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INDUSTRIAL PLANT NOISE MODELLING FROM EARLY PLANNING STAGE TO OPERATION

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ABSTRACT

This paper describes the tuning process of industrial plant noise modelling, from design stage, when acoustic data declared or guaranteed by equipment manufacturer have been acquired, to as built situation, when the plant is in operation. Like for other engineering sectors, modelling of outdoor sound field of industrial plant covers the whole project: at the beginning to set up the environmental impact assessment, during the design to follow the suitability of the supplies and plan mitigation systems, after the plan startup to make available an actual tool useful for controlling the equipment aging, for planning future refurbishments or for the design of further similar plants. Main elements of this work are the noise source list, the contour noise map, and the measured sound levels in field. The operating sequence of the followed methodology entails at first the setup of a detailed list of sound sources, used to obtain a predicted noise map, subsequently the execution of field noise measurements, representing the actual situation, which gives additional information to achieve the final sound sources balancing and as final step the development of the calculated in-plant noise map matching with the measured one, also accounting for design changing occurred during the design.

Keywords: *Industrial Noise, Modelling, Noise Control Design*

1. INTRODUCTION

Noise control design of industrial plants could be carried out according to the directions given by international standard ISO 15664 [1], this method has been widely applied by us for many years with satisfactory results.

The basic procedure foresees an assessment stage, then the noise control design phase and a final verification on field, after the plant startup. In detail, during the assessment, the so-called noise allocation study, the expected sound power levels of noise sources are defined, based on previous experiences, internal databases, vendor data or calculation formulas from bibliography, in absence of the previous ones. In this stage, the compliance with required noise limits is verified and first mitigation measured are individuated, if necessary. Following the noise allocation study, the actual noise control planning is carried out, by means of detail engineering design of measures to be implemented to satisfy the noise requirements, both in the plant area, for hearing protection purposes, and in the environment. In this phase, it is paramount the strict cooperation with equipment manufacturers and the follow up of their supplies. Subsequently, the industrial plant construction, pre-commissioning and commissioning phases take place [2]. Finally, the new erected industrial plant is put in operation and performance tests are carried out to check the compliance with all the guaranteed parameters. Noise tests are often among the latter, and remedial actions are prescribed if some fails. In this paper it is described the software acoustic modelling of an industrial ammonia plant both at the end of the noise control design and after the measurement tests in field. The outcomes of the final noise survey are useful for two reasons: on the one hand they may be kept by end user as a software copy of its own plant on the other they will be used for the design of future similar industrial plants.

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2. BACKGROUND

Software 3D modelling is widely employed in scientific fields, from medical to architecture. As regards the outdoor noise propagation from open air industrial plants, computer models have been developed since second half of last century, for example by CONCAWE [3] and Marsh [4], then Tonin [5] published one of the first software available on the market. Nowadays, both commercial and open-source noise modelling software are available, and they are used to predict the outdoor acoustic field and to select design changes to comply with requirements. With the new millennium there has been an important innovation in the civil construction sector, as the Building Information Modelling (BIM) [6][7] has been introduced. With BIM, among other features, a multidimensional digital copy of a real object is created and allows you follow the whole life of a construction, from design to decommissioning, passing through the modifications that occur throughout its life. The set up of a 3D acoustic model of a running industrial plant based on noise measurement survey to characterize all significant outdoor sound sources represent the application, in a small way, of the BIM philosophy.

3. METHODOLOGY

For the development of the noise control design of an industrial ammonia plant, a 3D acoustic software model has been setup, including noise sources of various shape, ground profile and coverage, buildings, screens and other obstacles to sound propagation. Among them, the most difficult input data to be modelled are the sound power levels of noise sources, which may be affected by large errors, due to distinct reasons. For example, at the beginning of an industrial plant detailed design, several information regarding noise sources is not yet available, therefore the assumption on their emission is generally affected by tolerances up to 7 dB. At the end of the engineering (i.e. completion of equipment purchase), when the mechanical and noise data sheets are finalized by suppliers, the tolerance reduces up to 2-3 dB, as the only modifying factor affecting noise emission could be the assembly of field equipment, including piping and accessories, unless not planned design changes will occur during the plant construction.

