Management at corporate level of noise exposure assessment and control for Petrobras refining

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Abstract. This article presents the work carried out as part of a project aiming to regulate the noise exposure of workers of PETROBRAS refining units. This is a corporate project carried out over a three years' period (2012 to 2015) by the Supply business unit of the Brazilian company. The uniqueness of this project is due to its scale. Indeed, this encompassed twelve refineries located throughout Brazil. The corporate approach to deal with noise exposure risk leads to an overall data consolidation allowed by a standardized methodology. The methodology used is split into four phases. First, a long but necessary planning stage, then an exhaustive assessment of the current noise situation of production areas was carried out during the first twelve months of the project. This stage allowed the involvement of several important tools used to identify and rank noise exposure issues. This lead to noise maps of every industrial area and an acoustic database of equipment exceeding regulatory limits (sound power level and directivity). Third, every industrial area was modelled into noise prediction software compliant with ISO 9613-2 standard. Finally, acoustic damping solutions were designed and proportioned by size of equipment. This mixed approach of measurement and numerical simulation mobilized a dedicated ACOEM project team comprising of eight acoustic experts. Principal achievement of this project, concluded in 2015, is a clear vision of the noise control priorities allowed by standardized methodology on all refineries in a short time. This achievement leads to a coherent set of controls for the future investments to be done to mitigate noise exposure risks. In addition to highlighting the benefits of integrated Health Safety and Environment (HSE) management, this work provides an understanding on the use of virtual computing doses from propagating acoustic model.

1. Introduction

The concern with workers exposed to high noise levels is an issue of constant importance. Such exposure can lead to unhealthy work environment and consequently be a potential cause of sleep and cardiovascular problems [1].

Based on this, an analysis and evaluation of the acoustical environment of 12 operational refineries and 4 refineries in the establishment phase were carried out. The size of this project is unique in a global context – analysis and simulation of environmental noise of 265 industrial zones in a total investigated area of 1,900,000 m². For each zone, a noise map was generated, helping the identification of noise sources of nearly 3500 equipment/installations. The mobilization of skilled technicians, detailed determination of required measuring equipment, meticulous logistic planning and
the quality in the analysis of collected data and acoustic simulations are amongst the factors leading to a successful project.

2. Development

The project was divided into 4 phases in accordance with its unique requirements. An initial planning phase where required resources and equipment were defined, a field campaign where data was collected, a diagnostic phase where acoustic computational simulation took place and a final stage including a conceptual and a detailed noise mitigation plan.

2.1. Resources and equipment

The first challenge was defining the required resources for the realization of the proposed scope within 36 months – the demanding logistics for field works which took more than 250 days and mobilization of a single measuring team of a total distance greater than 15000 km. The project planning considered all logistics, technical and operational requirements. The field campaign survey team was comprised of 6 technicians equipped with 6 sound level meters and concluded their measurements in 12 months.

2.2. Field campaign

Field campaign had two main objectives: mapping of sound pressure levels of each zone and determination of sound power levels of sources where sound pressure levels were measured above 80 dB(A).

2.2.1. Mapping of noise levels

Noise maps were calculated, depicting the iso-phonic contours calculated from sound pressure levels measured at 1.5 m above ground in a 5 x 5 m squared grid. Exception to the proposed grid occurred in accordance to the spatial noise gradient, a courser or finer grid was adopted per the local needs and the access to measurement areas. The adopted typical grid resolution was defined also with basis on the dimensions and distances of equipment in the refining plants, allowing source identifications on the final calculated noise maps.

2.2.2. Characterization of noise sources

The noise sources were identified with the noise maps of each zone. The ISO 3746 was employed in determination of sound power of sources. The standard defines the conditions and methods for calculating the sound power from sound pressure levels. Figure 1 depicts the typical noise measurement arrangements for calculating the sound power levels of the sources.

![Figure 1](image)

**Figure 1.** Measurement points for determining the sound power levels of (a) small and (b) large machines [2].

Adapting of the employed methodology was necessary due to operational constraints – in some areas the elevated background noise could not be isolated from the machine of interest. In these cases, the measurements were conducted in smaller grids, which means the measurement locations were closer to the source, nevertheless without reaching the source near-field [3]. Consequently, an overestimation of sound power levels of up to 3 dB(A) can incur, in this case the noise assessment plan assumes a
conservative criterion for noise control. Additionally, the computational noise models were adjusted and recalibrated with the sound pressure level measurements to minimize the risk of overestimation of noise levels.

2.3. Computational simulation and conceptual mitigation plan

Computational models in the CadnaA software were designed using the sound power of equipment determined in the simulation of the refinery sites to provide an initial mitigation plan. CadnaA’s prediction model is based on the ray-tracing method to calculate attenuation in the propagation of acoustical waves. In case of multiple source models, such as this study, the contribution of individual sources is added up assuming uncorrelated sources. The calculation protocol was in accordance to ISO 9613-2, including the parameters for insertion loss of obstacles, air and ground absorption and source sound directivity [4,5].

The sound directivity of noise sources was adjusted in the computational model taking into consideration the data collected in the field and the calculated noise map. The mitigation plan takes into consideration, that the sound pressure levels at 1 m of equipment should be limited to 90 dB(A) in accordance with the customers’ requirements (Petrobras).

Typical noise mitigation for equipment which did not fulfill noise requirements was proposed taking into consideration the type of equipment (pumps, motors, compressors etc.) and the required noise attenuation. Undesired noise sources related to maintenance issues (such as steam leakages in the pipelines) were not considered in the simulation. This is provided that the corrective maintenance was included in the mitigation plan.

