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Noise Control of Large Wet Cooling Towers

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ABSTRACT

During industrial processes, the most common energy transformation process is the transformation of mechanical, chemical or electrical energy into thermal energy. The generated heat cannot be utilized in every case, so it has to be removed from the process by cooling.

The technology discussed in the presentation is closely related to last year's presentation in which I was reporting on the noise control action plan of Hungary's largest chemical factory. The efficiency of chemical processes depends on the efficiency of the removal of the generated heat. One of the most widespread industrial cooling technologies is the evaporative wet cooling system, which is essentially the subject of this presentation.

The noise sources discussed in this presentation are unique to their size. In this case, the surveyed large, multi-cell cooling towers are 12-16 metres high and have several fans which are 9-10 metres in diameter. In the area of Hungary's largest chemical factory, fifteen of such large cooling towers are in operation; therefore, it is not surprising that these are the noise sources which dominantly determine the environmental noise pollution of the aforementioned facility.

In this presentation I am going to introduce the technology of the cooling tower, the mechanism of noise generation and the dominant noise sources. I am also going to present the measurements we performed, their results and the conclusions drawn from them.

The possibilities of the subsequent noise reduction will be presented comprehensively in relation to a specific case study by analysing the direct intervention possibilities at the noise source and the solutions achievable through sound propagation.

The aim of the presentation is to introduce the volume of the task expressively, and to give a sense of the challenges which we have to face during the survey of such noise sources that are large and technologically bound.

Keywords: Industrial Noise, Cooling Tower, Noise Control, Wet Cooling, Case Study, Industrial Noise Sources, Industrial Noise Measurements, Noise Model

I-INCE Classification of Subjects Number(s): 14, 55, 56

1. INTRODUCTION

The efficiency of several chemical processes depends on temperature, pressure and the efficiency of heat removal. The cooling technology discussed in the presentation is an open evaporative wet cooling system; therefore, the cooling agent (water pre-treated with special additives) is in contact with the environment. In the cooling tower, the airflow, which is required for heat transfer, is generated by fans. The cooling agent contacts the air coolant in a droplet form. Part of the water evaporates during the heat transfer, and another part of it is cooled by the heat transfer. [1]

In order to avoid the recirculation of the discharged air which is saturated with vapour, the fans are placed as high as possible (on induced draft towers the fans located in the exiting air stream). The distance between the discharge and intake locations of the air should be as large as possible (but at least as large as the height of the entry surface); moreover, fan stacks (fan cylinders or flared diffusers) help discharge of the saturated air stream and prevent recirculation. [2]

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2. NOISE SOURCE

2.1 Noise-generating Mechanism of the Open Wet Cooling Tower

The typical noise sources of the cooling technology discussed are the following:

- the main engineering units of the cooling system:
  - hermetically sealed water circulating pumps (mechanical noise),
  - fans for airflow required for heat transfer (mechanical noise),
- flow and cooling agent:
  - droplets falling into the water basin (in total, the impact noise of the water mass),
  - air flowing through the cooling agent or through the fans (aerodynamic noise).

The way of noise emission depends to a large extent on the structure of the tower, since in the case of coating materials with smaller specific mass, the sound energy flowing through the coating will also be more significant. In the case of reinforced concrete constructions, the sound insulation of the coating is so great that the sound energy passing through the concrete structure is practically negligible.

In the following, only the noise-generating mechanism of the main noise sources is detailed, because in the absence of space, it is not possible to provide a more detailed description on the noise-generation of the water circulating pumps, and on the (otherwise negligible) noise emission resulting from the construction of the tower.

2.2 Noise-generating Mechanism of the Fans

The components of the noise generated by the fans are essentially fall into the mechanical and aerodynamic categories. The mechanical noises are generated by the bearings and the vibrations caused by the unbalanced rotating elements. Normally, the bearings alone do not generate noise, but it can be a noise source due to their vibration-inducing effect. On the one hand, the vibration of the impeller and the shaft causes noise emission due the noise transmitted directly to the spiral case or tube case, and on the other hand, is also transmits noise in the external environment of the machine by propagating structure-borne sound to the wall of the fan housing.

Other complex noise sources associated with the operation of the fan are the noise generated by the engine that drives the fan and the noise generated by the power transmission (e.g. the belt drive). The mechanical noise of the electric rotary machines is the same as described above. Their flow noise is resulting from the cooling system and the movement of the rotor parts; moreover, the magnetic noise is generated by the magnetostrictive forces. The belt drive can also generate noise in the form of structure-borne and airborne sound.

