Comparing acoustic models with measured noise sources in complex industrial plants – Ammonia production units

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Industrial plant noise control design is currently supported by acoustic modelling. The process of fine-tuning this modelling allows for a progressive check of the overall noise control design plan, from design stage, when acoustic data declared or guaranteed by equipment manufacturer have been acquired and noise reduction systems have been planned, to as built situation, when the plant is in operation. Like for other engineering sectors, modelling of outdoor sound field of industrial plants 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 plant 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. In detail, after the setup of a sound sources list, used to obtain a preliminary noise model, the execution of field noise measurements, representing the actual situation, 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.
Keywords: industrial noise, sound sources modelling, sound source measurements, noise control design, measured versus modelled data fitting, auxiliary boiler noise

Confronto tra modelli acustici e sorgenti di rumore misurate in impianti industriali complessi – Unità di produzione ammoniaca

La progettazione del controllo del rumore degli impianti industriali è attualmente supportata dalla modellazione acustica. Il processo di messa a punto di questa modellazione consente una verifica progressiva del piano di progettazione del controllo del rumore complessivo, dalla fase di progettazione, quando sono stati acquisiti i dati acustici dichiarati o garantiti dal costruttore dell'apparecchiatura e sono stati progettati i sistemi di riduzione del rumore, allo stato di fatto, quando l'impianto è in esercizio. Come per altri settori dell'ingegneria, la modellazione del campo sonoro esterno degli impianti industriali copre l'intero progetto: all'inizio per impostare la valutazione di impatto ambientale, durante la progettazione per seguire l'idoneità delle forniture e pianificare i sistemi di mitigazione, dopo l'avviamento dell'impianto per mettere a disposizione un vero e proprio strumento utile al controllo dell'invecchiamento delle apparecchiature, per la pianificazione di future ristrutturazioni o per la progettazione di ulteriori impianti simili. In dettaglio, dopo la messa a punto di un elenco di sorgenti sonore, utilizzato per ottenere un modello preliminare del rumore, l'esecuzione di misure di rumore di campo, rappresentative della situazione reale, fornisce ulteriori informazioni per ottenere il bilanciamento finale delle sorgenti sonore e, come passo finale, lo sviluppo della mappa di rumore calcolata all'interno dell'impianto che corrisponde a quella misurata.
Parole chiave: rumore industriale, modellazione di sorgenti sonore, misura di sorgenti sonore, progettazione del controllo del rumore, adattamento dei dati misurati e modellati, rumore della caldaia ausiliaria

1 | Introduction

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

The basic procedure includes 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 [2-4], 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 [5]. 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.

Within the frame of this activity, the emission of individual sound sources has been estimated from a measurement dataset collected in the vicinity of a group of them by applying the Least Square method. This procedure, applicable when the number of measurement points is equal or higher than the number of unknown sound sources, has been implemented in commercial software SoundPLAN®, since version 7.4 issued in 2015 [6]. On the purpose, it is also investigated the possibility to determine the frequency band acoustic emission of single sources, part of an industrial auxiliary boiler packaged supply, from measured data around it, by means of such SoundPLAN® tool.

The software acoustic modelling of the whole ammonia plant and the auxiliary boiler package serving it, including the following activities for the best fitting with the actual sound levels distribution in field, is here reported. In section 2 | the work procedure is depicted, including theoretical basis, a description of the analysed objects, the setup of the preliminary acoustical models, the noise measurements and the subsequent adjustment to get the as built acoustical models. Then, section 3 | provides the outcomes of present study and section 4 | shows the related remarks and discussions.

2 | Materials and methods

2.1 | 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 [7] and Marsh [8], then Tonin [9] published one of the first software available on the market; some more detail on propagation models and software are in Bérengier [10] et al. and Sonaviya and Tandel [11]. Nowadays, both commercial (e.g. CadnaA, IMMI, Olive Tree Lab Terrain, SoundPLAN), and open-source (e.g. i-Simpa, dBmap, code_Tympan) noise modelling software are available, and they are used to predict the outdoor acoustic field and to select design changes to comply with requirements.

When defining such a 3D acoustic model, inverse methods such as Least Squares can be applied to determine the sound power levels of a subset of sound sources of the entire industrial plant, using noise measurements.

Least Squares method is a standard approach to approximately solve equations systems in which there are more equations than unknowns by minimizing the sum of the squared residuals in the results of each equation. This method is widely used for data fitting problems allowing to apply regression analysis to balance as much as possible the data sets. Referred examples of sound power level determination from measured sound pressure levels are the technique described by Lu and Hong [12], then applied by Chandha in workshops [13], both directed to investigate workplaces where many noise sources are operating; for completeness, application of inverse methods to obtain the acoustic power of noise sources in factories are the works published by Luzzato and Lecointre [14], Guasch et al. [15] and Cirac et al. [16].

Once implemented, SoundPLAN® tool to calculate the sound power level of unknown sources from measured data has been first tested by software developers and distributors on individual running equipment, subsequently endorsed by software's users, as no issues have been recorded yet.

2.2 | The ammonia plant under investigation

The industrial plant under investigation is a 2200 MTPD (metric tonnes per day) ammonia unit that has been in operation since 2016 and a 3D model view is shown in Fig. 1. The plant covers an area of 220 m by 120 m and the main noise sources are 4 huge compressors, one bull-gear type inside a noise hood and 3 centrifugal ones with acoustic insulation, driven by steam turbines with acoustic insulation (2 of them about 20 MW and the other 6 and 2 MW) with annexed piping systems (about 20" to 36" nominal diameter), 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 with acoustic insulation and driven by either steam turbine with acoustic insulation or electric motor.

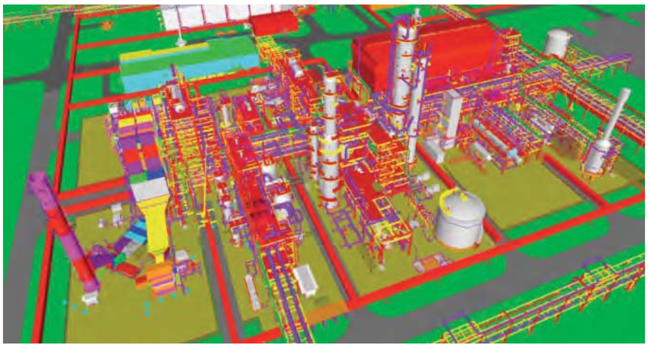

Fig. 1 – 3D model view of the ammonia plant. From left to right, there are the reformer package with its stack at the leftmost corner, the large pumps area in the middle and the compressor house behind the plant area on the right
Vista dal modello 3D dell'impianto ammoniaca. Da sinistra a destra, ci sono il gruppo del reformer con il suo camino nell'angolo a sinistra, l'area delle pompe grandi al centro e la sala compressori dietro l'area d'impianto a destra

To complete the overview of main sound sources of the ammonia plant, there are 5 pumps with acoustic blanket driven by either steam turbine with acoustic insulation or electric motors above 1 MW. In terms of sound power level, the size of above-described sources running at full load is around 115 dBA for each compressor, 110 dBA for the reformer including fans and 105 dBA for each large pump.

Along with the ammonia plant, also an auxiliary boiler packaged unit running at full load has been investigated. The auxiliary boiler has a capacity of 100 t/h steam production and the envelope dimensions are approximately 14 m by 18 m, and 8 m height, with a 25 m height stack on west side of the package footprint, as shown in Fig. 2 3D views.

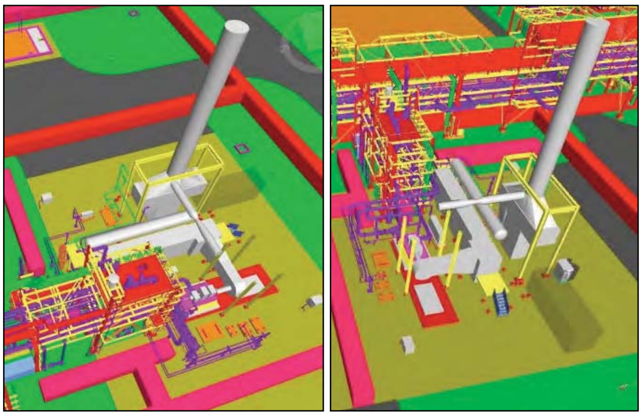

Fig. 2 – 3D model views of the auxiliary boiler package
Viste dal modello 3D del package caldaia ausiliaria

In detail, the main components of the auxiliary boiler package are a forced draft fan of 670 kW, 1780 RPM, with casing acoustic insulation, its outdoor air inlet, a natural draft burner with annexed combustion chamber, a superheater, an economizer and a steam drum, as shown in Fig. 3. The body and the outlet of flue gas stack are not considered as noise sources since the sound waves have already lost their energy passing through the previous equipment, besides they are located at higher elevation than the measurements and the calculation points.

