Noise Sources and Noise Control Measures for Flue Gas Cleaning Plants

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Introduction

For modern large-scale power plants, efficient noise control measures play an increasingly important role. This can mostly be ascribed to the fact that the noise requirements for new power plants become more and more stringent, which holds especially true for the noise limits at the points of interest in the neighbourhood of the plants, particularly at existing sites undergoing upgrading and/or extension. For coal-fired power plants the components of the flue gas cleaning plant (FGC) are the main noise sources, especially as FGCs are typically located outdoors without noise-reducing enclosure. Besides direct sound radiation from fans and pumps, sound from these sources is also propagating inside pipes and ducts and is eventually radiated indirectly via the – often large – surfaces of these structures. In particular, the flue gas ducts play an important role for the overall noise emissions of an FGC.

Several of the main noise sources can already be identified by having a look at a simplified description of the underlying process.

To separate the flue ash leaving the DENOX unit, electrostatic precipitators (ESP) are mostly used in coal-fired large-scale power plants. In the precipitators the dust particles dispersed within the gaseous fluid are charged electrostatically first and are then deposited at the so-called collecting electrodes. Downstream of the precipitator, the flue gas is transported to the flue gas desulphurisation unit by the use of induced draft fans. Most desulphurisation plants in large-scale combustion plants are run according to the wet absorption process with lime or limestone as absorbing agents. In this process, sulphur dioxide contained in the flue gas reacts with the injected lime suspension inside a scrubber where it is converted into calcium sulphide and then oxidised to calcium sulphate by air injected by compressors. After having left the scrubber, the cleaned flue gas is discharged into the atmosphere via stack or cooling tower. The gypsum suspension is removed from the scrubber sump by pumps and is dried by means of vacuum band filters.

In the following, the main noise sources associated to the above processes and the sound propagation and radiation mechanisms will be described. Furthermore, an overview of possible noise control measures for modern FGC units will be given.

Noise Sources and Noise Control Measures

Induced Draft Fan

Depending on the fuel and the rated power of the power plant in question, induced draft fans (ID fans) with a shaft power of up to 14 MW per unit are installed. Such fans generate noise, which can achieve sound power levels of $L_{WA} \geq 145$ dB(A) in the associated ducts on the pressure and suction side of the fan. Due to the underlying excitation mechanism this noise contains intense tonal components (blade-passing frequency and the associated harmonics, Figure 1). The noise of the ID fan may propagate – on the pressure side – through the whole flue gas cleaning plant up to the stack or cooling tower opening, and – on the suction side – up to the filters and further on in the direction of the boiler, respectively. In order to reduce the propagation and radiation of this noise via the ducts, scrubbers, filters and stack openings, silencers are installed. Typically these operate according to the resonator principle, and are tuned to the blade-passing frequency of the fan. Normally, the silencers are installed directly up- and downstream of the induced draft fan.

At present, predominantly silencers, which operate according to the $\lambda/4$ resonator principle, are used. For these devices, the silencer’s resonators are equipped with cavities, whose depth corresponds to a quarter of the wavelength $\lambda$ of the fan’s blade-passing frequency or one of its harmonics. As a result, a phase shift of 180° is established between the incoming sound waves and the waves reflected at the bottom of the cavity so that a destructive interference occurs. Alternatively, so-called Helmholtz resonators are applied which are also tuned to a specific frequency and work according to a similar principle. A Helmholtz resonator is a mechanical mass-spring-system with a distinct eigenfrequency determined by the mass of air inside the resonator chamber opening and the elasticity of...
the air volume inside the chamber (= the spring).

In the Figure 2 the basic design of such silencers is shown schematically.

With such tuned silencers, the noise at the blade-passing frequency and its harmonics – which usually dominates the overall noise from the fan – is considerably decreased and reductions of the overall noise level inside the flue gas ducts of 35 dB and more can be achieved. An example for the insertion loss of typical resonator-type silencers is shown in Figure 3.