In the case of a properly constructed and operated fan, the mechanical noise components are negligible compared to the aerodynamic noise components. Apart from the rotational noise that generates pure sound and the rotor-casing interaction, the components of aerodynamic noise can also include the vortex noise and the turbulence-induced noise generating broadband noise emission. [3] [11]

2.3 Noise-generating Mechanism of the Cooling Agent

Of course, the cooling agent stored in the basin of the cooling tower is not a noise source on its own. The noise itself is generated by the water droplets falling on the water surface of the basin. During the impact, the motion energy is transformed in a very short time, and a significant part of that energy will be lost in the form of sound energy, heat energy and the energy of the permanent transformation. The reason for this is that water is basically not compressible. It is an inflexible liquid, so the collision will resemble the physical parameters of an ideally inflexible collision.

The sound energy generated by the impact of water droplets depends on the magnitude of the motion energy. So, the noise emission is affected by the size and the mass of the water droplets, their falling height and their falling speed. Based on the known correlation of the motion energy, the effect of speed that affects the motion energy is more significant; therefore, a decrease in noise emission is expected to be achieved by decreasing the speed.

3. CASE STUDY

3.1 BorsodChem

In our case, the subject of our survey is the cooling tower of the Nitric Acid Plant of BorsodChem. BorsodChem is currently one of the leading chemical raw material manufacturing company of Central Europe. Its premise in Kazincbarcika is Hungary's largest chemical factory, where the main focus of production is isocyanates and PVC. The entire industrial area is nearly 4 km^2, of which the densely built-up production and development area is close to 2.5 km^2. The production area is wedged in between the towns of Kazincbarcika and Berente; therefore, the industrial area is surrounded by residential areas on both sides.

In the industrial area there are more than 20 stand-alone facilities (PVC, MDI, TDI, VCM, Chlorine, Nitric Acid, Ammonium, etc.), which operates continuously day and night with thousands of individual noise sources. These facilities are in a close technological relation with each other, so practically the whole industrial area operates as one factory. In the area of BorsodChem fifteen of such large cooling towers are in operation; therefore, it is not surprising that these are the noise sources which dominantly determine the environmental noise pollution of the aforementioned facility.

3.2 The Cooling Tower of the Nitric Acid Plant

The northwest-southeast oriented cooling tower is located in the north-western part of BorsodChem's densely built-up production and development area, where the populated area of Kazincbarcika borders the industrial area of BorsodChem. The houses that are the closest to the industrial area are approximately 400 metres away from the cooling tower.

The cooling tower was built by GEA EGI Energiagazdálkodási Zrt. (Today it is called ENEXIO Hungary Zrt.), and was actually handed over in 2011. According to the noise reduction action plan presented at the INTER-NOISE conference in Hamburg last year, the cooling tower is a dominant noise source in the area of the city of Kazincbarcika that has to be protected from noise; therefore, the tower contributes significantly to the development of noise pollution in the residential area.

Figure 1 – The cooling tower of the Nitric Acid Plant

The main parameters of the cooling tower:

- structure: reinforced concrete structure, two separated cells with a common water basin;
- dimensions (height/width/length): 11.6 m / 15.6 m / 29.4 m;
- air inlets: on both sides, total height is 4.8 m, total area is 137.3 m^2 on one side;
- cooling fans: two Cofimco 8-blade fans with a diameter of 9.1 metres (30 feet);
- rotating parts: located in the roof level of the tower (120 RPM / 50 Hz drive frequency);
- fan motors: 200 kW nominal power / 1486 RPM nominal shaft speed (with VFD);
- fan stacks: 2 m high light-frame (plastic) flared diffuser (no significant sound dampening);
- circulating cooling agent: 6000 nm^3/h (designed) / 6200 nm^3/h (current) pre-treated water.

During the hottest summer season of the year, the fans operate at nominal speed. During the cold season, the rotational speed of the fans may be reduced, but they cannot be operated at less than 20 Hz drive frequency, because in this case the loss of water will increase (in the absence of suction, there will be splash out at the air inlets); moreover, during winter, the fan blades could be frozen. The amount of the cooling agent is constant in winter and summer as well.

The water circulating pumps belonging to the cooling tower of the Nitric Acid Plant are located north of the cooling tower directly next to it in a semi-open shaft below ground level.

4. ANALYSES

4.1 The Methods of the Analyses

In order to assess the noise-generating mechanism, the source analysis and the noise emission parameters of the open wet cooling towers, we have carried out instrumental analyses in the vicinity of the cooling towers which are of the same design and the same technology. Since the production area of BorsodChem is full of plants and noise sources with considerable noise emission, the analyses were carried out close to the noise sources so that the measured values will not be affected by the noise emitted by the surrounding noise sources.