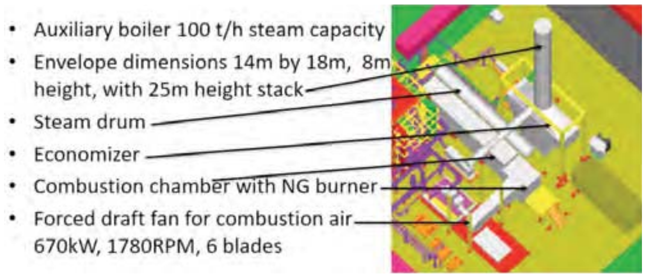

Fig. 3 – Auxiliary boiler package components
Componenti del package caldaia ausiliaria

For purely information purposes, Fig. 4 shows an overall satellite view of the ammonia plant and auxiliary boiler package under study. The auxiliary boiler package is part of the associated utilities of the ammonia plant, which includes, apart from two auxiliary boilers, also a cooling tower system, an air production unit and other facilities.

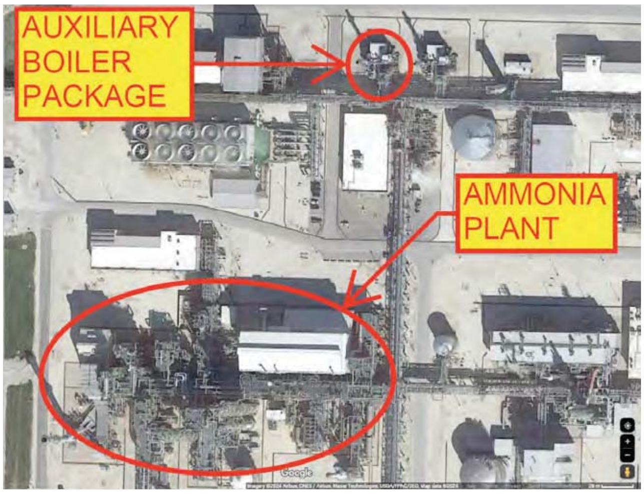

Fig. 4 – Satellite view showing the location of the ammonia plant and the auxiliary boiler package, as part of the utilities
Vista satellitare che mostra l'ubicazione dell'impianto ammoniaca e del package caldaia ausiliaria, nell'ambito delle utenze

2.3 | Sound sources emission and acoustic model defined during plant design

The design of noise control measures in industrial open plants is carried out by determining the noise limits for the environment and the work area to comply with, then by issuing a project specification that establishes the overall plant and the sources sound emissions that are allowed. The following step is the preparation of a list of plant noise sources, i.e. equipment, machinery, atmospheric discharges, etc. in which all items are described and, mainly, coded with a common tag valid for the whole project, so that all relevant information can be uniquely recovered from the (huge) design documentation. Such list, completed with the individual equipment items sound power level derived at first from previous experiences, internal databases or literature, represents the noise allocation, the core of the whole noise control design. The noise allocation table is not here reported, but an example with some typical record for the ammonia plant project is here below presented and analysed in Tab. 1:

Tab. 1 – Example of some entries of the noise allocation table
Esempio di alcune voci della tabella di assegnazione del rumore

Item Tag	*Description*	*Power [kW]*	*Lw [dBA]*
101-IDF	Induced Draft Fan	1.400	107
101-IDF-M	Motor for 101-IDF	1.400	103
104-HPBFP	HP Boiler Feed Pump	2.500	107
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The noise allocation also contains information regarding the planned noise control measures to be required to equipment supplier, like noise hoods, or to be installed during the plant construction, like piping sound insulations. During the engineering development, the noise allocation is progressively updated following the design modifications and the information received from suppliers; at the same time, the acoustic data inputted into the acoustic model are updated accordingly.

At the end of the plant design phase, when noise data from equipment manufacturers or suppliers were 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 predicted in this stage are shown in Fig. 25 chart, para 4.1 |.

The acoustic model, developed with the commercial software SoundPLAN®, is shown in Fig. 17, under para. 3.5 |. All sound sources have been assumed omni-directional and directivity effects, where significant, have been simulated with the insertion of screening walls.

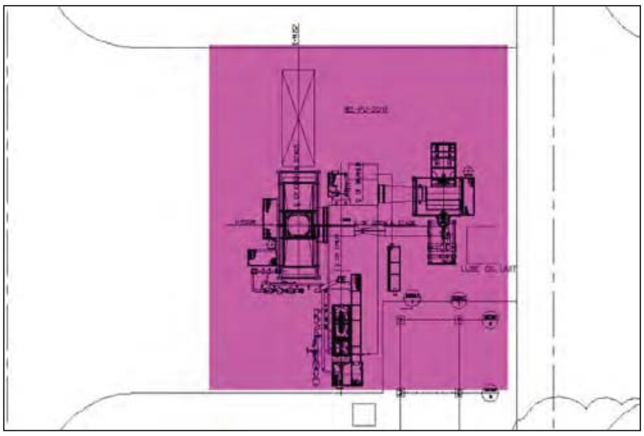

Fig. 5 – Auxiliary boiler package acoustic model at design stage; area source with a predicted sound power level (Lw) of 105 dBA
Modello acustico del package caldaia ausiliaria in fase progettuale; sorgente areale con livello di potenza sonora (Lw) stimato di 105 dBA

Regarding the auxiliary boiler package, during the design stage no information about the noise emission have been received from supplier, therefore it has been kept the allocated sound power level of 105 dBA, derived from literature [4] and based on boiler capacity and it has been modelled with an area source 25 m by 29 m, enclosing the entire package, at 2.5 m elevation above ground as shown in Fig. 5.

2.4 | Sound levels field measurements 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 [17].

The selected measurement points are shown in Fig. 6, 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, with linear time averaging and a duration of 60 s, until the sound level steadiness.

Fig. 6 – Ammonia plant measurement points
Punti di misura dell'impianto ammoniaca

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 analysed and discussed below, in para. 4.1.

For the auxiliary boiler package, only measurements to apply standard ISO 8297 was carried out. The set of measuring points along a contour path enclosing the group of sound sources of the auxiliary boiler package is shown in Fig. 7.

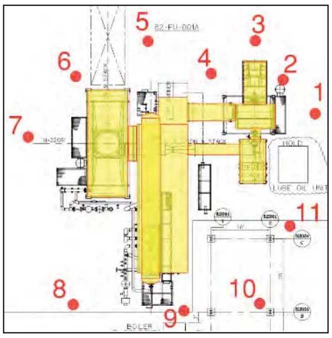

Fig. 7 – Auxiliary boiler package measurement points. Equipment casings are highlighted

Punti di misura del package caldaia ausiliaria. Sono evidenziati gli involucri delle apparecchiature

2.5 | Determination of the ammonia plant sound power level by means of ISO 8297 formula

During the noise survey a measurement session was dedicated to collect the octave band data to be used for the determination of overall ammonia plant sound power level according to standard ISO 8297, to subsequently compare it with the analytical results obtained by combining the sound power level of the individual sources. It is worth to remind that ISO 8297 formula may be applied for many different purposes, including the check of the compliance with environmental noise requirements of entire industrial complex [18]. The formula, formerly proposed by Stüber, is shown in Eq. (1):

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

where:
L_w is the total sound power level of enclosed sources [dB],
L_p is the energetic average sound pressure level along the measurement contour [dB],
S_m is the area delimited by measurement points [m^2],
h is the receiver height above the ground [m],
l is the contour perimeter [m],
$\bar{d}$ is the average measurement distance from sources [m],
S_p is the multisource plant area [m^2],
α is the air absorption coefficient [–].

An analogous noise measurement session has been carried out for the calculation of the auxiliary boiler package sound power level with standard ISO 8297.

2.6 | Ammonia plant sound sources adjustment 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 adjustments in the acoustic model have concerned not only the sound sources, in terms of emission and location, but also the components affecting the sound propagation, like screening elements and significant equipment casings or ducts. The piping systems, typical in industrial installations, have not been included in the modelling because not much dense up to 6 metres above ground level and most sound sources are below such elevation, therefore the measurements at 1.5 metres elevation were not influenced by the miscellaneous volume acoustic absorption mentioned in Annex A of ISO 9613-2 [19].

The analyses to adjust the elements in the acoustic model was carried out on the measuring point and not on the grid noise map.