The sound power levels of the noise radiated from the casing of the fan and the driving motor into the surrounding are lower than the sound power levels of the noise radiated into the ducts. At the fan itself, a sound pressure level of $L_{pA} \approx 80 \text{ dB(A)}$ at 1 m distance under acoustic free-field conditions can be achieved using a properly designed, high-quality sound insulation. In case of higher noise requirements, the fan has to be equipped with an enclosure or must be installed inside a building.

The noise radiated from the fan motor is not relevant with regard to the total noise emission of FGC plants in case of water-cooled motors, typically. In contrast to this, air-cooled motors have to be equipped with high-quality soundproofings or need to be installed inside enclosures if not in a building.

**Precipitators**

The filters can radiate noise which has originally been caused by other sound sources (e.g. induced draft fans, combustion noise inside the boiler, noise from soot blowers) and has been transmitted into the filters via the associ-
ated ductwork. The filter itself generates knocking sounds caused by its dedusting activities (rapping). Besides that, the high-voltage transformers located at the roof of the electrostatic precipitators generate noise.

Based on the sound power levels of the noise transmitted from the induced draft fan and the boiler, the average sound pressure level inside the filter can be calculated from the reverberation time in the filter which is a measure of the diffusivity of the sound field in a room. Measurements of this reverberation time in a number of different filters have shown that the filter can be regarded as room with a more or less diffuse sound field.

Based on the average sound pressure level inside the filter and the transmission losses of its walls and ceiling, the sound power level radiated via these surfaces can be estimated. The required transmission losses are known from measurements or can be taken from literature for a variety of wall and ceiling assemblies.

For older precipitators, the knocking noise of the rapping unit can be an important source of noise that can also be perceived in the surroundings of a filter unit. As a result of improved technologies, the noise of the dedusting processes nowadays only plays a minor role for new filter units.

For modern filters of coal-fired power plants, sound power levels of $L_{WA} \leq 88 \text{ dB(A)}$ can be achieved by appropriate noise control measures like resonator-type silencers between filter and fan and a combined heat/sound insulation on the filter walls, the inlet/outlet hoods and the connected ducts.

**Scrubber**

The sound emission of a scrubber can be attributed to the following noise generation mechanisms:

- excitation of the scrubber walls by vibrations caused by the wash water circulation pumps, transferred via the pipes of the wash water circulation system,
- excitation of the scrubber walls by the oxidation air fans,
- self-generated noise caused by the spraying and dropping of the wash water,
- noise from the induced draft fan that is remaining after passing the silencer.

Investigations of wet scrubbers from the 1980s [1] show that, at that time, the sound pressure level measured at a distance of 1 m from the scrubbers was still around $L_{PA} = 67 \pm 4 \text{ dB(A)}$. Depending on the dimensions of the scrubber and the associated surfaces of the casing, sound power levels of $L_{WA} = 102 \pm 5 \text{ dB(A)}$ were reached.

Stringent noise requirements nowadays do not allow such high noise emission levels. As a result, modern scrubbers often have to be equipped with especially designed combined thermal and sound insulation or they have to be installed inside a building. Alternatively, also a design of the scrubbers from concrete is possible. For a modern scrubber that conforms to the current state-of-the-art in noise control, sound power levels of $L_{WA} = 92 \pm 5 \text{ dB(A)}$ can be achieved.

**Recirculation Pumps for Wash Water**

To extract the lime suspension, several pumps with an input power of up to 2.5 MW each are utilised. Besides the input power, the sound power level of a pump’s noise emission also depends on the rotational speed and can be well estimated on the basis of these parameters. The associated noise is not only radiated from the casing of the pumps but, to a much higher degree, also from the connected pipes, which are partly located in the open. By installing expansion joints between pump and connected pipes, reductions of the piping’s noise emission level of up to about 10 dB are possible. By means of high-quality sound insulation, the noise radiation of the pipes installed outdoors can be reduced by another 10 to 25 dB.

The noise radiation of the driving motors can considerably be reduced by means of a sound enclosure. In case of particularly strict noise requirements, also the in- and outlets of the enclosure’s air ventilation system (required for cooling of the motor) need to be equipped with silencers.