In order to achieve the objectives set, a complex noise analysing instrument system had to be implemented, the units of which support the objective opinion by supporting each other:

- Subjective analysis based on hearing:
  - identifying typical noise sources and sound radiation directions,
  - determining the tone and time function in the vicinity of the noise sources,
  - exploring noise sources with critical radiation directions.
- Frequency analysis:
  - recording and analysing frequency spectrum in the vicinity of the noise sources,
  - comparing frequency spectrums generating at the evaluation points,
  - identifying noise sources with typical noise emission (e.g. narrowband nature).
- Noise measurement:
  - surveying environmental noise pollution at the evaluation points,
  - surveying impacts affecting sound propagation at reference measuring points,
  - measuring sound pressure levels emitted by noise sources in the vicinity of sources,
  - surveying geometric parameters and radiation characteristics,
  - determining sound power level by measurement and calculation.
- Software noise model (IMMI Premium 2016):
  - building a detailed model based on close-proximity measurements and source data,
  - calibrating noise model with the measurement results recorded at the reference points,
  - modelling sound propagation in horizontal and vertical raster,
  - determining the dominance of noise sources at the evaluation point,
  - modelling and analysing the impact of noise reduction solutions.

We have investigated the cooling towers of the same design and technology, which are located in the area of the plant, while they have operated under normal conditions, and we have also purposefully operated the noise sources that determine the noise emission of the cooling tower. The cooling towers, in a significant part of the year, operate according to the technological requirements, in a strictly set technological system, basically in accordance with the cooling needs. Consequently, the purposeful operation of the mechanical units is only possible in the cold season when the demand for cooling decreases. Therefore, we carried out our investigations during autumn (when the undercooling of the cooling agent cannot cause any problems), and during the annual shut down of the factory in August.

As we have already mentioned, our aim was to determine the sound radiation characteristics and sound power level of individual noise sources; therefore, we practically managed to determine the extent to which individual noise sources are involved in the total noise emission of the cooling tower. Of course, in order to achieve this, the noise sources of the cooling tower had to be surveyed independently of each other, because the radiated sound energy will be combined during the joint operation of the dominant sources. It could cause sound-overlapping phenomena, and the frequency spectrum of the individual sources could not be defined clearly as well.

4.2 Measurement Results and Their Processing

Between 2013 and 2016, a number of analyses were carried out, but unfortunately, in the absence of space, it is not possible to show the measurement results in detail. Therefore, only the conclusions drawn from the analyses results are given below.

4.2.1 Measurement Results of the Fans

While measuring the noise emission of the fans, our aim was to determine how the sound power would change in different operating states (rotational speeds). The purpose of the measurement was ultimately to determine the extent to which noise reduction could be achieved by using the variable-frequency drive.

The surveys of the fans in different operating states were performed at the cooling towers of the Nitric Acid Plant and TDI2 plant at varying rotational speeds (80-120 RPM) and drive frequency (27-50 Hz). At the time of the plant's annual shutdown, a set of surveys was carried out during which the fully turned off fans were rotated at maximum speed gradually. During the measurements, we carried out a logging with a sampling time of 100 ms simultaneously at multiple measuring points (above the fan, in front of the air inlet and at the reference points farther away from the cooling tower).

Based on the tests, it can be stated that the results of the measurements, carried out at different cooling towers at different distances (but at the same operating conditions), characterize the same sound power level. Accordingly, it can also be stated that the total sound power level of the tested fan (at nominal speed) is the following:

$$L_{AWmax} = 102 \pm 1 \text{ dB} / 64 \text{ m}^2$$

The sound power level of the fan engines of the cooling tower is the following:

$$L_{AW} = 91 \pm 1 \text{ dB}$$

The fans of the surveyed cooling towers operate with variable-frequency drives, so the sound pressure level changes of different rotational speeds were measurable for both cooling tower. According to the measurements, the degree of noise attenuation with 10 % rotational speed reduction is $\Delta L = 3$ dB, while the degree of noise attenuation with approximately 46 % rotational speed reduction is $\Delta L = 5$ dB.

It can also be stated that the noise emission of the fans is much higher the outlet side, while the inlet side has significantly less sound energy. The difference in the sound pressure level between the two sides at maximum rotational speed is 13 dB. Of course, part of the difference is due to the fact that on the inlet side the propagation is obstructed by the technological units under the fan (e.g. drift eliminators, water distribution system, exchange surface, etc.); moreover, the noise source is located farther away on that side from the measuring point.