Due to the large number of sound sources, i.e. the independent variables, and of the measured data, the progressive tuning of the sound power levels and other elements in the acoustic model was sequentially performed in small portions of the plant area, then combined.

At first, the acoustic model has been completely revised by including shielding equipment casings and ducts, modelled as volumes, and the compressor shelter which was not present in the one set-up during the design stage. Then, by means of a deep comparison of the sound levels measured versus calculated ones, isolated sound sources have been adjusted or added for each separate ammonia plant area, namely “purification”, “desulfuration” and “methanation”, focusing first in measuring point far from their boundary, to avoid the noise contribution from the sources out of the areas under investigation. Subsequently, the balanced tuning of the noise sources superimposed in the adjacent zone of the three mentioned plant areas has been extracted. So far, the adjustment process was rather simple, as the sound sources were spread, and no shielding effects have been observed. But for the remaining two plan areas, the “reformer” and the “compressors” the situation was more complex, due to the presence of many acoustic components heavily modifying the sound propagation, like large equipment casing, concrete slabs bearing heavy and noisy compressors along with the compressor shelter, responsible of a significant reverberant field, even though opened in its lower part.

In detail, for the “reformer” area, the most tricky zone was the one where the forced and induced draft fans with ancillary equipment are located, in which fans and driver cases, ducting and the stack (see left-bottom part of Fig. 17, para. 3.5 |, and Fig. 1) generate an intricate sound level field. Here, the simple adjustment of the sound power level of sources without introducing the screening effect of the equipment was not satisfactory. The sound power level balance of concerned sources has then been carried out in two steps, by including either shielding volumes or screens to account for the equipment casings and the best fitting has been obtained by using the screens. A further attempted method to determine the sound power level of the sources grouped in the "reformer" area, without progressively calibrating the emission levels one by one, was performed trying to apply the square matrix inversion, but the essayed combinations of source/receivers have always led to non-converging results, therefore this path has been abandoned, then the results previously obtained with the screens modelling and manual adjustments have been kept.

In a subsequent step, another study has been conducted on the forced and induced draft fan systems of "reformer" area by applying the software tool already applied for the auxiliary boiler package (see para. 2.7), to determine the source sound power level from measured sound level in adjacent points. For this purpose, two main configurations have been tested, with and without the screening effect of fans and motors casings; both were satisfactory, but the one with the acoustic screens looked to be more consistent with the measured data in field, therefore has been retained. The equipment layout inputted in the acoustic model is shown in Fig. 8.

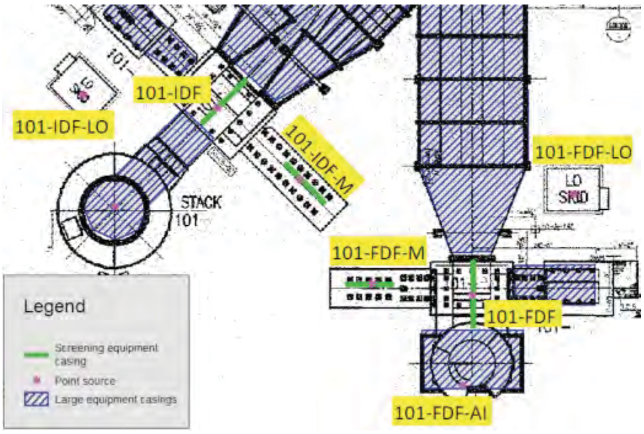

Fig. 8 – Modelled sound sources in the "reformer" area of ammonia plant for subsequent application of the SoundPLAN® tool

Sorgenti sonore modellate nell'area "reformer" dell'impianto ammoniaca la successiva applicazione della funzione di SoundPLAN®

The "reformer" area sound sources modelled for the calculation are reported in Tab. 2.

Tab. 2 – Ammonia plant "reformer" area noise sources

Sorgenti di rumore dell'area "reformer" dell'impianto ammoniaca

Name	*Description*	*Type*
101-IDF	Induced Draft Fan	Point
101-FDF	Forced Draft Fan	Point
101-FDF-AI	Forced Draft Fan Air Inlet	Point
101-FDF-LO	Forced Draft Fan Lube Oil Skid	Point
101-FDF-M	Forced Draft Fan Motor	Point
101-IDF-LO	Induced Draft Fan Lube Oil Skid	Point
101-IDF-M	Induced Draft Fan Motor	Point

For the "compressor" area, large sound sources are located at three different levels; at 15 metres above ground there are four compressor trains driven by steam turbines, at 9 metres above ground the steam turbine condensers, at ground level the compressors lubrication units and, below the compressors up to the ground floor, the relevant connected piping system. In this area, apart from the screens simulating the compressor and turbine casings, to account for their reciprocal screening effect, in the acoustic model have been inputted horizontal screens, representing the concrete slabs bearing the heavy equipment, and the machinery shelter, as a horizontal screen (the roof) at 29 metres above ground, with side panelling up to 12 metres above ground. Since the measuring points in this area are located both at ground floor and at compressors' basements level, the adjustment of sound pressure levels was carried out at upper level first, where it was confused by the superimposed reverberant field caused by the shelter in metal sheet. At the end of the "compressor" area sources sound power levels adjustment, the nearby sources of other adjacent areas have been reviewed and, where necessary further corrected to make the calculated sound levels matching with the measured ones.

For the definition of the sound power level of the single components of the auxiliary boiler package, a further method has been applied, as described in next para. 2.7.

2.7 | Determination of single source sound power levels of the auxiliary boiler package components

During the design stage the auxiliary boiler package was considered as a complete sound source, due to lack of information from the equipment supplier, to simplify the whole industrial plant modelling process too. After the noise survey in field, it was possible to accurately define the single noisy components of the package and, to calculate the sound power level of them, the implemented tool exploiting the Least Square Method included in commercial software SoundPLAN® has been used.

For the application of the tool, an acoustic modelling of the package elements has been carried out first, by means of point sources for relatively small items, line sources for long items, area sources for large items and vertical barriers to account for the screening effect by large equipment casings, to avoid unrealistic sound contribution on calculation points. After trials, the most approaching set of sources and screens has been found. Fig. 9 shows the final acoustic model top view.

The selection of noise sources to be modelled was based on experiences from present and previous field investigations and further adjustments have been applied for best fitting of results. Tab. 3 lists the modelled noise sources in detail.

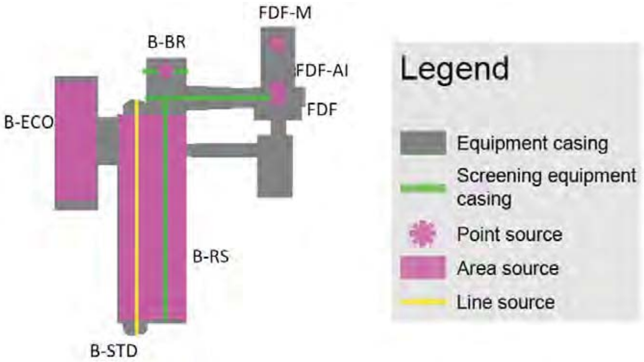

Fig. 9 – Auxiliary boiler package components modelled in the acoustic software

Componenti del package caldaia ausiliaria modellati nel software acustico

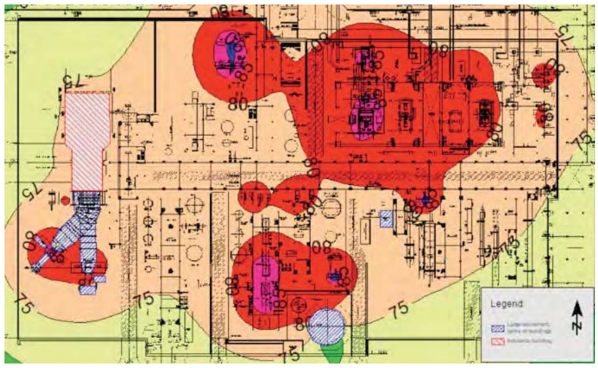

Fig. 10 – Ammonia plant predicted noise map

Mappa del rumore previsionale dell'impianto ammoniaca

Tab. 3 – Auxiliary boiler package noise sources

Sorgenti di rumore del package caldaia ausiliaria

Name	*Description*	*Type*
B-RS	Boiler Radiant Section	Area
B-BR	Boiler natural draft burner	Point
B-STD	Boiler steam drum	Line
B-ECO	Boiler economizer	Area
FDF-AI	Forced draft fan air inlet	Point
FDF	Forced draft fan	Point
FDF-M	Forced draft fan motor	Point

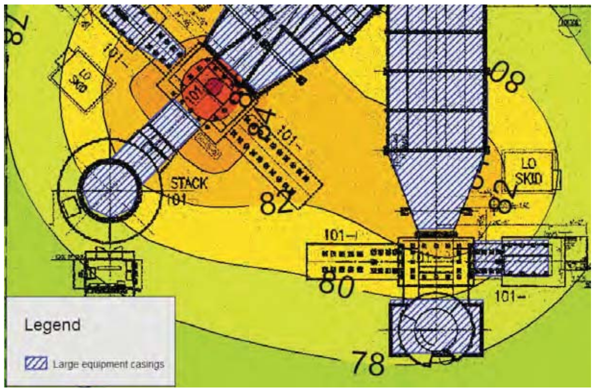

Fig. 11 – Enlargement of the ammonia plant predicted noise map on the induced and draft fans of "reformer" area

Ingrandimento della mappa del rumore previsionale dell'impianto ammoniaca sui ventilatori a tiraggio indotto e forzato dell'area "reformer"

Subsequently, the octave band noise measured values have been inputted as known data at receiver points of Fig. 7, then the calculation of source emission from measurement points function was activated and the sound power levels of the set of modelled noise sources has been obtained as result.

