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# The Effect of Biphasic Refrigerant Flow on Refrigerator Noise

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## ABSTRACT

Nowadays, sound level and sound quality are two very important buying criteria for the final users of a household or light commercial appliance. In order to assure good noise levels, the choice of a compressor with low noise at a specific condition is not the only point to care; it is important to evaluate the transient noise as well. The goal of this paper is to present two studies, the first one showing how a biphasic flow in the suction line, close to the compressor in a drinking fountain, can create transient noise due to the excitation of the compressor gas cavity. The second case concerns the flow noise generated by the refrigerant in the capillary tube. In both cases, thermocouples are placed in different parts of the refrigeration unit in order to better understand the behavior of the refrigerant flow and its correlation with the thermal profile. Different refrigerant charges are tested, verifying the thermodynamic and acoustic behavior of the units. Some different control techniques are also tried, aiming to avoid undesired noise (pure tone, for instance) and to reduce the overall levels. Finally, a proposed refrigerant charge is set, assuring a good trade-off regarding noise and thermodynamic performance.

## 1. INTRODUCTION

When refrigerators' manufacturers develop a new product, they usually take into account the sound level radiated by the appliance, besides the reliability, the cost and the power consumption. Lately not only the number in "dB" are evaluated: there is also big concern related to the perception of the noise listened by the final customer. It means that in order to give to the final customer a comfortable sound level, the manufactures choose fans, compressors and valves with good performance regarding radiated sound to design their products. In this moment, not only quiet individual components analyzed in a stable condition are enough to assure a small number of customer complaints regarding noise: it is important to assure that when all the refrigerator´s components are assembled, the interactions among them do not create big problems to the final user.

One of the main sources of complaints concerning noisy refrigerators is transient noises: big oscillations of the sound radiated by the product along the time are always undesirable. Among the transient noises, there is the flow noise generated in the capillary tube: it was already studied in some previous works and it has been showed that it depends on parameters like the refrigerant charge, the length and the diameter of the capillary tube, etc.

Another type of transient noise observed in refrigeration systems is the one correlated to the compressor: big variations of its evaporating and condensing temperatures are able to highly change the sound radiated by its shell, frequently creating complains in the field.

This work aims to firstly describe two cases of transient noise generated by the refrigerant flow that created complaints in the field; one of the problems was related to a drinking fountain and the other one to a wine cooler. The ways that the issues were solved is presented: after checking at reverberant chambers the sound spectra of faulty refrigeration systems, the temperature at specific points of the circuits was measured, helping to better understand the source of the high noise. Finally, some solutions to improve the sound quality were proposed, always assuring a good trade-off regarding thermodynamic performance.

## 2. CASE 1: NOISE CAUSED BY BIPHASIC FLOW IN THE COMPRESSOR REFRIGERANT CAVITY OF A DRINKING FOUNTAIN

The first case analyzed affected a typical drinking fountain. This equipment presents a hermetic compressor and some of the users complained about very high noise coming from the compressor after pouring bigger quantities of water.

According to the users, the problem usually appeared five or six minutes after the compressor starts. So, it was decided first of all to reproduce the problem inside a reverberant chamber.

### 2.1 Overview – noise evaluation

After obtaining a noisy drinking fountain from a final user, a setup for the evaluation of the noise was created, presented in Figure 1: the drinking fountain is placed in the reverberant chamber on a rigid and stable table, but it is connected to a water source, trying to reproduce the real application.

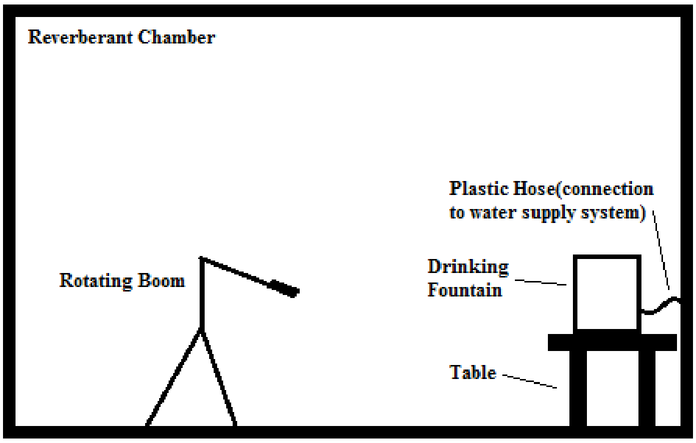


**Figure 1**: Setup to evaluate drinking fountain noise.

The first step was let the refrigeration unit working for 12 hours, in order to reach a stable condition. After placing the unit inside the reverberant chamber, about 2 liters of water were poured from the equipment and the compressor started to work. Then the chamber´s door was closed and the measurement started.