**Oxidation Air Blowers/Compressors**

To supply oxidation air, rotary piston blowers, screw compressors or turbo compressors with drive powers of up to 1.5 MW are used. Usually, these devices are of a compact package design including a noise hood and are often installed within a building. As a result, they are not relevant for the noise situation at the points of interests.

As the oxidation air blowers/compressors radiate considerable noise into the connected ducts, these ducts can emit too much noise when they are long and located in the open. As a countermeasure, highly effective absorptive silencers are installed in the ducts, which are located as close as possible to the oxidation air blowers/compressors and reduce the noise radiated into the ducts.

**Vacuum Pump**

In most plants, gypsum removed from the sump of the scrubber is subsequently desiccated on a vacuum band filter. The vacuum is created by vacuum pumps which are installed in buildings with massive walls to reduce the pump noise. As a result, the blow-off opening of the vacuum pumps, which is located in the open, becomes the main noise source. Due to the most common use of rotary piston compressors as vacuum pumps, the noise emitted via the exhaust opening is highly tonal. As a consequence, the considerable noise level reductions often required for new plants can only be achieved using specially designed resonator-type silencers. The silencers have to be highly resistant against corrosion as a result of the humidity from the drainage process which is discharged via the exhaust opening, and are, therefore, partly made of synthetic material. As plastic silencer casings have a comparatively low sound transmission loss, the noise radiation from the casing needs to be reduced by the use of appropriately designed sound insulation.

**Flue Gas Ducts**

Within the ducts themselves, no relevant noise source exists as long as the flow is evenly distributed across the cross sectional areas. Rather the noise caused by the different devices described above is radiated into and transmitted through the pipes and ducts and may be radiated from there into the surrounding via the large duct surfaces.

The noise levels emitted from the associated ducts depend on the height and the frequency spectrum of the sound power levels inside the duct as well as on the transmission loss of the duct walls, plus any additional transmission losses of thermal or sound insulation, if present.

The transmission loss of the duct walls depends on the duct geometry and the wall thickness and material.

Typical thermal insulation of ducts consists of a layer of insulation material and a cladding of sheet metal. The transmission loss of the insulation depends on

- the thickness and density of the insulation material,
- the distance between the outer cladding and the duct wall,
- the fastening of the outer cladding (spacers yes/no, type of spacers) and
- the weight and shape of the outer cladding.

The design of duct insulation in power plants is primarily based on the thermal insulation effect aimed at. However, by taking the above dependencies into account, the acoustic effects of insulation can be tuned, so that a thermal insulation also becomes an efficient sound insulation. To give an example, it may have a decisive influence on the acoustical situation whether a trapezoidal or a plane metal sheet is used for the outer cladding or whether aluminium or steel is used. As a thumb rule, it can be assumed that the noise-reducing effect is increased with an increasing mass per unit area of the outer cladding.

In Figure 4 the transmission losses of a standard thermal insulation and a high-quality
In both cases the insulation is attached to a steel duct with a wall thickness of 5 mm.

From an acoustical point of view, expansion joints, inspection doors and manholes are weak spots in flue gas ducts, which special attention should be paid to in acoustical design.

Depending on the respective noise requirements, additional noise control measures – like internal guiding plates, special insulations or even special enclosures – may be required. Furthermore, in case of very stringent acoustical requirements also the noise emission of non-insulated supporting structures has to be considered.

**Scrubber Agitators**

At the scrubber sump, up to six agitators are installed, two or three of them located in the open. The agitators consist of driving motor, gear box and shaft. Without any noise control measures, common agitators radiate noise with a sound power level of up to $L_{WA} = 98$ dB(A). By installing acoustically highly effective enclosures, whose air intakes and outlets are equipped with silencers, this sound power level can be reduced by up to 20 dB (Figure 5).