3 | Results

The application of the procedures described in previous section on input data has led to the outcomes presented in the following paragraphs.

3.1 | Predicted sound level distribution during plant design

The set of sound power levels of the 54 sources allocated during the design stage (see Fig. 25, para 4.1) has been used for the calculation of the plant noise map shown in Fig. 10.

An enlargement of the induced and draft fans "reformer" area of the ammonia plant predicted noise map is reported in Fig. 11.

After the noise survey with ammonia plant in operation, the same measurement points (see Fig. 6) have been inputted in the acoustic software for the calculation of single point sound levels to be compared with both the measured ones and those recalculated with the adjusted sound sources.

The graph of the assessed sound levels at design stage is shown in Fig. 28 in para. 4.2.

As regards the auxiliary boiler package, the sound power level of the enveloping area source allocated during the design stage (see Fig. 5) has been used for the calculation of the noise map shown in Fig. 12.

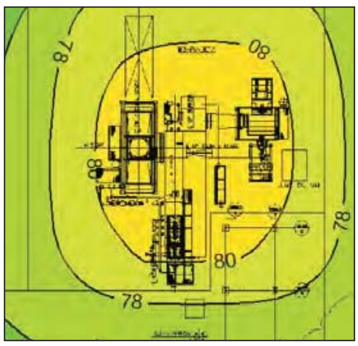

Fig. 12 – Auxiliary boiler package predicted noise map

Mappa del rumore previsionale del package caldaia ausiliaria

Another calculation has been carried out to get the assessed sound levels at the measurement points where the noise data have been collected during the unit in operation (see Fig. 7); the result is shown in the graph of Fig. 13. Discussion on this calculation is given in para. 4.3.

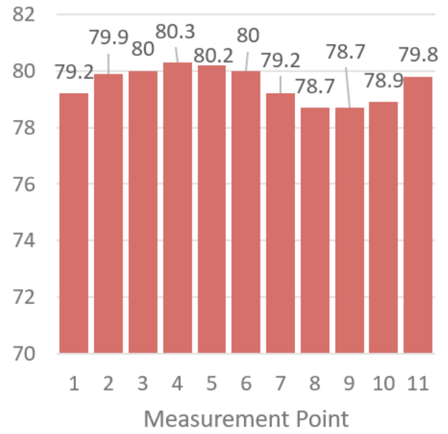

Fig. 13 – Assessed sound levels in dBA during design phase at measurement points around the auxiliary boiler

Livelli sonori in dBA valutati durante la fase di progettazione nei punti di misura attorno la caldaia ausiliaria

3.2 | Sound levels measured during plant operation

The complete set of measured sound levels on the ammonia plant is shown in the chart of Fig. 28 in para. 4.2.

The collected noise data were 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 Fig. 14.

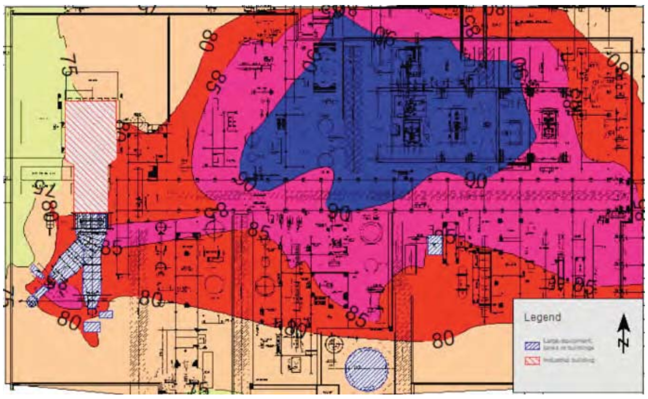

Fig. 14 – Ammonia plant measured noise map

Mappa del rumore misurato dell'impianto ammoniaca

The enlargement of the induced and draft fans "reformer" area of the ammonia plant measured noise map is reported in Fig. 15.

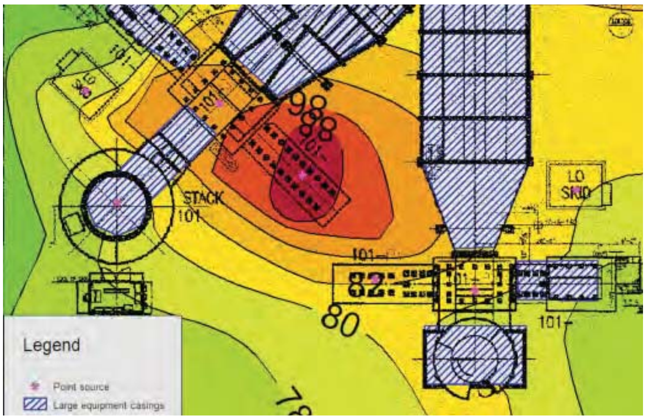

Fig. 15 – Enlargement of the ammonia plant measured noise map on the induced and draft fans of "reformer" area

Ingrandimento della mappa del rumore misurato dell'impianto ammoniaca sui ventilatori a tiraggio indotto e forzato dell'area "reformer"

The sound levels measured around the auxiliary boiler package are shown in Fig. 16.

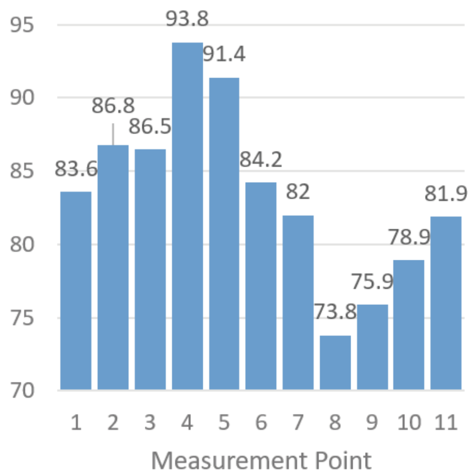

Fig. 16 – Sound levels in dBA measured around the auxiliary boiler

Livelli sonori in dBA misurati attorno la caldaia ausiliaria

The noise contour map obtained by inputting the collected noise data into the noise modelling software, is shown in Fig. 34 (a) under para. 4.4.

3.3 | Ammonia plant sound power level obtained with ISO 8297

For the determination of the complete ammonia plant sound power level, the formula given in ISO 8297 has been used.

The application of formula (1) is shown in Tab. 4, where overall and octave band measured L_p and calculated L_W are reported, for S_m = 23500 m², h = 4 m, l = 630 m, $\bar{d}$ = 12.4 m, S_p = 17000 m² and the air absorption, resulting in 1 dB on the overall value.

Tab. 4 – Ammonia plant octave band sound power level in dB calculated with ISO 8297 formula

Livello di potenza sonora in bande di ottava in dB dell'impianto ammoniaca calcolato con la formula della ISO 8297

	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

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

3.4 | Auxiliary boiler sound power level obtained with ISO 8297

The result of the calculation carried out with formula (1) for the auxiliary boiler package is reported in Tab. 5, in which overall and octave band measured L_p and calculated L_W are presented for S_m = 410 m², h = 1.5 m, l = 78 m, $\bar{d}$ = 3.9 m, S_p = 144 m² the contribution for air absorption is negligible, due to the short distances.

Tab. 5 – Auxiliary boiler octave band sound power level in dB calculated with ISO 8297 formula.

Livello di potenza sonora in bande di ottava in dB della caldaia ausiliaria calcolato con la formula della ISO 8297

	OVR (A)	63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
L_p	87	89	82	84	77	73	78	84	76
L_w	115	116	109	111	104	100	106	112	103

The results of the average sound pressure level and the sound power level obtained for the auxiliary boiler package by applying the ISO 8297 formula are discussed also in below para. 4.3.

