorption has significantly higher values below the ring expansion frequency (see /1/). Reduced sound absorption occurs in the range of the critical frequency that is dependent on each wave and vibration form (mode) (see /1/, /5/). Above the ring expansion frequency, the acoustic characteristics
of pipes are the same as for flat plates with a characteristic drop in sound absorption in the range of coincidental frequency (see also /3/).

From /1/, the following equations are used. In addition, the influence of coincidence according to /3/ and /4/ is taken into account.

Formula for attenuation is:

\[ D_e = R_e - 10 \log \left( \frac{4 \cdot \frac{1}{(10 \cdot d^3)}}{\sinh(B)} \right) - 10 \log \left( \frac{\sinh(B) - \frac{1}{B}}{B} \right) + \Delta L \quad (1) \]

Where:

\[ R_e = 10 + 10 \log \left( \frac{c_w \cdot \rho_w \cdot s}{c_f \cdot \rho_f \cdot d} \right) + 10 \log \left( \frac{f_r \cdot s}{f} \cdot 3 + 5 \cdot \frac{f}{f_r} \right) + R_k \quad (2) \]

\[ c_f = \left( \frac{1.4 \cdot p \cdot 10^3}{\rho_f} \right) \quad (3) \]

\[ f_r = \frac{c_w}{\pi \cdot d \cdot 10^{-3}} \quad (4) \]

\[ R_k = -35 \cdot 10 \log \left( 1 + \frac{2}{\left( \frac{f_g - 1.5 \cdot f_c}{f} \right)^2 + 1} \right) \quad (5) \]

\[ R_k = 0 \text{ for } f_g < f_r \]

\[ f_g = 6.4 \cdot 10^4 \cdot \left( \frac{c_w}{c_f \cdot \left( 8 \cdot 10^{-3} \right)} \right) \quad (6) \]

\[ B = \frac{1}{(d \cdot 10^{-3})} \left[ \frac{2 \cdot 10^{-0.1 \rho_e} + \alpha (d \cdot 10^{-3})}{8.69} \right] \quad (7) \]

\[ \alpha = 4.9 \cdot 10^{-4} \cdot \left( \frac{f}{(d \cdot 10^{-3})} \right) \sqrt{\frac{273 + t}{293}} \cdot \left( 1 + 11 \cdot M_a \right) \quad (8) \]

\[ M_a = v/c_f \]

\[ \Delta L = 0.5 \left( 17.37 \cdot \frac{1}{(d \cdot 10^{-3})} \right) \cdot 10^{-0.1 \rho_e} + \alpha \quad (9) \]
Considered parameters are:

- $L_m$ [m] section length
- $d$ [mm] pipe diameter
- $v$ [m/s] flow speed in the pipe
- $p$ [bar(abs)] absolute gas pressure in the pipe
- $\rho$ [kg/m$^3$] gas density in the pipe
- $t$ [grd°C] gas temperature in the pipe
- $s$ [mm] pipe wall thickness
- $\rho_w$ [kg/m$^3$] pipe wall density
- $c_w$ [m/s] expanding wave speed of the pipe material

**Flow Noise Generation**

Flow noises are caused in flows through pipes by turbulent boundary layer flow. In accordance with /1/, a proportion of $10^{-3}$ of the flow energy is converted into sound energy. In industrial facilities, flow noise is usually of subordinate significance, but can be a dominating sound source in piping fittings with high pressure loss (e.g. Valves / Armatures) and the outflow from silencers. To determine flow noise, various equations are specified in the literature. The A-evaluated sound power level increases with around the power of 6 of the flow speed. Flow noise is independent of the pipe length, but is also dependent on the pressure loss.

\[
L_{\text{eq}} = 39.2 + s - 0.16 \cdot w + 60 \log(w) + 10 \log(S) + 10 \log(p) - 25 \log(N \cdot T) - 15 \log(\kappa) \text{dB}
\]  

(10)

Where $T = t + 273$

The considered parameters in this case are:

- $w$ [m/s] flow speed
- $S$ [m$^2$] cross-section area
- $p$ [bar] pressure in the pipe or channel
- $N$ [kJ/kg/K] specific gas constant
- $T$ [°C] temperature
- $K$ [---] adiabatic exponent

**CALCULATING THE SOUND POWER LEVELS OF GAS PIPING SYSTEMS FROM TECHNICAL PARAMETERS USING SIMULATION SOFTWARE**

Sound power levels of technical sound sources depend on source-typical parameters. Those can – depending on the kind of source – for example be the nominal value, the length, the diameter, etc. The software program CadnaA /6/ features a module based on the idea (SET), that the resulting sound power level can be calculated by the program depending on the values of these parameters. This feature can be used to automatically calculate sound power levels of sources as well as transmissions to further elements, depending on the appropriate frequency dependent attenuation; single sources can thus be combined to assemble complex noise emitting systems.