4.2.2 Measurement Results of the Air Inlets

Based on the measurement results of the air inlets, it can be stated that the measurements, carried out at different cooling tower at different distances (but at the same operating conditions), approximately characterize the same sound power level. Accordingly, it can be stated that the total sound power level of the entire surface of the air inlet, irrespectively of the cooling tower, is the following:

$$L_{AW} = 97 \pm 1 \text{ dB} / 137 \text{ m}^2$$

4.2.3 Measurement Results of the Water Circulating Pumps

The results of the measurements carried out at the different water circulating pumps of the different cooling towers (at the same operating conditions) do not correlate as much as the above-described results, so the uncertainty of the calculated sound power levels is significantly higher here:

$$L_{AW} = 92 \pm 3 \text{ dB} / 27 \text{ m}^2$$

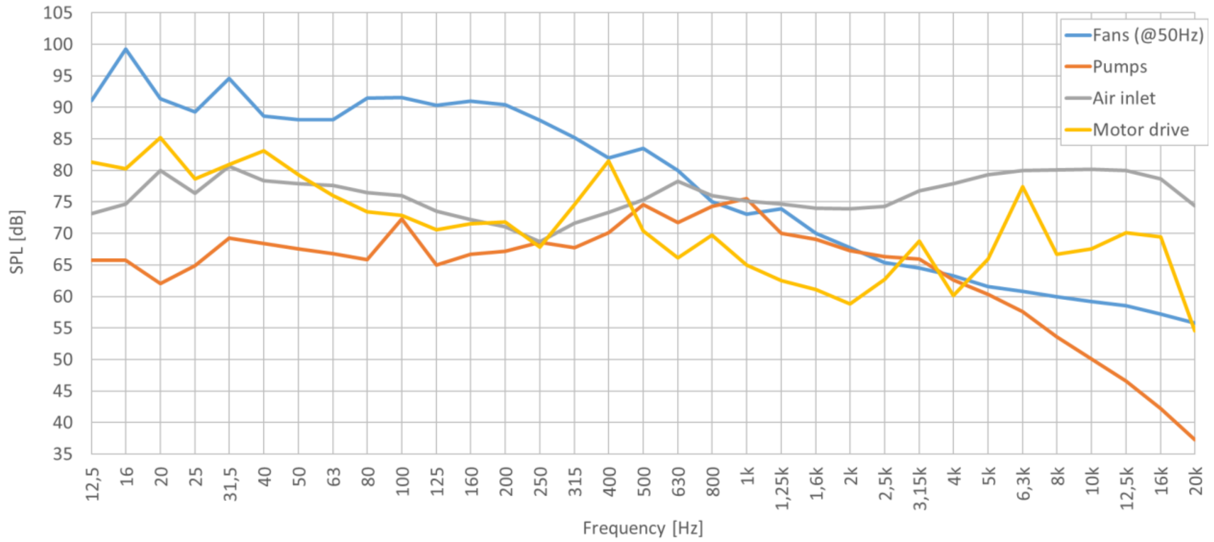

Figure 2 – The unweighted frequency spectrum of the noise sources

Based on the analysis of the frequency spectrum of the noise sources, it can be stated that the characteristic tonal frequency of the noise emitted by the fans results from the rotational speed and the number of blades. At 50 Hz drive frequency, the rotational speed of the rotating part is 120 RPM, which means 2 full turns per second. Therefore – since the rotor is equipped with 8 blades – we have to calculate on a total of 16 blades passing per second, namely 16 Hz basic frequency, and the harmonic 32 Hz frequency also appears in the spectrum. The significant sound energy between 80-200 Hz is generated by the aerodynamic noise.

Based on the noise measurements carried out at the air inlets, it can be stated that noise generated by the impact of water droplets is broadband; most of the sound energy appears in the range of high tones (3.15-16 kHz). Nevertheless, some low-frequency 1/3 octave frequency bands are emerging from the spectrum, because the internal space of the cooling tower could probably be induced by these frequencies.

4.3 The Dominant Noise Sources

By using the measurement results and determined source data (sound power levels, frequency spectrums), and by using standard calculation methods and IMMI 2016 Premium software propagation model, it is possible to determine the dominance order and noise attenuation need of the noise sources. The results of the sound propagation calculations done with the model are compared to the sound pressure levels recorded at the measuring points, and during the iteration procedure, we gradually calibrate and refine the noise model step by step. After the calibration of the measurement results (not affected by the background noise of surrounding noise sources) recorded near the noise sources, the sound pressure levels at the evaluation points can be calculated.

In order to determine the role of each noise source in the noise pollution, we need to operate these noise sources selectively. However, the noise sources operating in the industrial area are in close technological relation with each other, the operation of the sources are extremely bound, they cannot be operated independently. In addition, the propagation of sounds between the noise sources and the perception points is greatly affected by the meteorological factors. The influence of meteorological factors on the propagation of sound always makes the results of such surveys uncertain.

During the dominance analyses, the effect of meteorological conditions on sound propagation can be eliminate by using the software propagation model, because the noise mapping software always calculates with the best sound propagation parameters, modelling an extreme, but realistic weather situation in all directions. Consequently, the software calculation method eliminates possibilities of errors to a certain extent in the measurement methods, errors resulting from non-reproducible operating conditions and measurement conditions.