3.5 | Adjusted ammonia plant source sound power levels, recalculated sound levels at measurement points and on a noise map

The sound power levels of 58 as built noise sources of the ammonia plant (4 were added to improve the accuracy of the updated acoustic model) are shown in Fig. 25, para 4.1 |.

Specifically, with reference to plant description in para. 2.2 |, 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.

The additional sources were included for different reasons; in the cases of the inlet air opening, the joint and the lubrication unit pump to compensate the previous acoustic model with missing noise information from vendors, and, in the case of the opened valve, for unexpected operation condition.

Following to the noise source adjustment activity, the acoustic model has been revised by changing the sources sound power level and adding the 4 additional sources as well, which location in the actual as built ammonia plant is highlighted in Fig. 17.

Fig. 17 – Ammonia plant as built acoustic model: sources at design stage are fuchsia, 4 added sources are marked in green

Modello acustico dell'impianto ammoniaca nello stato di fatto; le sorgenti in fase progettuale sono fucsia, le 4 sorgenti aggiunte sono indicate in verde

The sound levels resulting from the calculation in the measurement points (see Fig. 6) by using the adjusted sound power levels for the updated noise sources in the acoustic model, are represented in the graph in Fig. 28 in para. 4.2 |.

The noise map calculated with the adjusted set of noise sources is shown in Fig. 18.

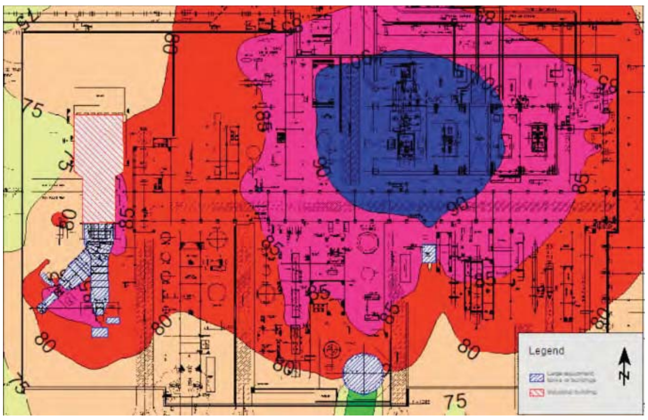

Fig. 18 – Ammonia plant as built calculated noise map

Mappa del rumore calcolata dell'impianto ammoniaca nello stato di fatto

The enlargement of the induced and draft fans "reformer" area of the ammonia plant noise map calculated with the adjusted set of noise sources is reported in Fig. 19.

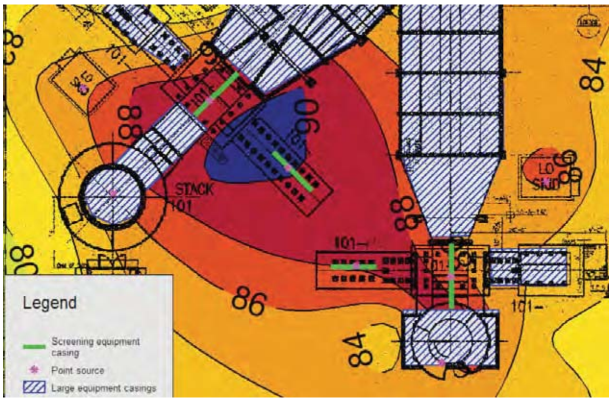

Fig. 19 – Enlargement of the ammonia plant as built calculated noise map on the induced and draft fans of "reformer" area

Ingrandimento della mappa del rumore calcolata dell'impianto ammoniaca nello stato di fatto sui ventilatori a tiraggio indotto e forzato dell'area "reformer"

The post-processing analysis, conducted on the forced and induced draft fan systems of "reformer" area with the SoundPLAN® tool to retrieve the source sound power level from measured data, has given the results shown in Tab. 6.

Tab. 6 – Ammonia plant "reformer" area sources sound power levels in dBA obtained with SoundPLAN® tool

Livelli di potenza sonora in dBA delle sorgenti dell'area "reformer" dell'impianto ammoniaca ottenuti con la funzione di SoundPLAN®

Name	*Description*	*Lw*
101-IDF	Induced Draft Fan	105
101-FDF	Forced Draft Fan	107
101-FDF-AI	Forced Draft Fan Air Inlet	100
101-FDF-LO	Forced Draft Fan Lube Oil Skid	91
101-FDF-M	Forced Draft Fan Motor	90
101-IDF-LO	Induced Draft Fan Lube Oil Skid	91
101-IDF-M	Induced Draft Fan Motor	108

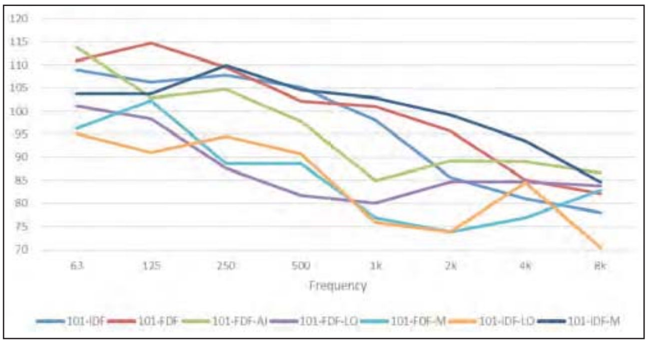

Fig. 20 – Ammonia plant "reformer" area sound power level spectra in dB of sources obtained with SoundPLAN® tool

Spettro del livello di potenza sonora in dB delle sorgenti dell'area "reformer" dell'impianto ammoniaca ottenuti con la funzione di SoundPLAN®

Since the SoundPLAN® tool applies the least square method operating on each octave band, the sound power level spectra for the ammonia plant "reformer" area sources of Fig. 20 have been found.

By inputting the noise source sound power level set of Tab. 6 in the acoustic model, the sound pressure levels calculated at measurement points shown in Fig. 21, and the relevant noise map is reported Fig. 22 have been obtained.

Fig. 21 – Calculated sound levels in dBA by means of the sources obtained with SoundPLAN® tool at measurement points near the induced and draft fans of "reformer" area

Livelli sonori in dBA calcolati nei punti di misura presso i ventilatori a tiraggio indotto e forzato dell'area "reformer" mediante le sorgenti ottenute con la funzione di SoundPLAN®

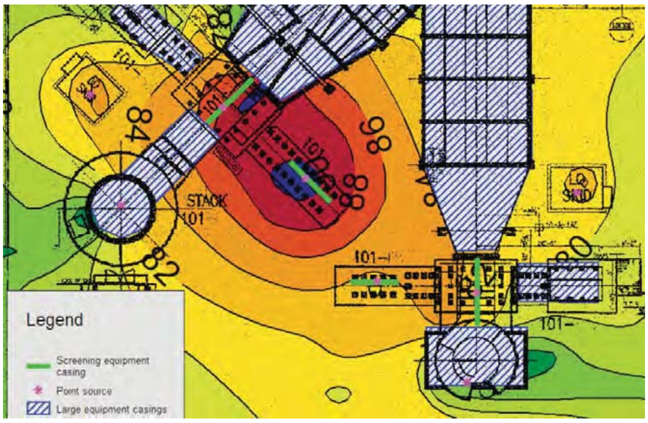

Fig. 22 – Noise map at the induced and draft fans of "reformer"area calculated with the sources obtained with SoundPLAN® tool

Mappa del rumore presso i ventilatori a tiraggio indotto e forzato dell'area "reformer" calcolata con le sorgenti ottenute con la funzione di SoundPLAN®

Auxiliary boiler package determined single source sound power levels, sound levels recalculated at measurement points and on a noise map

The resulting package component single sound power levels following the application of SoundPLAN® tool are reported in Tab. 7.

Tab. 7 – Auxiliary boiler package sources sound power levels in dBA obtained with SoundPLAN® tool

Livelli di potenza sonora in dBA delle sorgenti del package caldaia ausiliaria ottenuti con la funzione di SoundPLAN®

Name	*Description*	*Lw*
B-RS	Boiler Radiant Section	99
B-BR	Boiler natural draft burner	111
B-STD	Boiler steam drum	99
B-ECO	Boiler economizer	98
FDF-AI	Forced draft fan air inlet	105
FDF	Forced draft fan	103
FDF-M	Forced draft fan motor	95

The sound power level octave band spectra obtained with the SoundPLAN® tool on the auxiliary boiler package sources are reported on Fig. 23.