Figure 2 shows the noise behavior as a function of the time.

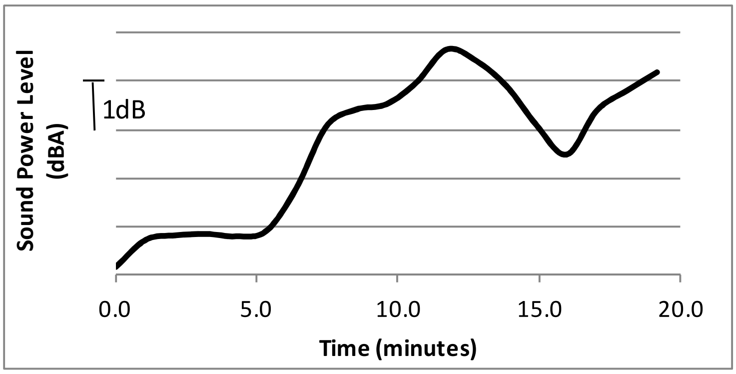


**Figure 2:** Noise behavior of the unit during the evaluation.

The results showed basically what the customer was complaining: five minutes after compressor started to work, the drinking fountain noise increased about 3dBA. In the peak, the noise was 3.5dBA higher than when compressor started up.

Comparing the third octave band spectrum just after compressor started to work to the spectrum in the peak of noise in Figure 3, it is clear the sound power level was amplified specially in the frequencies over 2500Hz, which is the band the compressor shell has its first natural frequency. Based on this chart, one concludes the customer complaint is related to some phenomenon happening inside the compressor that is exciting its casing.

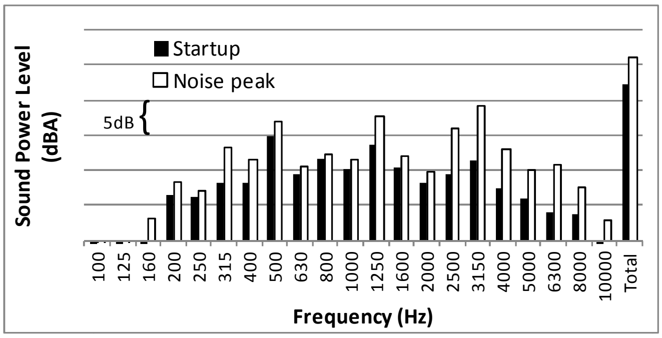


**Figure 3:** Spectrum comparison between startup and noise peak.

So, the decision was the following:

- Find an immediate but temporary solution focusing on the compressor, to guarantee the short term production.
- After validating the temporary solution, study and implement a definitive and robust solution.

## 2.2 Use of absorption material to reduce noise in high frequency

One of the first attempts to reduce noise in high frequency was to place some material to attenuate the noise on the compressor shell. Figure 4 presents the size and the position of asphalt blanket placed on the compressor cover and Figure 5 contains depicts a spectrum showing the sound power level difference over 2500Hz band due to the use of this component. The sound power level difference considers the time integration of the whole period after compressor started to work and pouring 2 liters of cold water (as per the procedure described in Section 2.1).

**Figure 4:** Position and size of asphalt blanket on compressor cover.

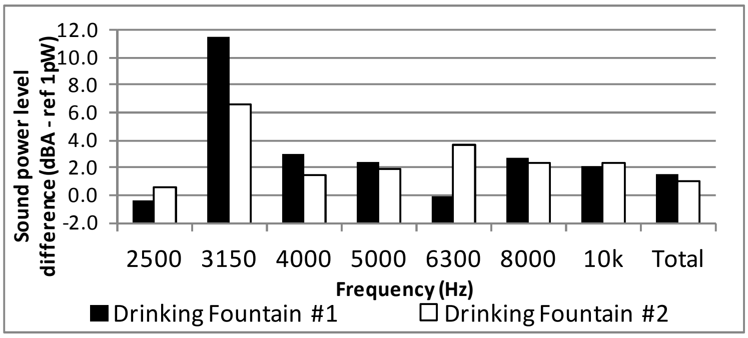


**Figure 5:** Difference of sound power comparing the regular configuration versus the configuration with asphalt blank on compressor´s cover.