Based on calculations done with the software model, the dominance order of the noise sources at the critical evaluation point (in terms of noise pollution) is the following:

- Air inlets (L_{Aeqi} ≈ 45 dB at the critical evaluation point)
- Fans (L_{Aeqi} ≈ 40 dB at the critical evaluation point)
- Water circulating pumps (L_{Aeqi} ≈ 25 dB at the critical evaluation point)
- Fan drive engines (L_{Aeqi} ≈ 10 dB at the critical evaluation point)

Assuming that environmental conditions are favourable to the propagation of sound, the noise pollution caused by the surveyed cooling tower at the evaluation point is so much that if it would operate alone in the plant (i.e., all other noise sources of BorsodChem would be shut down), it would still cause a noise pollution that exceeds the limit.

5. NOISE REDUCTION

5.1 Principles of Noise Reduction

The methodological principle of noise control and the priority order for noise reduction solutions (with examples) are the following:

- Primary: reduction of noise at source (emission)
  - replacing the noise source with a lower noise emission type
  - reducing the power of the noise source or changing its operating time
  - reducing of typical flow velocity
  - damping mechanical noises and avoiding structural resonances
- Secondary: attenuation of sound during propagation (transmission)
  - choosing a proper protection distance and direction of radiation
  - noise protection coating, encasing, wall
  - using silencers in air ducts
  - using locally active noise reduction
- Tertiary: protection of protected areas (immission)
  - increasing the sound insulation of facade structures and windows [3]

Of course, the most effective way to reduce the noise emitted by the cooling towers is the preliminary acoustic design and dimensioning, because the maximum noise reduction can be achieved by selecting the proper distance and direction of the noise source. Subsequent noise reduction is practically an unfavourable solution, because it is not only more costly than choosing the more silent technology during investing, but it could also increase the operating and maintenance costs.

It seems obvious, but in this line of thought it should be emphasized that regular scheduled maintenance is also one of the most effective ways of noise reduction. The proper operation and maintenance of the equipment keeps the emission of noises within well-regulated boundaries.

The fundamental issues to be addressed in relation to noise reduction solutions are well known: the total acquisition cost, the degree of noise reduction (under certain conditions), the maintenance requirement and cost (over a minimum of 10-year perspective), how does it affect the operation of the cooling tower (e.g. pressure drop), and is it achievable without significant transformations.

5.2 Determining the Noise Reduction Requirement

The noise reduction requirement is based on the specific noise pollution calculated at the critical evaluation points and on the noise emission limit, required by the applicable legislation, for noise protected areas. The environmental noise pollution caused by the noise sources of the cooling tower in question is causing a significant problem only at the residential area of Kazincbarcika, which is approximately 400 metres away from the noise sources. Since the fans of the cooling tower emit noise at an approximate height of 12 metres, mainly the upper floor apartments of the residential area are affected by the noise emitted by the cooling tower.

5.3 Analysis of Primary Noise Reduction Options

Primary noise reduction measures reduce the sound energy (sound power level) emitted by the sound source, directly intervening during the noise-generating mechanism (emission).

Such a solution may be:

- the aerodynamic sophistication or replacement of fans,
- the regulation of the rotational speed with a variable-frequency drive,
- the reduction of the impact noise of water droplets.

Of course, in this presentation we have to exclude the technological change of the existing cooling system, because the realisation of a more efficient cooling technology would be too expensive (and the facility surveyed in this presentation is not considered obsolete at all). If the change of the cooling technology is not possible, transforming the existing technology (transforming the equipment, replacing the noise sources for other types that would emit less noise) can reduce environmental impacts. At the same time, reducing environmental impacts may be accompanied by a reduction in cooling performance, which may require higher power fans and therefore greater energy consumption. Therefore, besides the noise reduction considerations – taking into account the BAT guidelines – the expected environmental impact of each intervention should always be surveyed in a complex way. The simplified analysis of the primary solutions is the following:

- ADVANTAGES
  - the cooling performance changes only slightly or does not decrease at all,
  - in many cases, energy efficiency can be improved,
  - cost savings can be achieved over a longer period of time,
  - the geometry and the environment of the cooling tower do not change.
- DISADVANTAGES
  - the invention options are limited,
  - usually the achievable noise reduction is less than it could be with post solutions,
  - in the case of a complex solution, intervention will be needed at several points with significant costs,
  - in the case of a more complicated solution, the chance of breakdown will be much higher,
  - the number of maintenance tasks and their costs will increase.