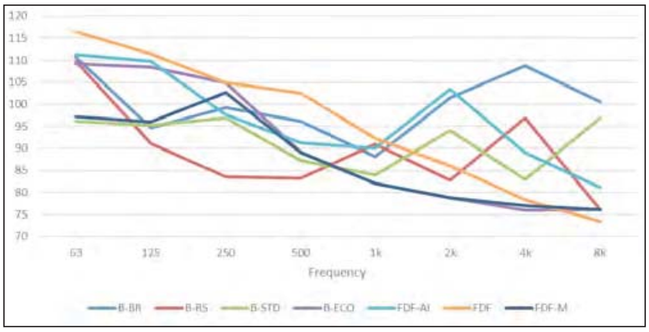

Fig. 23 – Auxiliary boiler package sound power level spectra in dB of sources obtained with SoundPLAN® tool

Spettro del livello di potenza sonora in dB delle sorgenti del package caldaia ausiliaria ottenuti con la funzione di SoundPLAN®

The total sound power level of the complete auxiliary boiler package is then obtained by adding the noise emission of noise sources listed in Tab. 7 and is reported in Tab. 8.

Tab. 8 – Auxiliary boiler octave band sound power level by adding the sources obtained with SoundPLAN® tool

Livello di potenza sonora in bande di ottava della caldaia ausiliaria ottenuta sommando le sorgenti ricavate con la funzione di SoundPLAN®

	OVR (A)	*63 Hz*	*125 Hz*	*250 Hz*	*500 Hz*	*1k Hz*	*2k Hz*	*4k Hz*	*8k Hz*
L_w	113	118	115	110	104	96	106	109	102

From the noise source set of Tab. 7, the sound pressure levels at measurement points, shown in Fig. 24, and a further noise map, reported in Fig. 34 (b) under para. 4.4 |, have been calculated.

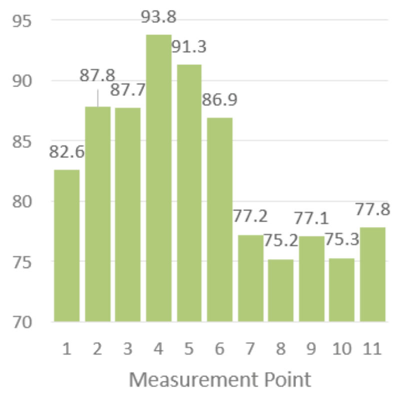

Fig. 24 – Calculated sound levels in dBA by means of the sources obtained with SoundPLAN® tool at measurement points around the auxiliary boiler

Livelli sonori in dBA calcolati nei punti di misura attorno la caldaia ausiliaria mediante le sorgenti ottenute con la funzione di SoundPLAN®

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. Besides, for the auxiliary boiler package, comparisons between the overall sound power levels calculated with ISO 8297 formula and by adding the single sources obtained with the SoundPLAN® tool, and between the sound pressure levels measured and calculated with the single sources of above are investigated.

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.

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 Tab. 9.

The sound power level of the two sets of sound sources is shown in the chart of Fig. 25.

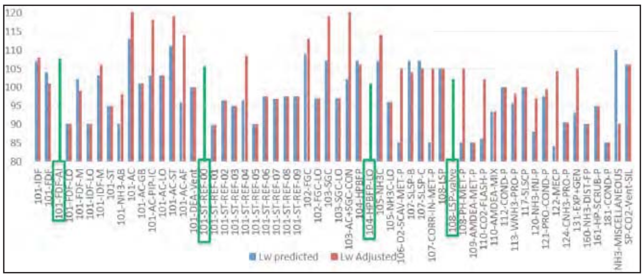

Fig. 25 – Predicted and adjusted (as built) sources sound power levels (Lw) in dBA; the 4 added sources are marked in green The overall ammonia plant predicted Lw is 120.5 dBA and the adjusted Lw is 129.7 dBA

Livelli di potenza sonora (Lw) in dBA previsti e adattati (stato di fatto) delle sorgenti; le 4 sorgenti aggiunte sono indicate in verde. Il Lw complessivo dell'impianto ammoniaca previsto è pari a 120.5 dBA, quello adattato a 129.7 dBA

Tab. 9 – 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

Statistiche delle sorgenti sonore adattate nell'impianto di ammoniaca: da segnalare media e deviazione standard elevate dovute a un'importante modifica progettuale avvenuta durante la costruzione dell'impianto

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 Fig. 25 and Tab. 9, some consideration must be done.

The number of sound sources has increased just to improve the previous acoustic model and 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 points have been influenced by the noise of a pair of unstoppable steam jets above the compressor house, as anticipated at the end of para. 2.4 |. 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.

The effect of the increased noise levels in the compressors area (area code 500) and in adjacent areas (area codes 300 and 400) due to the lack of acoustic insulation on piping and those because of the steam jets, is evidenced by the pattern of the graph in Fig. 26, where the assessed and the measured sound levels at measurement points are compared.

Fig. 26 – Discrepancies between assessed and measured sound levels in dBA at measurement points, for numbering system see para. 2.4

Differenze tra i livelli sonori in dBA valutati e misurati nei punti di misura, per il sistema di numerazione vedere par. 2.4

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

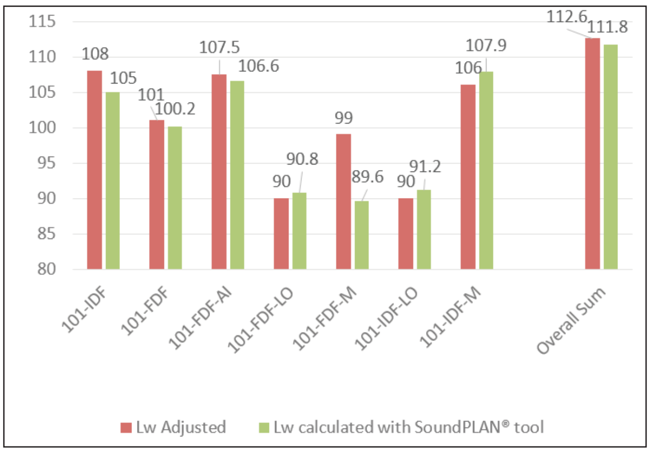

Fig. 27 – Adjusted (as built) and obtained with SoundPLAN® tool sound power levels (Lw) in dBA of the sources in the ammonia plant "reformer" area

Livelli di potenza sonora (Lw) in dBA adattati (stato di fatto) e ottenuti con la funzione di SoundPLAN® delle sorgenti nell'area "reformer" dell'impianto ammoniaca

As regards the post-processing analysis performed on the induced and draft fan systems connected to the "reformer" unit, the updated source sound power levels obtained with the SoundPLAN® tool are like those previously adjusted and assumed as actual. In fact, the comparison of the above-mentioned sound power levels reported in Fig. 27 shows interesting results.

First of all, it has to be noticed that the overall balance of the sound power level of the sources related to the induced and the draft fan systems was over adjusted to obtain the as built values. This is also highlighted by the comparison of the noise map enlargements of Fig. 15 (measured noise map) and Fig. 19 (calculated as built noise map). In particular, with reference to the sound power levels, if the concerned noise sources are classified in three ranges, i.e. high emission (105 to 108 dBA), medium emission (99 to 101 dBA) and low emission (90 to 92 dBA), following considerations can be drawn:

- the overall sum of the noise sources adjusted and calculated with the SoundPLAN® tool are similar (0.8 dB) difference;
- the high emissions of induced draft fan (101-IDF) and its motor (101-IDF-M), one overestimated and the other underestimated during adjustment phase, are now inversely balanced between them, so the use of the SoundPLAN® tool has lead to a more accurate sound power levels distribution;
- the adjusted sound power levels of the forced draft fan and its air inlet seems to be in line with those obtained with the SoundPLAN® tool (less than 1 dB difference);
- following to the application of the SoundPLAN® tool, the noise emission of the forced draft fan motor turned out to be unexpectedly low, as the one evaluated during the source adjustment phase was overestimated. Consequently, the least square method has given a valuable contribution on the determination of the actual sound power level;
- the low emission of both lube oil pumps has been slightly underestimated during the source adjustment phase (about 1 dB), therefore they are aligned with those obtained with the SoundPLAN® tool, even though not affecting the overall result

In short, the post-processing application of the least squares method on the sound source group nearby the "reformer" area has confirmed in a way the global effect of the adjusted sound power levels, but changed the single components contribution.

About the ammonia plant overall sound power level, Tab. 10 shows the results of the logarithmic sum of the sound sources, both predicted and adjusted, along with the application of ISO 8297 formula.