Based on the optimization achieved, not only in terms of sound power level, but also in terms of sound quality, it was aligned to keep next productions of the drinking fountain placing a sheet of mastic material on the compressor cover.

### 2.3 Study of the unit with thermocouples

After implementing the immediate, temporary solution to reduce problems in the field, the next step was to investigate a possible definitive solution.

To do so, another drinking fountain with noise problem was instrumented with three thermocouples, in order to better understand the physics of the issue: one of them was placed in the middle of the evaporator; the other two at the suction tube. 100 and 50mm from the compressor two pressure transducers were also installed in the unit, aiming to know the suction and the discharge pressures.

The position of the transducers is shown in Figure 6.

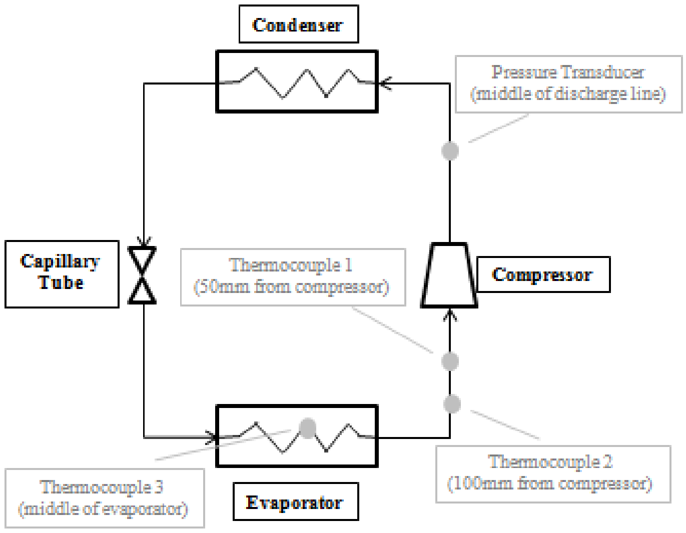


**Figure 6:** Position of the transducers in the drinking fountain.

The goal of these transducers was to understand the variation of the temperatures and pressures, especially when the noise becomes high. In Figure 7 it is possible to see the variation of the pressures and the temperatures as a function of the time.

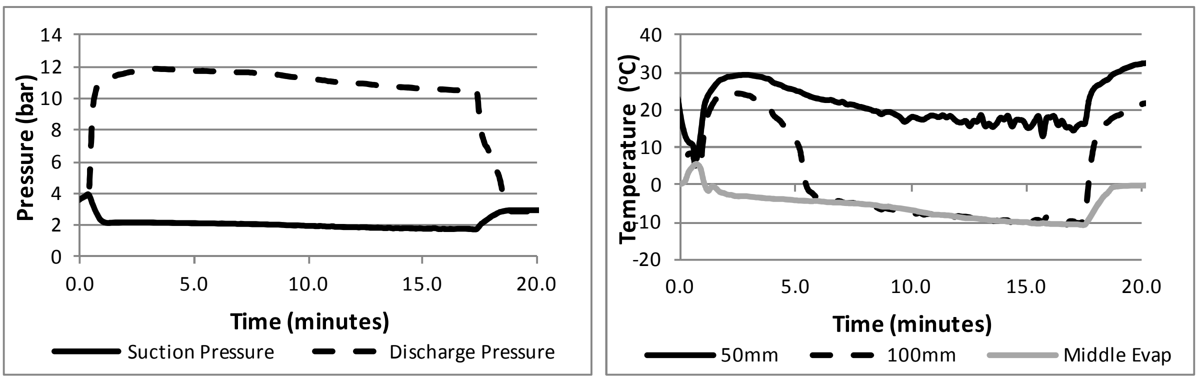


**Figure 7:** Analysis of the drinking fountain with (a) variation of the pressure and (b) variation of the temperature as a function of the time.