3.1 Plant Description

The industrial plant under investigation is a 2200 MTPD (metric tonnes per day) ammonia unit that has been in operation since 2016. The plant covers an area of 220 m by 120 m and the main noise sources are 4 huge compressors driven by steam turbines (2 of them about 20 MW and the other 6 and 2 MW) with annexed piping systems (about 20” to 36” nominal diametre), steam condensers and lubrication oil units. The compressors are located below a metal sheet shelter with side walls extended from the roof up to 12 m above ground, to allow the equipment and underlying piping system to run out of the area. Other significant noise sources are the steam reformer, a large furnace of 71 GCal/h capacity with burners on top, including a 750 kW forced draft fan, for air combustion supply, and a 1.4 MW induced draft fan, to extract exhaust gases and discharge them to stack, both driven by either steam turbine or electric motor. To complete the overview of main sound sources, there are 5 pumps driven by either steam turbine or electric motors above 1 MW. In terms of sound power level, the size of above-described sources is around 115 dBA for each compressor, 110 dBA for the reformer including fans and 105 dBA for each large pump.
A 3D model view of the ammonia plant is shown in Figure 1.

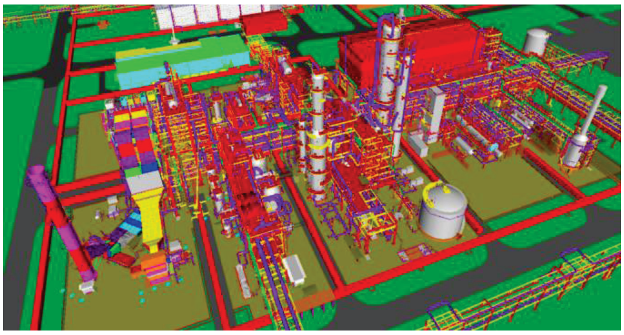

Figure 1. 3D model view of the ammonia plant. From left to right, there are the reformer package, with its stack at the leftmost corner, the large pumps area in the middle and the compressor house behind the plant area on the right.

3.2 Sound levels defined during plant design

At the end of the plant design phase, when noise data from equipment manufacturers or suppliers was available, the list of predicted sound sources was updated with more reliable sound emission values to feed into the acoustic software for the calculation of the noise maps.
The sound power levels of the 54 noise sources defined in this stage are shown in the chart of Figure 6 under para. 4.1, and the calculated noise map with such dataset, by means of commercial software SoundPLAN®, is shown in Figure 2.

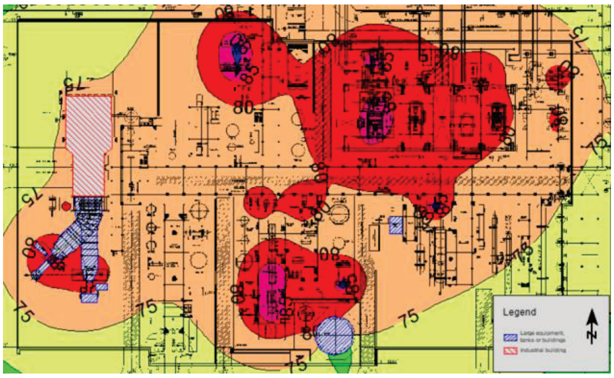

Figure 2. Ammonia plant predicted noise map.

3.3 Sound levels measured during plant operation

The sound levels collected during the survey have been measured at 1.5 m elevation and close to all noise sources with the purpose to define their emission in normal operating conditions. In addition, noise measurements around the whole ammonia plant have been carried out at 4 m elevation, to calculate the overall sound power level by means ISO 8297 standard [8].

The selected measurement points are shown in Figure 3, where the point numbers with 3 digits are relevant to microphone locations near the sources and within the plant area in which first number is the plant unit code, while point numbers with 4 digits are the ones around the whole ammonia plant. In total, 160 measurements have been carried out for equipment sound sources fine-tuning purposes and 34 for the determination of the overall ammonia plant sound power level with ISO 8297.

Figure 3. Ammonia plant measurement points.

The complete set of measured sound levels is shown in the chart of Figure 7 under para. 4.2.

The collected noise data was then inputted into noise modelling software, which interpolated the values and obtained the corresponding contour lines.

The graphic result of the procedure is reported in Figure 4.