Tab. 10 – Ammonia plant sound power level

Livello di potenza sonora dell'impianto ammoniaca

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 Tab. 10, 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, there are some not quantifiable effects (caused by steam jets located above the compressor shelter roof) which should be recorded: such effects anyway appear to be 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 Fig. 28 and the statistical analysis in Tab. 11.

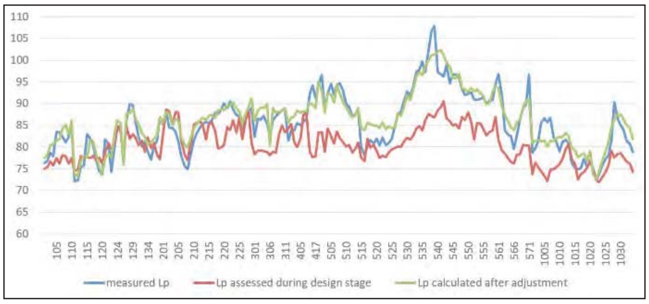

Fig. 28 – Assessed, measured and calculated with adjusted (as built) sources sound levels in dBA at measurement points, for numbering system see para. 2.4

Livelli sonori in dBA valutati, misurati e calcolati con sorgenti adattate (stato di fatto) nei punti di misura, per il sistema di numerazione vedere par. 2.4

Tab. 11 – Statistics of the differences among assessed (A), measured (M) and calculated (F) with adjusted (as built) sources sound levels (Lp) for the 194 measurement points

Statistiche delle differenze tra i livelli sonori (Lp) con sorgenti valutate (A), misurate (M) e calcolate (F) con sorgenti adattate (stato di fatto) per i 194 punti di misura

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 Fig. 28, 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 Tab. 11 (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.

The post-processing study on the induced and draft fans systems of the "reformer" area, by means of the SoundPLAN® tool, has also prosecuted with the sound pressure levels recalculation both in the measurement points and in a noise map. Therefore, four data sets to be analysed became available: assessed during design stage, measured in field, calculated after sound sources adjustment (as built) and recalculated after the sound sources obtained following to the application of the least squares method included as the SoundPLAN® tool.

The sound pressure levels at the measurement points in the "reformer" area are summarized in Fig. 29.

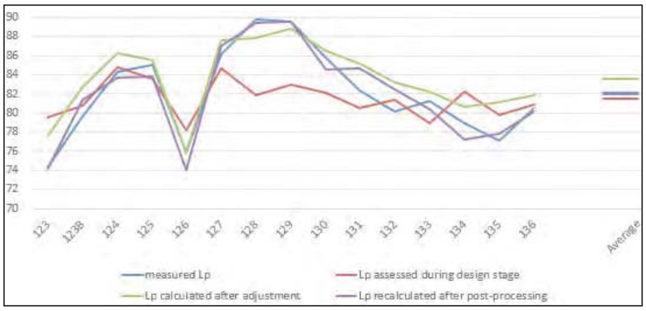

Fig. 29 – Assessed, measured and calculated with adjusted (as built) and obtained with SoundPLAN® tool sources sound levels in dBA at measurement points in "reformer" area, from 123 to 136

Livelli sonori in dBA valutati, misurati e calcolati con sorgenti adattate (stato di fatto) e ottenute con la funzione di SoundPLAN® nei punti di misura dell'area "reformer", da 123 a 136

Looking at Fig. 29 it is evident that the best fitting between measured and calculated sound levels has been obtained with the source sound power levels derived from the application of the SoundPLAN® tool in frequency bands, for which the average values are matching and the differences are always less than 2 dB, except for two measurement points, 131 and 132, where the shielding effect of the forced draft fan motor casing was rather difficult to be modelled compared with all other equipment casings nearby, see Fig. 30 for reference. For the other two sets of calculated sound levels, one assessed during design stage and the other with adjusted sources sound power levels, they are underestimated and overestimated, respectively.

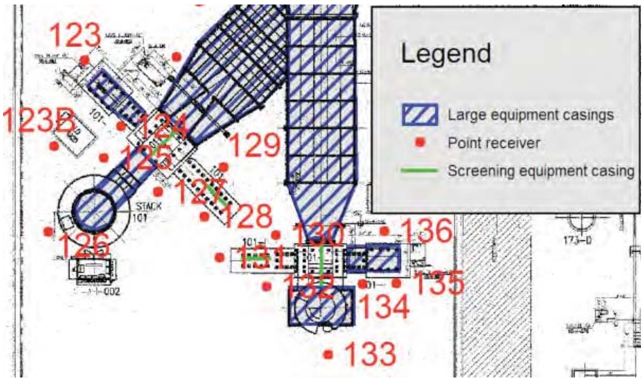

Fig. 30 – Measurement points near the induced and draft fans of ammonia plant "reformer" area

Punti di misura presso i ventilatori a tiraggio indotto e forzato dell'area "reformer" dell'impianto ammoniaca

The comparison of the noise maps in the "reformer" area here analysed, leads to analogous considerations. The noise maps shown in Fig. 11, Fig. 15, Fig. 19 and Fig. 22 are below reported in Fig. 31 for quick reference and following discussion.

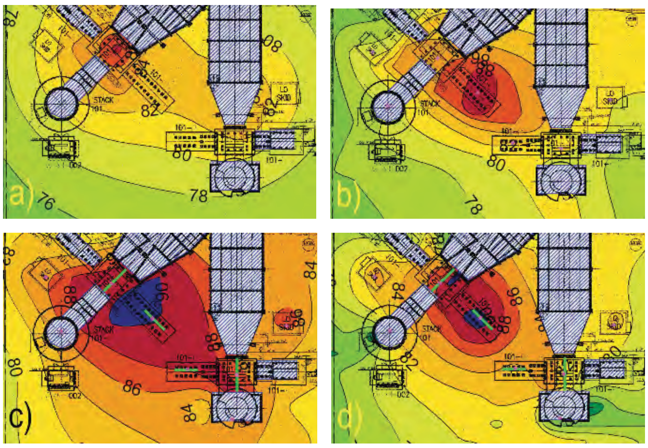

Fig. 31 – Predicted (a), measured (b), adjusted (c) and calculated with the sources obtained with SoundPLAN® tool (d) ammonia plant noise maps on the induced and draft fans of "reformer" area

Mappe del rumore previsionale (a), misurata (b), adattata (c) e calcolata con le sorgenti ottenute con la funzione di SoundPLAN® (d) dei ventilatori a tiraggio indotto e forzato dell'area "reformer"

The noise contour maps in Fig. 31 highlight what already noticed during the analysis of the sound level at discrete measurement points (see Fig. 29), both strictly related to the discussion on the sources sound power levels above reported for Fig. 27.

The assessed sound levels distribution on this area during design stage is confirmed to be underestimated, as the relevant sound power levels of noise sources were underestimated as well, for poor information from equipment manufacturers.

The measurements on site have shown that the induced draft fan electric motor is the noisiest source in the area, followed by its driven equipment.

The noise map calculated with the adjusted (as built) sources sound power level proved to be overestimated, due to the excessively high noise emission attributed to the induced draft fan, to balance the measured sound levels. The induced draft fan motor has been rightly considered an important noise source too, but this noise map shows the effect of the reflections because of the modelled induced draft fan casing, which has increased the sound levels. Probably a different model for such casing would mitigate in a way that discrepancy with the measured data.

Finally, the noise map calculated with the source sound power levels derived from the application of the software tool in a subsequent research step has led to a distribution of the sound levels closer to the measured ones with exceptions that can be explained as follows:

- the very high noise levels shown in the induced draft fan and related motor areas are software artifacts, since the noise map calculation is performed according to a point grid in which some of them may end very close to the modelled "point" noise source, even inside the real equipment casing;
- like for the noise map calculated with adjusted (as built) acoustic model, some calculation point may be affected by the sound screening and reflecting effects of the equipment casing, which should be better investigated and modelled in future.

In summary, the application of the least square method included in the software tool has surely improved the acoustic characterization of the sound sources in this specific plant area even though the noise survey was not specifically planned and organised for this purpose. In fact the field activities were conducted to collect comprehensive information regarding the ammonia plant sound emissions and create an as built acoustic model useful for future applications, but for the induced and draft fans on the "reformer" area, the actual configuration found on site was much complex, due to the large sound sources, ducts and other shielding and reflecting equipment that are difficult to model.