Analyzing the data, one verifies no abnormal trend regarding the suction and the discharge pressures. On the other hand, it is clear that the temperature of the suction tube at 100mm from the compressor is equal to the one of the evaporator after 5 minutes the compressor starts to run: it means there is saturated refrigerant at this position. Anyway, the most interesting information is related to the thermocouple placed at 50mm from the compressor: there is a big oscillation in the temperature some minutes after the compressor is turned on.

According to some previous works, as Lemos *et al* (2013), this variation of temperature measured by the thermocouple is usually related to a two-phase flow pattern. Take into account that this behavior is happening very close to the compressor, it is possible that part of the refrigerant becomes superheated vapor inside the compressor or, in other words, that the vaporization is finishing inside the compressor what might create some abnormal noise (Sabroe Marine, 1998). Based on this, it was decided to reevaluate the unit with 2 different refrigerant charges: 8% lower and 15% lower. So, Figure 8 shows the behavior of the temperatures after the reduction of the refrigerant charge.

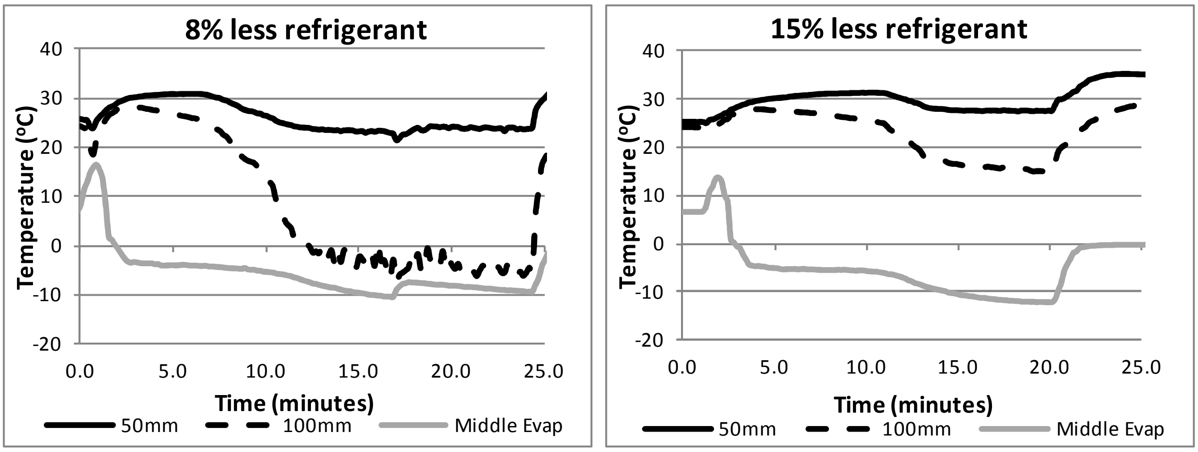


**Figure 8:** Analysis of the temperatures of the drinking fountain with (a) 8% and (b) 15% lower gas charge.

With an 8% refrigerant charge reduction, the temperature at 100mm from the compressor is a little higher than the temperature the middle of the evaporator. On the other hand, both thermocouples close to the compressor measured some oscillation of the temperature, which means the presence of two-phase flow in the end of the suction line was not completely eliminated.

The chart with the temperatures of the unit with 15% less refrigerant shows the desirable behavior regarding sound emission: the thermocouples in the suction line show superheated vapor close to the compressor and no big oscillation of mass flow is expected inside the compressor gas cavity; therefore it was decided to evaluate in both application and reverberant chamber the performance of the drinking fountain with reduction of refrigerant charge.

## 2.4 Noise evaluation with lower refrigerant charge

After the analysis previously presented, the drinking fountain evaluated in Session 2.1 was reevaluated with a reduction of 15% of refrigerant charge. Figure 9 illustrates the noise behavior as a function of the time of the drinking fountain with reduced refrigerant charge compared to the baseline sound power level presented in Figure 2. A comparison of the third octave band spectrum just after compressor started to work to the spectrum in the peak of noise is in Figure 10.