5.3.1 Aerodynamic Sophistication or Replacement of Fans

Knowing the mechanism of noise-induction, the primary noise reduction intervention may be justified where the noise is generated. A typical component of the noise emission of fans is the vortex noise and the turbulence-induced noise, which can be reduced with aerodynamically optimised blade profiles and aerodynamic inserts. [4]

The proper aerodynamic design – or subsequent optimisation – directly intervenes where the noise is generated without reducing the efficiency of the fan. The direct benefit of interventions within the fan housing is that, since there is less noise inside the fan housing, less noise is radiated through the casing. In principle, we could set an aim to increase the efficiency of the cooling tower in parallel with reducing its noise, reduce vapour formation and ultimately save money by increasing energy efficiency and reducing maintenance costs.

One of the most commonly used primary noise reduction solution is the SX series fan manufactured by Howden (in this case, the 30-foot 6-blade version can be used). Due to the unique design of the blades, according to the manufacturer's catalogue, the blade's noise is less than 8 dB(A). At the same time, according to the manufacturer, if this is combined with a smaller fan speed, the SX range reduces noise by up to 20 dB(A) compared with standard cooling fans.

Comparing the data of the current Cofimco 9144-8-36N/G2.0T fan and the recommended Howden 30-SX 6-blade fan, the noise reduction expected after the fan replacement is the following:

$$\Delta L \approx 9 \text{ dB}$$

Nevertheless, in the case of a fan replacement, such Howden SX fans typically require higher fan housing than normal type fans, i.e. the housing needs to be rebuilt and elevated subsequently (but it is not certain that the existing fan housing is structurally adequate to withstand an additional element). Moreover, if the fan housing is equipped with a diffuser, it is also necessary to examine whether it is possible to insert another housing part under the diffuser.

Apart from the fan, it is likely that the motor and the drive shaft have to be replaced as well, because they would rotate the new fan slower than the current one, but the power on the shaft would be higher. Moreover, it is also necessary to examine whether the variable-frequency drive or the electrical switchgear corresponds to the higher power requirements. Alternatively, it may be possible to rotate the engine more slowly with the variable-frequency drive, but in this case the engine should be examined to see whether it can withstand higher power at a lower rotational speed.

As you can see, the replacement of the fan blades is not a simple technical intervention. It is expected that a lot of related equipment will need to be replaced and modified, which means that the cost of a new fan can be quite expensive.

5.3.2 Controlling the Speed of the Fans with a Variable-frequency Drive

The Variable-Frequency Drive (VFD) controls the speed of the fan motor, and this was it also controls the rotational speed of the fan wheel and the amount of air delivered. In a noise protection aspect, the control of the speed is particularly effective, because the sound power of the flow-based noise component is proportional to the power of the typical speed (peripheral and flow speed). So, when the rotational speed is halved, the expected noise reduction is not 3 dB but 6 dB. At this time, the amount of air delivered is about 60% of the total capacity. [2]

In Hungary, during July and August, the fans of the cooling tower constantly operate at maximum speed, so the operating condition that generates the highest environmental noise emission is practically achieved. At the same time, the ambient temperature can be sufficiently reduced at night, so it may be sufficient to operate the fans of the cooling towers at a lower rotational speed. As the ambient noise pollution limits at night are stricter with 10 decibels, the limit value will be significantly exceeded even at night.

According to our analyses, in the case of the cooling tower of the Nitric Acid Plant, the frequency of the drives (from the nominal 50 Hz) was reduced to no more than 43 Hz in the summer during night time, and with that the maximum noise reduction possible would only be:

$$\Delta L \approx 2 \text{ dB}$$

Therefore, a significant noise reduction can only be achieved, if the temperature drops below 20 °C during the night time. The use of the VFD can have its own risks, so its use for noise protection is essentially determined by whether the desired result can be achieved from an environmental point of view.

5.3.3 Waterfall Noise Reduction

As I have mentioned, a major component of the noise emission of the cooling tower is the impact noise caused by the water droplets when they fall into the basin, and this noise is essentially depends on the mass of the water drops and their impact speed.

It goes without saying that by changing the size of the water droplets, the mass of the falling droplets will also be reduced, and this way the emitted sound energy will be less as well. At the same time, reducing the size of water drops can also reduce the amount of water flowing through per unit time, and this way reduce the cooling capacity of the cooling tower as well. Therefore, in order to achieve efficient heat transfer, the maximum amount of cooling agent should be contacted with the cooling air along the air inlet with the given cross section. Namely, reducing the size of water droplets in this respect is not appropriate.

The noise generated by the impact of water droplets is essentially due to the fact that the collision is inflexible, as the colliding bodies cannot be compressed. If the collision becomes elastic (i.e., at least one of the impacting bodies goes through an elastic deformation), a significant part of the movement energy will not turn into sound energy.

By using the retrofitting waterfall noise reduction mats, the falling water droplets collide with a flexible surface instead of the surface of the cooling agent, so the collision becomes elastic, and the emitted sound energy will decrease depending on the thickness (in some cases the number of layers) of the mats.