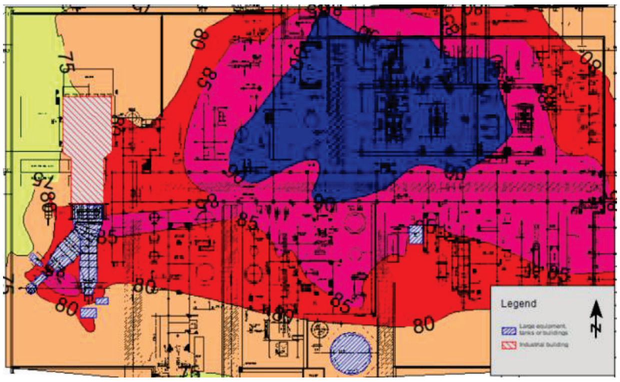

Figure 4. Ammonia plant measured noise map.

During the noise survey, an attempt was made to collect more reliable data for following analyses, however, some noisy steam discharges were unavoidable, increasing the detected sound level detected at some measurement positions. The effects of this disorder are discussed below, in section 4 .

3.4 Sound levels adjusted after measurements

The fine-tuning of the sound power level of sources modelled at the end of the plant design stage was possible as the set of measurement points selected was accurate enough to allow the appropriate adjustments. For example, for each equipment train consisting of a rotating machine and a driver, sound measurements were taken at two or more locations, depending on the size and the variability of the noise emission around it.

The process of sound sources fine tuning has been carried out in different stages, concerning isolated sound sources first, then analysing groups of sound sources and finally the largest items.

The sound power levels of the 58 as built noise sources, 4 have been added to improve the accuracy of the updated acoustic model, are shown in Figure 6 under para. 4.1, and the calculated noise map is shown in Figure 5.

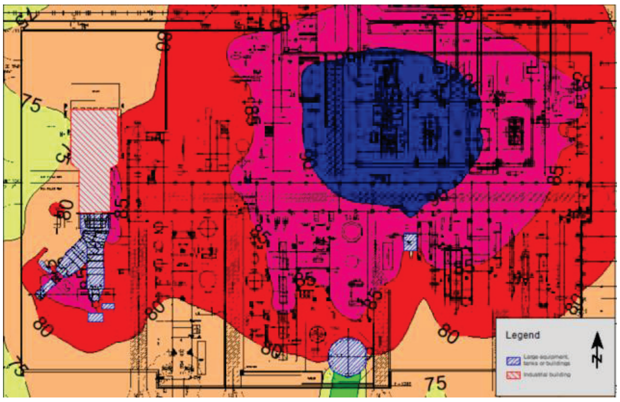

Figure 5. Ammonia plant, as built noise map.

3.5 Ammonia plant sound power level (ISO 8297)

During the noise survey a measurement session was dedicated to collect the data to be used for the determination of overall ammonia plant sound power level according to standard ISO 8297, so as to subsequently compare it with the analytical results obtained by combining the sound power level of the individual sources. The formula, proposed by Stüber, is shown in equation (1):

$$L_W = L_p + 10Log(2S_m + hl) + Log\left(\frac{\bar{d}}{4\sqrt{(S_p)}}\right) + 0.5\alpha\sqrt{(S_m)} \qquad (1)$$

where:
L_w is the total sound power level of enclosed noise sources,
L_p is the energetic average sound pressure level along the measurement contour,
S_m is the area delimited by measurement points,
h is the receiver height above the ground,
l is the contour perimeter,
$\bar{d}$ is the average measurement distance from sources,
S_p is the multisource plant area,
α is the air absorption coefficient.

The application of formula (1) is shown in below The overall ammonia plant sound power level obtained by means the application of ISO 8297 is discussed further in below para. 4.1.
Table 1, where overall and octave band measured L_p and calculated L_W are reported, for $S_m = 23500$ m^2, h = 4 m, l = 630 m, $\bar{d} = 12.4$ m, $S_p = 17000$ m^2 and the air absorption, resulting in 1 dB on the overall value.

The overall ammonia plant sound power level obtained by means the application of ISO 8297 is discussed further in below para. 4.1.

Table 1. Ammonia plant sound power level calculated with ISO 8297 formula.

	OVR (A)	63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
L_p	82	78	76	77	73	75	77	75	74
L_W	128	122	102	121	118	120	122	121	121

4. DISCUSSION

The analysis is covering the sound power level of the noise sources in the ammonia plant and the sound pressure levels predicted, measured and re-calculated with adjusted sound sources in the measurement points.