**Facade, Roof and Ventilation Openings**

The sound power level of the noise radiated from the facades of a building depends on the sound pressure level inside the building at the inner side of the exterior walls, the transmission loss of the walls and the area of the radiating surfaces. This applies analogously to the roof. For ventilation openings, instead of a wall transmission loss, the insertion loss of any installed silencers determines how much noise from the inside is transmitted to the outside. The sound pressure level inside the building depends on the room-acoustic properties of the building (absorption coefficient of the walls) and the emitted sound power level of the machines located inside the building.

To reduce the sound power radiated from the walls and roofs of buildings, three starting-points for noise control measures are possible:

- noise control measures at the noise sources inside the building,
- enhancement of the sound absorption coefficient at the inner side of the enclosing surfaces,
- enhancement of the transmission loss of walls and roof as well as of the gates and doors, or enhancement of the insertion loss of the silencers, respectively.

Applying the first or second of the above measures results in a reduction of the average sound pressure level inside the building. Such measures become necessary, in particular, when very low sound pressure levels are required inside the building, e.g. to comply with workplace requirements.

Walls and roofs should have a transmission loss that ensures that the noise radiated from the facade does not make a relevant contribution to the total sound power level of the plant’s noise emissions. The same holds for the noise radiation of ventilation openings, natural and mechanical smoke extraction systems and roof lights.

In Figure 6 the frequency-dependent transmission loss of an acoustically highly effective steel sheet cassette design is compared with that of a simple sandwich panel design. From Figure 6 it can be seen, that a difference between the transmission losses of these two different designs of more than 20 dB exists in the frequency range between the 125 Hz and 1000 Hz octave. In many cases, the transmis-
Sound Propagation and Sound Radiation Mechanisms/Noise Control Measures

Due to the size of the associated volumes and surfaces, the sound propagation inside the ducts and scrubbers and the sound radiation to the outside of these structures play an important role within the acoustical design process. As an example, the sound propagation path from the pressure side of the induced draft fan up to the cooling tower (or stack) opening will be looked at in the following and the most important sound propagation and sound radiation mechanisms will be outlined. For the most important noise emitters typical noise control measures will be described.

Induced Draft Fan

The main noise source in our example is the induced draft fan that radiates noise generated by the movement of the impeller and the associated flow effects into the pressure side duct.

Noise control: To reduce this noise as close as possible to its origin, a resonator-type silencer is installed immediately downstream of the fan.

Flue Gas Ducts and Raw Gas Ducts

On its way through the ducts, the sound power, originally radiated into the ducts from the induced draft fan (and already reduced to some extent by the fan silencer), decreases more or less continuously. This happens mainly due to the following effects:

- longitudinal attenuation due to dissipative processes in the flow and due to sound absorption at the duct wall,
- sound radiation into the surroundings via the duct wall,
- sound attenuation within the material of the duct wall,
- sound reflection at bendings and cross-sectional jumps, and discharge of sound at duct junctions.

All these effects are well understood and their impact can be estimated with sufficient accuracy in the framework of the acoustical design process.

Noise control: As outlined, the noise received from the ducts in the surroundings is determined by the noise radiation from the duct walls. Accordingly, thermal and/or acoustic insulation (depending on the limits to comply with) needs to be installed to reduce these emissions.

Scrubbers

When passing through the scrubber, the sound power level is further reduced by the following effects:

- sound absorption/attenuation caused by the droplet mist inside the scrubber,
- sound reflection/attenuation at the spraying level,
- sound absorption/attenuation by the droplet separator inside the scrubber,
- sound reflection as a result of cross-sectional jumps at the inlet, or the outlet of the scrubber, respectively.

In total, the noise level reduction (transmission loss) of sound passing through the scrubber can be more than 30 dB. However, all of the above effects are strongly dependent on the frequency, as can be seen in Figure 7. It shows the total noise level reduction for sound propagation through the scrubber in octave bandwidth. The results were determined from various measurements within the last four years on the one hand side and correspond to older assumptions stemming from [1] on the other hand side.

