Optimized noise control for gas compressor station pipework

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ABSTRACT
Typical equipment in a gas compressor station is an extensive network of gas piping and supporting steelwork. Due to the energy-intensive rotating equipment and processes involved, this pipework is marked by a considerable sound emission that neighbors and workers need to be adequately protected from. Typically, sound emission from piping is reduced by installing insulation (lagging) on the pipes. However, from a safety and maintenance point-of-view, lagging can be a problem as it can promote corrosion and limits accessibility of the pipe for inspection and maintenance. Therefore, from an operator's point-of-view, it is preferred to leave pipes without lagging wherever possible. The present paper focuses on this conflict of interests. It describes a case study in which the pipework in a gas compressor station was optimized by leaving as much piping without lagging as possible while, at the same time, lagging as much piping as necessary to ensure that all acoustic requirements are met. The key elements in this optimization process were use of a special high-insertion loss lagging design with reduced potential for corrosion, resilient supporting of critical piping and a detailed sound propagation modeling of the compressor station to test the effect of different noise control configurations.

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1. INTRODUCTION
An important way to transport natural gas over large distances is to move the gas through a pipeline. The pipeline mass flow rate is proportional to the pipe diameter, the difference in pressure between inlet and outlet of the pipeline and the gas pressure within the pipeline. Accordingly, to efficiently move large quantities of gas through pipelines, the gas is compressed to up to 150 barg in gas compressor stations – a process that involves energy-intensive, high-speed rotating equipment (turbo compressors), highly turbulent flow and significant gas velocities and pressure raises/drops with a corresponding mechanical and flow-mechanical generation of sound. An important transmission path for this sound into the surroundings of a compressor station is the gas piping and its supporting steelwork.

The gas piping network often comprises several hundred meters of piping in the open with diameters of up to 800 mm and above. Together with the steelwork required to support the pipes, a large sound radiating surface is created with a high emission of acoustic energy that can lead to considerable sound pressure levels inside and outside of the compressor station. Consequently, adequate noise control needs to be applied to ensure that noise levels remain within acceptable limits to protect neighbors and workers and to ensure compliance with legal requirements.

The most commonly used noise control for piping is to apply acoustic insulation (lagging) to pipes with excessive sound emissions. Typical pipe lagging consists of one or more layers of porous (sound absorbing) material and a cladding made from sheet metal (see Figure 1). The main disadvantages of pipe lagging, as seen from a safety and maintenance point-of-view, is that standard lagging can promote corrosion and limits accessibility of the pipe for inspection and maintenance. Figure 2 shows examples of pipe corrosion under lagging. Furthermore, to lag piping also means increased capital costs and – by making access to the pipe more complicated and time consuming – increased operating costs. Accordingly, from a compressor station operator's point-of-view, it is preferred to leave pipes without lagging wherever possible.
In the case study presented in this paper the pipework in a gas compressor station was optimized by leaving as much piping without lagging as possible to save costs, facilitate inspection and maintenance and reduce the risk of corrosion while, at the same time, lagging as much piping as necessary to ensure that all acoustic requirements are met. The key elements in this optimization process were use of a special high-insertion loss lagging design with reduced potential for corrosion, resilient mounting of critical piping to reduce sound transmission via the supporting steelwork and a detailed sound propagation modeling of the compressor station to test the effect of different lagging configurations.

2. SOUND EMISSIONS

2.1 Piping

The approach followed requires knowledge of the sound emission from all acoustically relevant piping in the compressor station without any lagging applied and with the station operated in the "worst case" condition in terms of acoustic impact. To acquire this information, a measurement campaign has been performed. By far the largest number of measurements taken (> 1000) was for surface acceleration using acceleration sensors attached successively to about 1200 m of piping under test and the main supporting steelwork. Tests were performed with typical but differing station flow rates set to be able to extrapolate for maximum flow (since maximum flow could not always be set in the measurements performed under real-life operation).