The validation of necessary noise attenuation was assessed in CadnaA using an iterative process. A global attenuation was introduced at each source’s façade and noise maps were recalculated, allowing the assessment of the impact of each mitigation measure and its combined results in the acoustic field.

2.4. Detailed mitigation plan

In this stage, a basic plan of noise attenuation measures was presented, indicating the spectral attenuation of employed materials. An analysis and selection of potential suppliers capable of providing the indicated noise solutions was also part of the scope.

Based on the response of consulted potential suppliers, a final cost estimative was calculated and a revalidation of noise maps were conducted considering the guaranteed attenuation informed by potential suppliers.

3. Results

As of now, the concluded phases include the field campaign, characterization of noise sources, computational simulation and conceptual mitigation plan.

The field campaign was performed from October 2012 to November 2013, on an average pace of 1 refinery per month. The project management was successful in allowing all activities to be concluded within the expected time, causing no delays to the customer and respecting all health and safety requirements imposed by the activities.

From the collected grid measurements in the field, the noise maps were calculated with the aid of CadnaA noise mapping software using ISO9613-2 standard for the 265 operational units investigated. The noise maps provided crucial information in the identification of relevant noise sources in each unit. The figure 2 below illustrates a noise map calculated in this phase.

In figure 2, it is possible to identify some of the more critical noise sources in the unit, helping the selection of noise sources to be further characterized. The selected sources were investigated by determining its equivalent noise level, $L_{eq}$ at a specific distance in the boundary of the source, as described in 3.1.2.

In the initial mitigation plan phase, the results obtained with the noise map were compared with the computational model of the noise sources of the plant. In most cases the resulting analysis indicated a direct coherence between the maps, nevertheless in some cases regions depicting sound pressure levels
above 90 dB(A) were only present in the maps calculated from the simulated model which can be attributed to different operation condition of machines along the measuring day, in other words, the sound sources may not be perfectly stationary.

![Noise map of operational unit zone](image)

**Figure 2.** Noise map of operational unit zone [6].

In this phase of the study, the contribution of undesired sources (pipeline leakages) were considered for adjusting the simulated model with respect to the measured map. Later on, their contribution was ignored in the simulated model.

The figure 3 below shows the noise map obtained from the computational model of the same zone as figure 2.

![Computational noise simulation](image)

**Figure 3.** Computational noise simulation, (a) 2D Representation (b) 3D Representation [6].

In the noise simulation model, all noise sources were calibrated with respect to measured values in the refinery, including the directivity of the sources. The sound propagation was computed via CadnaA, in accordance with ISO 9613-2, following the equation 1:

\[
L_{RT} = L_w + D_c - A
\]  

(1)

Where: \(L_{RT}\) is the sound pressure level at receiver; \(L_w\) is the sound power level of the source in octave bands; \(D_c\) is the directivity correction index and \(A\) is the attenuation from source to receptor in octave bands.
For noise sources exceeding the defined noise limit, the mitigation measures were based on the type of equipment:

| Mitigation measure | Equipment                        |
|--------------------|----------------------------------|
| Noise enclosure     | Electric motor                   |
| Low noise fan       | Electric motor                   |
| Lagging             | Pipeline and valves              |
| Acoustic blanket    | Air compressors                  |
| Noise enclosure     | Air compressors                  |
| Silencer            | Exhausting                       |
| Acoustic barrier    | Furnace Oven                     |

The presented solutions were adapted per the required attenuation levels and the equipment’s constraints regarding installation of mitigation measures. In some due to the lack of space or the proximity of other equipment, the mitigation measures could not be implemented. An initial cost estimate could be determined based on the sources dimensions and CAD of the entire plant.

The use of noise control measure in the computational model of an oven is illustrated below. The oven’s wall was extended around the burners, acting as a noise barrier. The cost of this noise control measure was estimated based on the cost of wall per square meter.

(a)  
(b)

Figure 4. The figures present the bases of the oven with burners depicted in blue. In (a) original installation and extended wall acting as a barrier for noise from [6].

To verify the initial mitigation plan, a noise map is calculated considering the applicable noise control measures. The overall result of the combine mitigation plan can then be appreciated.

(a)  
(b)

Figure 5. Map of noise simulation including the mitigation measures [6].
The methodology described above for mapping, modelling and mitigating the environmental and noise exposures defines a structured management framework to be applied to all 265 zones. Based on a noise contribution ranking and evaluation of the effectiveness of the noise control of individual sources, the mitigation plan could be determined and focused in the areas with higher circulation of workers.

4. Conclusions
The stages of sound pressure measurements, noise mapping, characterization of noise sources and the noise modelling were concluded within schedule, including the initial mitigation plan.

The software CadnaA was proven to be a decisive tool in the project, allowing in depth investigations and conclusive results. It has allowed the calculation of noise maps from sound pressure and the construction of a computational noise model representing all the sources of interest. The results from the computational model could be compared to the noise maps and fine-tuned in terms of source level and directivity. In possession of a representative noise model of the refinery, the contribution of individual sources, ranking and assessment of mitigation effectiveness could be performed – proving valuable information in defining a complete mitigation plan to all zones.

The goal of the mitigation plan was to reduce the risk of noise exposure of workers and to reduce the environmental impact of assessed areas.

The developed framework for managing environmental and noise exposure was proven to be well adapted to the requirements and the characteristics of this project despite their bring no precedents – Activities were concluded within schedule and provided conclusive results for defining a noise mitigation plan. Such frameworks can be extended to other large industrial plants were noise control is often a concern either in legal or occupation safety terms.

5. References
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