The degree of noise reduction achieved with the mats depends on the present droplet noise and essentially depends on the drop height of the droplets and the number of layers of the applied mat. According to the manufacturer's data, the expected noise suppression rate is the following [5] [6] [7]:

$$\Delta L \approx 4\text{-}9 \text{ dB}$$

The mat is a lightweight, elastic, open, three-dimensional fibre mattress, usually made of polyamide, polystyrene or polypropylene. The base material must have excellent UV resistance, which will ensure the durability of the material for at least 10 years. The product must have adequate chemical and mechanical resistance, cannot react with chemicals used in the cooling agent, biocides, and must be bacteria-resistant. With regard to maintenance, it is advantageous if the mat can be cleaned easily (e.g. with soap and water).

Basically it is essential that the waterfall noise reduction mat must float on the surface of the water, because the required noise reduction can only be achieved, if the falling droplets do not directly contact the surface of the water, except through the material. This can be accomplished in such a way that the material is initially floating on the surface of the cooling agent, or a support structure has to be installed above the basin, which structure could hold the noise reduction mat.

5.4 Analysis of Secondary Noise Reduction Options

When solving noise reduction tasks, many times we have encountered such cases that it was not possible to modify the noise source or reduce the sound power by reconstructing the machine. In such a case, an effective method of reducing environmental noise is to prevent the propagation of sound. Such a solution may be:

- using absorbing silencers,
- creating acoustic louver panels,
- building sound barrier walls.

When using secondary noise reduction solutions, it is generally assumed that subsequent technical interference with propagation results in a pressure drop, which can reduce the cooling capacity and energy efficiency of the cooling tower. Therefore, these solutions can be used with great certainty only when the tower is sufficiently oversized to compensate for the pressure drop generated by the subsequent noise reduction solution. The simplified analysis of the secondary solutions is the following:

- ADVANTAGES
  - it does not interfere directly with the cooling tower technology,
  - it can be implemented step by step,
  - there are more solution options,
  - sometimes the available noise reduction is greater than in the case of the (subsequent) primary intervention.
- DISADVANTAGES
  - its cost exponentially increases depending on the noise reduction requirement,
  - it generally results in a pressure drop,
  - the cooling capacity and energy efficiency of the cooling tower can be reduced,
  - access to mechanical units may be more difficult,
  - maintenance tasks and costs will increase,
  - the geometry and the environment of the cooling tower will change.

5.4.1 Absorbing Silencers

Noise reduction of absorbing silencers is caused by the loss of friction occurring during propagation in the porous structure (e.g. glass wool or rock wool with fibrous structure, open cellular foam) placed within them. Absorbing silencers are effective in a wide range of frequencies. The sound absorption at low frequency is limited by the finite thickness of the built-in sound absorbing material, while at high frequency it is limited by the decrease of the bending ability of the sound waves. [3]

The degree of acoustic absorption of absorbing silencers is determined by the size of the free cross-section between the louvers and the length of the absorbing inserts. The smaller the gap between the louvers, the greater the noise reduction that we can achieve. At the same time, the operational principle of the louvered silencer is that the sound energy is absorbed in the louvers that are in the path of the flowing agent, so we usually have to assume that this solution results in a pressure drop. Therefore, the absorbing silencers can be used with great certainty only when the tower is sufficiently oversized to compensate for the pressure drop generated by the subsequent noise reduction solution.

5.4.2 **Louvered Air Inlets**

When designing air inlets and outlets, it is essential that the cooling agent does not leave the internal space of the tower, and also the sunlight must not reach the surface of the basin and must not heat the cooling agent (this way the algae formation will be reduced). For this purpose, it would be advisable to use vertical drift eliminators which affect the flow speed to some extent, and which are individually dimensioned for forced or induced draft cooling towers. The water separation efficiency of the drift eliminators and the pressure drop are approximately proportional; therefore the inadequately selected drift eliminator can cause a significant pressure drop, thus reducing the cooling performance and the efficiency and lifetime of the fan.

An effective noise reduction solution is the creation of absorbing louvered inlets, described in the previous section, the louvers of which are sound absorbing so as to reduce the flowing sound energy. At the same time – similarly to the air inlets with acoustic louvers – the louvers also reduce the suction cross-section, resulting in a further pressure drop that the fan needs to overcome. The degree of pressure drop at the air inlets must be taken into account when determining the working point of the selected fan, and the entire drive chain should be dimensioned accordingly, so using noise reduction solutions that cause significant pressure drop is not recommended.

5.4.3 **Sound Barrier Wall**

In the case of the cooling towers in question, in order to ensure maximum cooling performance, it is crucial to use a solution, which can provide maximum noise reduction with the lowest pressure drop. Therefore, in the present study, the possibility of an intervention by propagation is limited to sound shielding, which, when properly designed, achieves the reduction of the noise emitted by the fans and the air inlets.