Figure 7 also shows an interesting development. The red curve shows results from measurements in older scrubbers while the blue curve shows the transmission loss determined for modern state-of-the-art scrubbers. The considerable difference between the two transmission loss curves can be explained by the fact that in newer scrubbers, operated according to the actual state-of-the-art, more water than in older units is used. Besides that, nowadays, the water is atomized to droplets consisting of a much smaller size than in the past. Both effects have a beneficial effect on the absorption of sound and thus increase the transmission loss.

Sound Propagation through Stack and Cooling Tower

In most modern flue gas cleaning plants, the cleaned gas is led to the cooling tower via the clean gas duct after having left the scrubber.
Alternatively, the gas may be emitted through a stack. Along this way, the sound power level decreases further on its way to the cooling tower or stack opening. Noise reduction inside the cooling tower is mainly by similar effects as for the noise level reduction in ducts (longitudinal attenuation, also for stacks) and in the scrubber (sound absorption/sound attenuation by the droplet mist).

Due to the characteristics of sound propagation inside the cooling tower or in a stack, the noise from the opening is not radiated evenly in all directions but is mainly directed upwards. In the framework of the acoustical design process, it is crucial to take this directivity of the sound radiation - which is dependent on the frequency - into account to obtain reliable results. The so-called directivity index, which represents the deviation from spherical noise radiation, has to be calculated separately for each point-of-interest and depends on the angle between the centreline of the cooling tower/stack and the connecting line between the point-of-interest and the cooling tower or stack opening.

Sound Propagation through the Plant in Total

In the following example, the sound level reduction due to the different effects described above is illustrated for a typical flue gas cleaning plant, starting from the pressure side of the induced draft fan up to the cooling tower opening.

Figure 8 shows that for the noise propagation path under concern the most significant noise level reduction takes place inside the silencer and in the scrubber. Further relevant reductions of the noise level occur during the passage through the cooling tower. In contrast to that, the noise level reduction within the ducts is rather low for the present case but may be higher in systems with many bends and cross-sectional jumps within the ducts.

Elaboration of an Optimised Noise Control Concept

Development of a noise control concept for a flue gas cleaning plant – optimised in terms of technical as well as economical aspects – involves the following principal steps:

- Determination of the maximum permissible total sound power level of the noise emitted from the whole plant, based on the specified noise limits/contractual guarantees/legal requirements etc.
Allocation of maximum permissible sound power levels for individual equipment.

Identification of all equipment that requires noise control and specification of suitable noise control measures.

The allocation of maximum permissible sound power levels for individual equipment in the second step must not only be compliant with the maximum total sound power level of the plant but must also take technical and economical aspects into account. For example, it must be avoided that low sound power levels are allocated with sources for which noise control is difficult and/or expensive.

The third step – together with he second step – requires a profound understanding of the sound emission characteristics of the sources in question, the sound propagation and transmission effects involved, and the effect, impact and costs of the possible noise control measures. With respect to costs, it is essential to not only take the capital costs for the noise control equipment into account but to carefully observe any long-term effects due to higher or lower operational costs. Examples:

- The more accurately the intrinsic noise level reduction through the various system components along the noise propagation path can be predicted (see Figure 8 – basically the level reduction between the blue and the black curve), the better the ID-fan resonator silencer can be optimized. An optimised silencer design – with little or no safety margin in the silencer’s transmission loss – results in a smaller silencer that will have a lower pressure loss and, thus, will result in lower energy costs.

- Similarly, higher costs for additional acoustic insulation may be perfectly justified if they make it possible to use a smaller silencer in the flue gas system instead, with the same beneficial effects as outlined above.

From a practical point of view, the process of working out an optimised noise control concept requires a well balanced approach that relies both on suitable mathematical models and empirical/measurement data. While mathematical models and computational simulations are indeed very important tools in modern noise control planning, measurements – in the test stand and on site – are at least of equal importance: A solid and extensive basis of reliable measurement data for a large variety of typical noise sources is an indispensable basis for the development, continuous improvement and regular verification of the mathematical tools that yield reliable results and, thus, planning safety for the power plant manufacturer and operator.

References