4.1 Sound power levels of noise sources and of the whole ammonia plant

During the engineering phase, at the end of the noise control design, 54 sound sources were individuated, which overall logarithmic sum gave 120.5 dBA. This result, obtained by combining the sound power level declared by equipment vendors, and in line with the expected values, is useful to size the noise emission of the industrial plant, as a function of both the plant type and the production capacity.
Following the noise survey, the number of sound sources has increased to 58, as 4 new items have been added to improve the acoustic modelling within the plant area.
Specifically, with reference to plant description in para. 3.1, the added sources were:

- The inlet of the forced draft fan which supplies combustion air to the steam reformer, at 8 m elevation,
- A noisy flexible expansion joint found between the air supply duct and the preheater of the steam reformer at 4 m elevation,
- A lubrication oil pump associated to the 2.5 MW water pump at 1.5 m elevation,
- An unexpectedly opened re-circulation valve connected to the main circuit of a 2.5 MW amine with additives solution pump out of service at 1 m elevation.

Besides, 22 sound sources out of the former 54 ones have been adjusted to match the sound pressure levels measured both at measurement points and in the noise map, and the overall logarithmic sum has become 129.7 dBA. The reason of such increase will be analysed further. The statistics of the adjusted sound sources is reported in Table 2.

The sound power level of the two sets of sound sources is shown in the chart of Figure 6.

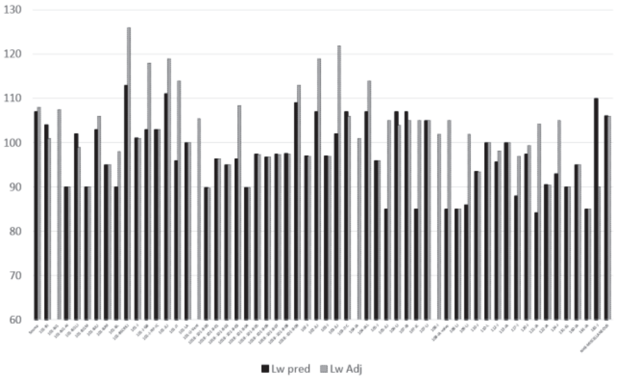

Figure 6. Predicted and adjusted (as built) sources Lw. Overall ammonia plant predicted Lw = 120.5 dBA and adjusted Lw = 129.7 dBA.

Table 2. Statistics of the adjusted sound sources in the ammonia plant: high average and standard deviation due to an important design modification occurred during the plant construction to be recorded.

Parameter	Value
Predicted number of sound sources	54
Final number of sound sources	58
Number of adjusted sound sources	22
Minimum adjustment	-3 dB
Maximum adjustment	20 dB
Average adjustment	6.8 dB
Adjustment standard deviation	7.1 dB
Mode of adjustments	-3 dB

Looking at both Figure 6 and Table 2, some consideration has to be done.

The number of sound sources has increased just to compensate the previous acoustic model with missing noise information from vendors, for the inlet air opening, the joint and the lubrication unit pump, and an abnormal operation condition, in the case of the opened valve. This slight modification is compatible with the plant design process, then not to be discussed further.

Although the most recurring adjustment is -3 dB, the average adjustment is high due to a design change that took place during the plant erection, agreed with final user, but not implemented in the acoustic model, as it was finalized only for design reporting needs. This change was not to install the planned acoustic insulation on the whole piping system and the connected equipment part of the huge compressor assemblies, even though the relevant rotating machines were all soundproofed with noise hoods or acoustic insulations. As a matter of fact, the largest adjustments on the sound power levels are concentrated on the compressors area.

Besides, during the noise survey, some measuring point have been influenced by the noise of a pair of unstoppable steam jets above the compressor house, as anticipated at the end of para. 3.3. This effect has been counteracted, but not eliminated, by including some “extra” noise source nearby the sound sources affected, in a way, by such steam discharges. It was not possible to clearly locate and acoustically characterise the two steam jets, for several reasons: timing of the activities, high elevation from ground, presence of numerous piping systems above the measuring points which were unevenly shielded and difficult to be modelled with the software. The steam jet noise was detected on the east and the south-east part of the ammonia plant up to the boundary.

Nevertheless, considering that the sound level distribution in the plant area complied with the contractual requirements, despite these two abnormal noise sources being in operation, no further investigation was carried out.