4.3 | Sound power level of the auxiliary boiler package

By comparing the values reported in Tab. 5 and Tab. 8, here summarized for convenience in the graph at Fig. 32 (a), the overall sound power level of the boiler package calculated with ISO 8297 formula is 2 dB higher than the resulting one from the sum of single components obtained with the SoundPLAN® tool, even though the difference between the associated logarithmic average sound pressure levels (the measured versus the calculated with the source sound power levels obtained with the SoundPLAN® tool ones) is 0.7 dB only (see Fig. 32 (b)).

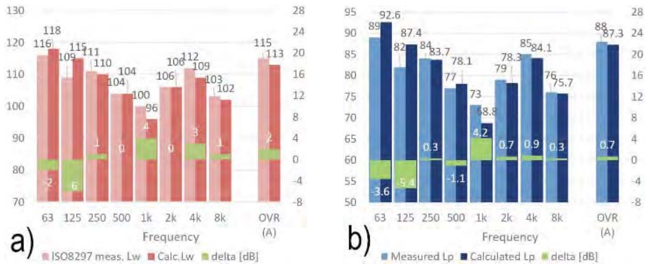

Fig. 32 – Auxiliary boiler package sound power level (a) and average sound level (b) octave band measured and calculated by means of the sources obtained with SoundPLAN® tool at measurement points

Livelli di potenza sonora (a) e livelli sonori medi (b) in bande di ottava, calcolati nei punti di misura attorno la caldaia ausiliaria mediante le sorgenti ottenute con la funzione di SoundPLAN®, del package caldaia ausiliaria

The reason of such difference is not clear but, at a glance, it appears to be related to the definition of the "measurement surface" to be used in the ISO 8297 formula. A comprehensive investigation on this point and the combination with other factors shall be analysed separately in future research developments.

4.4 | Sound pressure levels at measurement point location around the auxiliary boiler package

The analysis of the differences between the assessed sound pressure levels during the design phase and those measured during auxiliary boiler in operation was not considered because the calculations points are actually inside the modelled area source, therefore not significant. Furthermore, this assessment was conducted with an estimated sound power level not based on vendor data and far from the actual one found in field.

The comparison between the measured sound pressure levels and those modelled with the source sound power levels obtained with the SoundPLAN® tool, both assessed at measuring points (Fig. 16 and Fig. 24 combined in Fig. 33 for

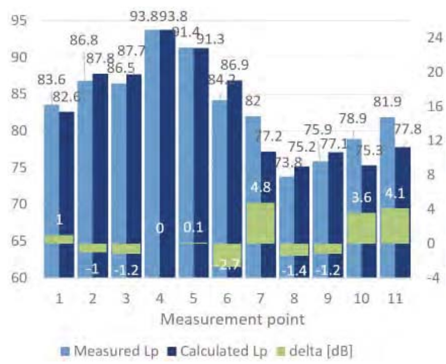

Fig. 33 – Sound levels in dBA measured and calculated by means of the sources obtained with SoundPLAN® tool at measurement points around the auxiliary boiler

Livelli sonori in dBA misurati e calcolati mediante le sorgenti ottenute con la funzione di SoundPLAN® nei punti di misura attorno la caldaia ausiliaria

convenience) and as noise contour lines (gathered in Fig. 34 to ease the crosscheck), shows that the software tool is working better for small sources with limited screening or reflecting surfaces nearby, since the least gaps are close to noisiest sources, i.e. points 1 to 5, influenced by the burner (B-BR) and the forced fan (FDF) with its air inlet (FDF-AI).

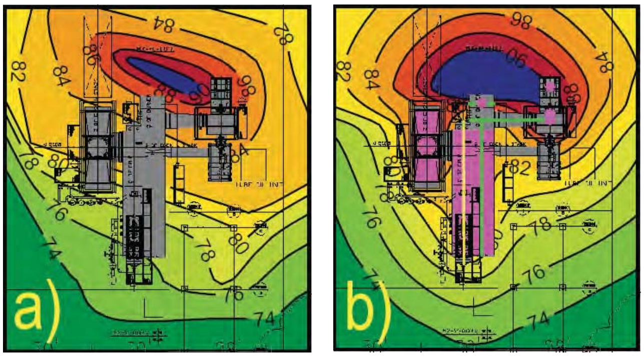

Fig. 34 – Comparison of auxiliary boiler measured noise map (a) with the noise map calculated with the sources obtained with SoundPLAN® tool (b)

Confronto della mappa del rumore misurato della caldaia ausiliaria (a) con la mappa del rumore calcolato con le sorgenti ottenute con la funzione di SoundPLAN® (b)

Nevertheless, this inverse method looks to be more viable than the use of ISO 3744 [20] or intensimetry [21], for the complex configuration of such multi source boiler package: indeed, both above techniques cannot be applied for sound sources shaped with protrusions and recesses.

Perhaps, a more detailed acoustic model with volume sources would improve the accuracy of the results obtained by applying the SoundPLAN® tool, but this surely increase the number of required measurement points.

The experience described here has shown that planning the measurement points according to the multi-source to be studied is fundamental in order to apply the software tool. In reality, the points used here were previously chosen for the determination of the total sound power level of the boiler package using ISO 8297, not for the application of the software tool. The sound power level data accuracy of individual sources might be improved if there were additional measurement points within the package envelope.

Finally, there are two options for acoustic modelling of multisource items to apply the software tool: the use of volume sources, or by means of basic sources and screens, the latter may require fewer measurements.

5 | Conclusions

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 noise data received 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 calibrated, to get a final "as built" acoustic model 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 calibration of the acoustic model could be more substantial on the equipment or piping systems that have been affected by the modifications. In this paper, an example of the plant acoustic design tracking with the support of a dedicated acoustic modelling has revealed the lacks in noise data received from some equipment suppliers (less significant) and the detrimental effect of planned acoustic insulation removal in a noisy piping system (highly impacting), by means of the comparison with the actual sound level distribution during normal operation, showing the differences of both sources sound power levels and in-field sound pressure levels.

For the definition of the "as built" acoustic model using measured data, inverse methods may be used. For multi component sound sources (shaped with protrusions and recesses) such inverse methods appear more practical than those envisaged by ISO 3744 or intensimetry. Integrated software tool for calculating sound power levels from measured data is useful for complex multisource noise characterization, provided the data set is consistent. In present work, the application of such software tool, not otherwise available in literature, is described and analysed. Future investigations on the accuracy and precision of attainable results will follow, to define applicability conditions and limits.

Conclusioni

L'adozione di un modello acustico di un impianto industriale è utile durante l'intero processo di progettazione, sin dalle prime fasi, quando vengono condotti studi di rumore ai fini autorizzativi. Successivamente, le soluzioni tecniche di progettazione del controllo del rumore e i dati di rumore ricevuti dai fornitori di apparecchiature vengono utilizzati per aggiornare progressivamente il modello acustico per il quale la distribuzione dei livelli sonori attesi è prevista prima dell'avvio dell'impianto. Dopo la costruzione dell'impianto, una volta che l'impianto è in funzione, il modello acustico può essere messo a punto, per ottenere un modello acustico finale secondo lo stato di fatto che possa essere utilizzato per controllare l'invecchiamento delle apparecchiature, pianificare modifiche all'impianto o progettare ulteriori impianti simili. Nel caso in cui durante il montaggio meccanico dell'impianto siano intervenute modifiche progettuali, la messa a punto del modello acustico potrebbe essere più consistente sulle apparecchiature o sui sistemi di tubazioni che sono stati interessati dalle modifiche. In questo lavoro, un esempio di tracciamento della progettazione acustica dell'impianto con il supporto di una modellazione acustica dedicata ha rivelato la mancanza di dati sul rumore ricevuti da alcuni fornitori di apparecchiature (meno significativi) e l'effetto negativo della rimozione dell'isolamento acustico progettato in un sistema di tubazioni rumoroso (altamente impattante), attraverso il confronto con l'effettiva distribuzione del livello sonoro durante il normale funzionamento, mostrando le differenze sia tra i livelli di potenza sonora delle sorgenti sia tra i livelli di pressione sonora in campo.

Per la definizione del modello acustico secondo lo stato di fatto utilizzando i dati misurati, possono essere utilizzati metodi inversi. Tali metodi inversi sono più pratici della ISO 3744 o dell'intensimetria per sorgenti sonore multicomponente, conformate con sporgenze e rientranze. Lo strumento software integrato per il calcolo dei livelli di potenza sonora dai dati misurati è utile per la caratterizzazione complessa del rumore multisorgente, a condizione che il set di dati sia coerente. Nel presente lavoro viene descritta e analizzata l'applicazione di tale strumento software, non altrimenti disponibile in letteratura. Seguiranno future indagini sull'accuratezza e la precisione dei risultati ottenibili, per definire condizioni e limiti di applicabilità.

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