In addition, measurements of sound intensity of lagged and unlagged piping sections have been taken to determine the effective radiation efficiency index needed in the processing of the acceleration data acquired.
2.2 Other Sound Emitters

The acoustic impact of operating the compressor station is not determined by the sound emission from the pipework alone. In addition to the piping and its supporting steelwork a number of other sound sources and sound transmission paths are relevant for the sound pressure levels created in the station and in its neighborhood. Important examples are the exhaust stacks and air intake openings of the gas turbines driving the turbo compressors, the ventilation openings for the gas turbine packages and the engine halls, the fin fan coolers used for cooling the engine lube oil or the hot gas after compression as well as the gas filter station. The sound emissions and directivities from each of these sources are needed in the optimization approach described later and have been determined in separate measurements.

3. LAGGING DESIGN AND TESTING

The standard design for acoustic lagging for piping has one layer of sound absorbing material on the pipe (e.g. mineral wool) covered by a sheet metal cladding on the outside to protect the absorbing layer. To reduce the transmission of structure-borne sound in the cladding, the acoustic loss factor of the sheet metal is increased by lining it with an elasto-plastic layer. See Figure 1 for a typical implementation. The acoustic insertion loss and the reduction in sound emission that can be achieved with pipe lagging depends on the specific design, the sound emission spectrum of the pipe to be treated and its diameter (see (1)). In the context described here, a high acoustic insertion loss is preferred because, by strongly reducing emissions from lagged sections, it can help to reduce the total length of piping that needs to be lagged by compensating, to a certain extent, the higher emission from unlagged pipe sections.

In principle, standard lagging does not increase the risk of pipe corrosion as long as the outer cladding is sealed tightly so that no water can get to the pipe. However, in practice, a certain ingress of water is inevitable in outdoor applications where small leaks form over time at joints or penetrations (unlagged side branches, sensors, valve drives etc.). As there is no significant ventilation, water can accumulate inside the cladding and is sucked towards the pipe by capillary forces in the absorbing layer, keeping the pipe wet and prone to corrosion.

In view of this, a special lagging design was developed in the case study presented here, with the following properties targeted for:
- a very high acoustic insertion loss and loss factor,
- increased protection of the gas pipe from water that has penetrated the outer cladding,
- a possibility for water that has leaked into the outer cladding to drain,
- some ventilation to allow water inside the cladding to dry.

Figure 3 shows the high acoustic insertion loss, anti-corrosion pipe lagging that has been developed in close cooperation with an insulation specialist company. Design and optimization of the lagging was accompanied by measurements of the lagging insertion loss according to ISO 15 665 (1) in Müller-BBM's piping test stand. The basic design is a double-shell lagging with an inner sound absorbing shell of mineral wool with a sheet metal cover and an air gap for ventilation purposes between the inner shell's cover and the outer cladding sheet metal. The outer sheet metal is provided with a damping layer on the inside. To reduce transmission of structure-borne sound from the pipe to the outer cladding, the lagging does not use any rigid spacers between the pipe and the outer layers: there are no spacers between pipe and inner metal sheet and the air gap between the inner and outer metal sheet is maintained by short (in axial direction) rings of dimpled sheet. To allow for water drain, the outer cladding has drain holes.

In summary, the air gap and drain holes allow for ventilation and water drain, the inner metal sheet provides for an additional barrier to prevent water from getting to the mineral wool layer and the pipe. Because of the double-shell design, the lack of rigid spacers and the damping layer, the lagging has a very high insertion loss.
Figure 3 – High acoustic insertion loss, anti-corrosion pipe lagging.

Figure 4 – Results from on-site measurements: sound power level spectrum of a 4 m section of gas compressor discharge pipe (DN500/20” D = 508 mm) without lagging (red curve) and with special lagging (blue curve).

Figure 4 shows results from on-site measurements: a comparison of the power level spectrum of the sound radiated from a 4 m section of the gas compressor discharge pipe (DN500/20” D = 508 mm) without any lagging and with the new special lagging applied results in an effective total level reduction of 33 dB.
4. RESILIENT PIPING SUPPORTS

Where piping is in rigid contact with supporting steelwork, structure-borne sound can be transmitted from the pipe to the steelwork. This sound may then be radiated from the steelwork as secondary airborne noise into the open, resulting in additional sound emissions that can be significant because of the large surface of the steel structure. This effect is of particular importance with piping that has acoustic lagging installed because a rigid support connection can effectively allow structure-borne sound from the pipe inside the lagging to "by-pass" the lagging, noticeably reducing its overall effect. Therefore, on-site measurements to identify steelwork with excessive sound emissions have been performed. As part of the optimization process the piping responsible has been acoustically decoupled from the steel structures by installing resilient supports. Figure 5 shows an example.