The degree of sound reduction that can be achieved with the sound barrier wall can be determined by a purely geometrical principle (e.g. with the Huygens-Fresnel principle), if the sound reduction of the wall material is sufficiently large (as expected). The degree of sound reduction that can be achieved with sound shielding is calculated by the IMMI software model used in accordance with ISO 9613-2:2005.

The effectiveness of the barrier is dependent on the mass and height of the barrier, and its distance from the noise source and the receiver. To be effective a barrier must block the line of sight between the highest point of a noise source and a barrier must be long and continuous to prevent sounds from passing around the ends. Nevertheless, the flow principle associated with the placement of the barrier wall is that in the case of cooling towers which have air inlets on both sides, the distance between the barrier and the tower must be larger than the height of the air inlet (in case of a cooling tower which only has air inlet on one side, the distance doubles).

The structure of the wall should be chosen so that the sound reduction of the wall structure must be much larger than the expected reduction, because the dimensioning is essentially meant for diffraction and not transmission. The sound absorption and sound insulation requirements for the wall block or wall structure that is used are the following:

- sound absorption at the sound source side is at least $\alpha \geq 0.8$
- the degree of airborne-sound reduction is at least $R_W \geq 25$ dB

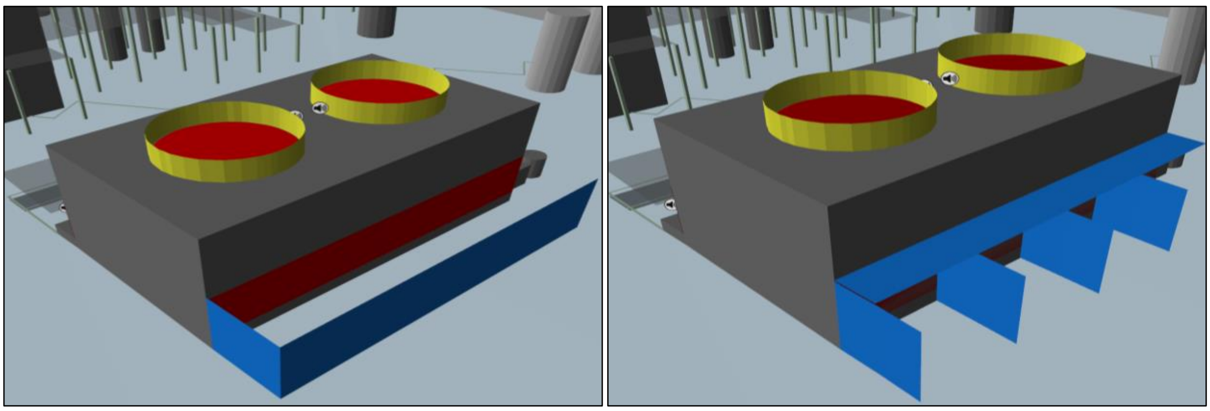

Figure 3 – The design options of the sound barrier wall in the case of this study

The design of the sound barrier wall is basically depends on the area to be protected from noise and on the location of the points of evaluation. In the case of this study, the following options have been offered to place the wall:

- one L-shaped sound barrier wall parallel to the air inlet,
- four sound barrier walls perpendicular to the air inlet.

Sound energy emitted by fans can also be reduced with a sound barrier wall. It would be possible to construct a sound barrier wall on the edge of the cooling tower (which is statically the strongest), but – taking into account the sound power of the fans, the size and location of the noise sources – the required wall height would be so great (at least 7 metres), which is not recommended on the edge of the tower, because of the wind pressure.

Accordingly, the proposed solution is to construct fan stacks suitable height instead of the existing diffusers, or to construct, directly around the existing diffuser, circular (or polygonal) barrier with sound absorbing design on the inner surface, with the required additional support structure. There are currently three options for the implementation:

- pre-fabricated diffuser retrofitted to be sound absorbent (with sound absorbing coating),
- construction of a specially designed fan stack,
- construction of a sound barrier wall directly around the existing diffuser.

6. CONCLUSIONS

The purpose of this presentation was to explore and analyse the possibilities of noise reduction of large open wet cooling towers in a specific case study. There are many primary and secondary solutions to reduce the noise emission of the sources that determine the environmental noise of the cooling tower; however their applications can have technological and cost constraints. In the case study presented, the management of Nitric Acid Plant refused all technical interventions that could change the operation of the cooling tower, because the facility has already operated above the nominal cooling capacity. In such cases, in the case of a noise source of this size, only the possibilities of intervention by propagation remain. Nevertheless, since the cooling tower originally had no waterfall noise reduction installed, it was crucial to reduce the collision noise of the water.

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