Updates in these systems – for example due to the insertion of new elements or the position change of an existing one – lead to technical correct changes of the complete system; this way, the effects of a silencer can for example easily be tested, or different system’s operation conditions can be evaluated with minimum time and effort.

Technical source elements are defined in the software according to the following figure, and can later be used in the model. Up to 10 parameters can have influence on the calculation of sound power levels or the attenuations;
Linkages for consideration of transmission can be defined with up to 9 inputs and outputs; furthermore there is an output for the transmission.

**FIGURE 2:** Theoretical model of a SET-S element

In the following example a fan puts pressure in a piping system consisting of 4 elements, which finishes in a steel chimney. Apart from the radial fan these are the pipes, the steel chimney and the element for the mouth reflection. Transmission between the different elements of the piping system is also considered. These are all assembled linearly after each other, which allows the structure to still be relatively simple (as seen in the following figure). Per element, not more than one in- and output is used.

**FIGURE 3:** Logic structure of a conduit’s elements (from left to right).

**Definition of the system**

Single blocks can be easily created line by line in the so-called SET-T table. All the necessary lines are shown in the following figure.

**FIGURE 4:** Conduit with a fan, 4 pipes and a steel chimney with opening
Single modules need to get the necessary values for the parameters. The following figure shows values on the example of a pipe section.

Furthermore, linkages between system elements are relevant. In this example, the start point is the radial fan, where pressure side (output 2) is linked with the pipe 1. For all further elements, the default setting “next” can be kept for output 1, as the linked elements are directly connected to them in the SET-T table (Figure 4).

![FIGURE 5(A): Exemplary values for the required elements in SET-T](image1)

![FIGURE 5(B): Parameter configuration of a pipe section.](image2)

**FIGURE 5(A):** Exemplary values for the required elements in SET-T

**FIGURE 5(B):** Parameter configuration of a pipe section.

### Modeling and calculation

The modeling is conducted with regular industrial sources for all the elements. The fan can be modeled with a point source. The following pipes can be modeled with line sources and the chimney is created with a line source entered vertically.

At last the chimney opening is modeled; this is done with a point source with a specific directivity. The described model is shown in the following figure.

![FIGURE 6: Conduit with fan, 4 pipes and a steel chimney. The values shown at the industrial sources are sound power levels calculated with exemplary parameter values.](image3)
Once the model is set, a calculation can be done in order to get the sound pressure levels at the receiver points.

GAS PIPEWORK MODEL´S MODIFICATION AND UPDATING

Once a pipework model is created, it can easily be updated or modified. For example, elements can be moved via drag & drop; furthermore new elements can easily be inserted. In both cases, all emission spectra and the transmitted sound can be updated with just one click.

Modeling non - physical aspects

In some cases, further elements need to be inserted even if no physical elements are added to the system. This should be considered when working with SET and is shown with the change of a cross-section here.

The cross-section of a pipe has influence on noise emission and transmission, which is considered correctly in SET. But the sudden jump between 2 diameters also has an influence; this is not considered with the single parts so far. So beside the adjustment of pipe parameters (diameter, fluid speed, etc.) a further element must be entered to consider the changing cross-section. To achieve this, the block “Cross Section Jump” can be utilized.

In SET-T it can be inserted at the desired position between two pipes; depending on the cross-sections entered in the element, a further attenuation between the respective pipe elements is considered.

The cross-section jump is only mentioned as an example among others. Especially for pipe systems, many elements are documented and can be used.

Entering and changing position of further elements in the system

For already existing pipework systems, new elements can be created easily in order to evaluate different scenarios. In this example, a silencer should be included between the last pipe and the chimney. The silencer shall be a carriage with attenuation according to a predefined, frequency dependent curve.

Once the new element is entered the noise transmissions and emissions are completely re-calculated. Figures 8(a) and 8(b) show the system’s table before and after the entry of a silencer with exemplary values. As can be seen, the silencer itself doesn’t emit any noise. To change this, an output for RAD could have been added in the appropriate table.
This easy tool is also drag & drop sensitive, allowing quick assessment of all possible actions. In the following figure, the silencer, which was between Pipe 4 and the Steel chimney, will be moved to the position between pipe 1 and pipe 2. After a recalculation the complete system’s table is automatically renewed, which means that the changed emission- and transmission values and (as far as receivers are present) the changed sound pressure levels are immediately visible.

Whereas in the case of conventional programming, all radiation surfaces and sources downstream of the silencer have to be “touched” to reduce their sound power accordingly, this is now dealt with by inserting the silencer with one operation. The same procedure continues until immission calculation. If a calculation is run after changing the plate thickness of a pipe in an industrial system, the consequences have been correctly taken into account for all calculated levels and also for entire noise maps.
FIGURE 10: Resulting Sound Powers and Sound Pressure level at receiver when placing the silencer between pipe 1 and 2

REFERENCES

1. VDI 3733 “Noise in pipes”, July 1996
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5. W. Straßen: Noise creation through inserts in pipes and solids in the fluid, lecture 'House of Technology', 1998