![Figure 5 – Pipe supports: rigid and resiliently mounted for acoustic decoupling from steelwork.](image)

5. 3D ACOUSTIC CALCULATION MODEL

The focus in the noise control optimization process described here is on protection of the workers in the station and the neighbors in its surroundings from excessive sound pressure levels caused by operation of the station. The sound pressure level received from the station equipment at any given point of interest (POI) depends on the sound emissions of all relevant sources in the station and on how the sound propagates from the sources to the receiver. Accordingly, to evaluate the effective impact at a POI of any noise control applied to individual equipment (e.g. acoustic lagging for piping), a sound propagation calculation needs to be performed, taking into account the contribution of all sound sources relevant at that POI.

For this purpose, a 3D acoustic calculation model for sound propagation calculations has been set up. By means of this model, the sound field in the compressor station and the sound pressure levels received from the station at Noise Sensitive Receptors (NSRs) in the neighborhood can be predicted for different noise control configurations. The model is used to assess the effect of applying or not applying the special lagging and the resilient supports described in sections 3 and 4 to different sections of the gas piping in the station and to determine an optimized noise control concept for pipework and supports. The calculation method used by the model is described in ISO 9613-2 (2). The calculation has been performed in octave band frequency intervals.

The most important input data for the model are the relevant sound sources and sound transmission paths as point, line and area sources in their proper locations, their sound emissions and directivities and the topography in the area of interest, including buildings and other obstacles that can affect sound propagation. In particular, all acoustically relevant piping in the compressor station is implemented section by section as line sound sources. Such line source elements represent pipe segments between typical elements from pipeline construction (bends, tie-ins, flanges, valves, etc.) and range from less than 1 m to above 10 m in length.

Note that a noise control concept for a multi-source industrial installation can only be truly optimized if all relevant sound sources are accounted for (i.e. not only the station piping in the case reported here). Accordingly, in the calculation model used not only the complete gas piping in the station according to section 2.1, but also all other relevant sound sources according to section 2.2 have been included, taking properly into account any noise control applied to these sources. For the compressor station in this study, a noise control concept for all non-piping sound sources has been determined in separate work that is not within the scope of this paper.
6. OPTIMIZATION PROCESS

The overall objective of the pipework noise control optimization is to find a solution that protects neighbors and workers from excessive noise levels, that ensures compliance with legal requirements, that facilitates inspection and maintenance and reduces the risk of corrosion and that is also economically adequate. To this end, the following acoustic and non-acoustic targets have been defined for the process:

a) Remove as much of the existing standard pipe lagging as possible and leave as much piping as possible without lagging.

b) Make sure that the A-weighted sound pressure level inside the compressor station in all areas in the open that are accessible to workers and at $\geq 1$ m distance from any equipment does not exceed $L_A = 85$ dB(A) in all failure-free operating conditions.

c) Make sure that the noise received from the compressor station pipework at the noise sensitive receptors (NSRs) in the neighborhood does not result in a deterioration of the acoustic situation at the NSRs as compared to the state before the optimization.

Finding a solution that satisfies all three criteria is not trivial: in principal, leaving piping unlagged is in conflict with criteria b) and c) and also for the purely acoustic targets b) and c) many solutions can be found that satisfy either one or both criteria. Among the solutions that satisfy both criteria b) and c) many will not satisfy criterion a). As a result, the optimization procedure is an iterative and partly "trial-and-error" procedure.

In this procedure, the acoustic model from the previous section – using emission and insertion loss data from measurements, as described previously – is used to calculate the sound field in and outside of the compressor station for different sections of piping equipped with the new special lagging. The results are then checked against the criteria to be fulfilled. Applying lagging to a section of piping is simulated in the model by basically subtracting the lagging insertion loss as determined in the test stand from the pipe section emissions as determined from the on-site measurements. A similar procedure is applied to steelwork decoupled from the piping by a resilient support with the support transmission loss spectrum taken from product data sheets. To compensate for acoustical shortcomings of the lagging when installed on site that lead to lower insertion losses as in the test stand, a deduction has been made from the values obtained in the test stand.