Regarding the ammonia plant overall sound power level, Table 3 shows the results of the logarithmic sum of the sound sources, both predicted and adjusted, along with the application of ISO 8297 formula.

Table 3. Ammonia plant sound power level.

Sound power level determination	Lw [dBA]
Sum of the predicted sound sources	120.5
Sum of the as built sound sources	129.7
Application of ISO 8297	128.0

Looking at Table 3, it is confirmed the above observation on the effect of design change not to install the sound insulation on compressors piping systems and related equipment, which leads to an increase of the as built overall sound power level by 9 dB over the predicted one.

Furthermore, some not quantifiable effect due to the noisy steam jets should be accounted, but less impacting than the sound levels increase due to the missing acoustic insulation on the compressor piping systems.

Concerning the sound power level of the ammonia plant calculated with ISO 8297 formula, it is around 2 dB lower than the resulting one from the sum of the as built sound sources. This reduction is generally due to the fact that the rough sum of single noise sources gives a "size" of an industrial complex, whereas the value determined with ISO 8297 procedure, includes also the source casing reciprocal reflections, shielding, absorbing and scattering effects, combined with those owing to piping systems, structures and other equipment present in the plant area.

4.2 Sound pressure levels at measurement point location in the ammonia plant and on its boundary

The sound pressure levels at measurement point locations, both calculated before and after the sound source adjustments and measured in field, are shown in the graph of Figure 7 and the statistical analysis in Table 4.

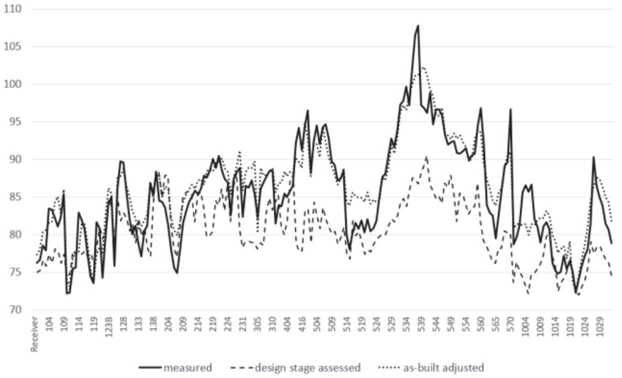

Figure 7. Assessed, measured and calculated with adjusted (as built) sources Lp at measurement points, for numbering system see para. 3.3.

Table 4. Statistics of the differences among assessed (A), measured (M) and calculated (F) with adjusted (as built) sources Lp for the 194 measurement points.

Parameter	M-A	M-F	A-F
Minimum	-6.6dB	-5.8dB	-14.4dB
Maximum	21 dB	6.6 dB	2.6 dB
Average	4.9 dB	-0.9 dB	-5.8 dB
standard deviation	5.2 dB	2.4 dB	4 dB
Mode	4.2 dB	-1 dB	-1.9 dB

Looking at Figure 7, by analysing the sound pressure level gaps at measurement points according to plant areas, it can be noted that for areas 100 and 200, the furthest from the compressors area (500), predicted and as built values are not much different, whereas for areas 300 and 400, close to compressors area, this difference is higher. For measurement pints around the ammonia plant, "1000" series, the difference is rather high. The reason of that is the very high difference between predicted and measured sound pressure levels in area 500, compressors, for the missing soundproofing measures as described in para. 4.1.

The same considerations can be drawn from the overall plant data in Table 4 (column "M-A"), which states that, after the sound sources adjustment process, the sound level differences are reduced to less than 1 dB and the standard deviation is less than 3 dB (see column "M-F") which it was deemed a satisfactory result.

5. CONCLUSION

The adoption of an acoustic model of an industrial plant is useful during the whole design process, since earliest stages, when noise studies for authorization purposes are conducted. Subsequently, the noise control design technical solutions and the updated noise data from equipment suppliers are used to update progressively the acoustic model for which the expected sound levels distribution is predicted before the plant startup. After the plant construction, once the plant is in operation, the acoustic model may be tuned, to get a final "as built" acoustic likely to be used for controlling the equipment aging, planning plant modifications or design further similar plants. In case of design changes took place during the plant mechanical erection, the tuning of the acoustic model could be more substantial on the equipment or piping systems that have been affected by the modifications.

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