Starting point is the situation without any lagging applied to the station piping. Obviously, starting the optimization process by applying lagging to the pipe sections with the highest sound emissions greatly speeds up the process of finding a solution.

In the process, technical aspects related to the application of lagging on the real piping must always be kept in mind because the simulation approach described may result in solution details that satisfy the criteria but are otherwise impractical or not cost efficient. For example, short sections without lagging in an otherwise lagged pipe (higher costs than to continue the lagging) or lagging a valve (complicated and costly) instead of a straight piece of pipe (simple and less costly) if the two items have the same sound emissions (= similar effect achievable by lagging).

Figure 6 illustrates the optimization process. It shows color contour plots of the A-weighted sound pressure level (at 1.5 m above grade) calculated for different states of the process. The area shown comprises one of the compressor halls and the associated gas coolers and the various gas piping in between (compressor suction and discharge piping, cooler bypass piping etc.).
Figure 6 – Calculated sound pressure level contour plots for different states of the compressor station in the optimization process.

The top left plot in Figure 6 shows the situation before the optimization where acoustic criterion b) has been complied with by applying standard lagging to a total of 663 m of piping in the station. The plot on the top right shows the noise contours for the situation without any lagging where maximum sound pressure levels at 1 m from the piping reach 96 dB(A) in some places. The bottom left plot shows the sound pressure levels calculated for the final result of the optimization: In this configuration, both acoustic targets b) and c) are complied with while only 346 m of piping need to be provided with the special lagging. This means a total of 317 m where the lagging can be removed as compared to the initial state prior to the optimization.

7. VERIFICATION

In the optimization process described in the previous section, all sound pressure level data used to assess compliance with the acoustic targets has been calculated with the acoustic model for sound propagation calculation. To confirm that the noise control concept developed by means of the model indeed complies with all requirements and to verify the quality of the model, the results from the calculations have been compared with on-site measurements. In these measurements, the sound pressure level at head height has been determined at 42 positions spaced approximately evenly on a measuring grid in the area of the gas piping between the compressor halls and the gas coolers (see Figure 6). The comparison shows a maximum A-weighted sound pressure level of 84.1 dB(A), which complies with acoustic criterion b) in section 6.

For the sound pressure levels received from the station at Noise Sensitive Receptors (NSRs), the acoustic model predicts a level reduction after vs. prior to the optimization of between 0.3 dB and 0.9 dB. In practice, it is not possible to determine the noise levels at the NSRs with sufficient accuracy by direct measurements to reliably detect such small differences – the main reasons being the influence of parasitic noise from sources other than the station (e.g. traffic) and the influence of meteorology. Accordingly, a direct verification of criterion c) could not be performed.
8. FINAL REMARKS

Acoustic lagging is a well-established method to control sound emissions from noisy piping, but limits accessibility of the pipe, can promote corrosion and can be a cost factor. By optimizing the piping noise control strategy in a gas compressor station, the length of piping provided with lagging could be reduced by more than 300 m while maintaining full compliance with all acoustic requirements for protecting neighbors and workers. The approach applied combines on-site measurements, a special highly-efficient and corrosion-retarding lagging design and 3D sound propagation calculations as well as a close cooperation between acoustic experts, the operator of the compressor station and insulation specialists.

In the acoustic calculations that use a ray-tracing approach, piping has been modeled as line sources with zero diameter – i.e. the piping in the model is present as a sound emitter, but otherwise invisible to all sound rays. While the model has been applied very successful in the case study presented here, it is important to note that this modeling technique will be sensitive to how densely the pipes modeled are arranged. Typical pipework in a compressor station rather has a lower "density" (as compared to piping in refining, for example) so that the fact that the modeling approach used does not take the piping itself into account as a physical structure does not lead to significant errors. However, if the piping density is too high, neglecting reflections, refraction and barrier effects caused by the piping can lead to errors in the model calculations.

REFERENCES