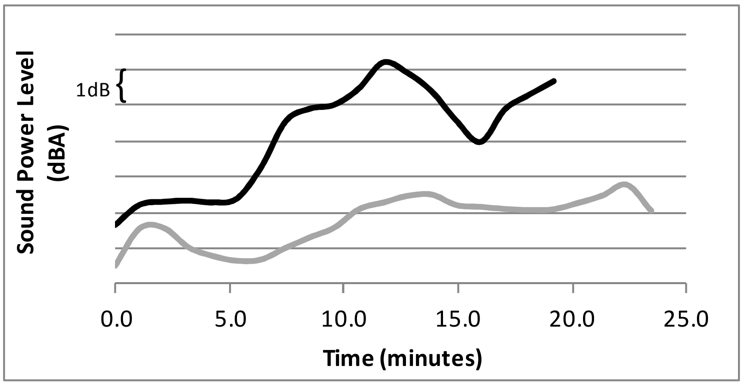


**Figure 9:** Noise behavior of the unit during the evaluation with different refrigerant charges.

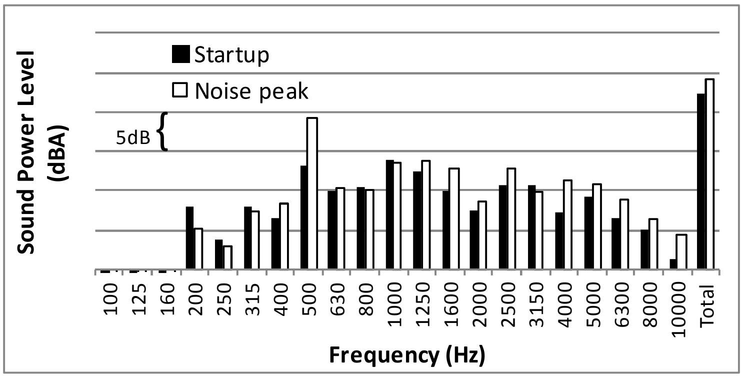


**Figure 10:** Spectrum comparison between startup and noise peak.

Based on Figure 9 and Figure 10, one concludes the variation of the overall noise reduced from almost 4 dB to less than 2 dB. Besides, the difference between the startup sound level and the noise peak was impacted specially in high frequency, as a consequence of the elimination of two-phase flow close to the compressor.

After verifying the improvement regarding the radiated sound, as well as the sound quality, and checking no negative impact in the refrigerating capacity, the project team decided to adopt the reduction of the refrigerant charge in 15%, solving the noise issue in the field.

## 3. CASE 2: WINE COOLER WITH FLOW NOISE IN CAPILLARY TUBE

The second case studied is a wine cooler with three independent compartments and refrigeration circuits, each one used for a specific type of wine. The three refrigeration circuits are simple ones, composed by a compressor, two heat exchangers and an expansion device.

The main complaint from the manufacturer was related to the very high flow noise, possibly happening at the capillary tubes.

### 3.1 Overview

One of the noisy wine coolers was evaluated in a reverberant chamber. During the sound power level measurements, it was also decided to place some thermocouples in different places of each circuit: in the middle of the condenser, in the filter dryer, 100mm from the compressor in the suction line and inside each compartment.

Figure 11 shows the sound level spectrum of the wine cooler during the first three hours of working. The request of the manufacturer was to reduce in about 5 dBA the overall noise of the product.

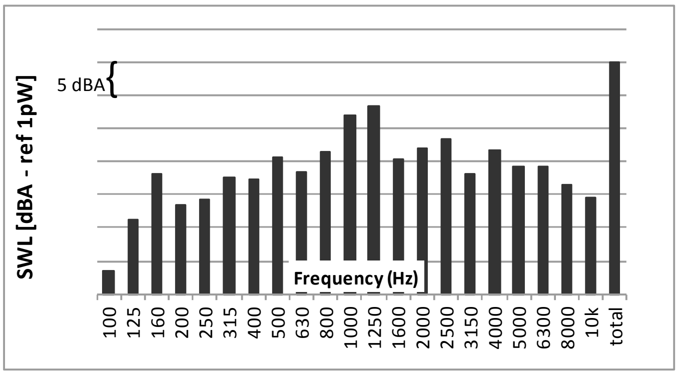


**Figure 11:** Spectrum of the noisy wine cooler.

### 3.2 Refrigerant reprocessing

One of the main characteristics of the wine cooler analyzed in Figure 11 is the presence of very high expansion noise, created by the throttling of refrigerant passing through the capillary tubes. Espindola *et al* (2016) comments that this process produces a turbulent two-phase compressible flow and at the end of the expansion device an under-expanded supersonic jet is usually present. This phenomenon generates not only high acoustic excitation at the expansion device, but also at the evaporator that can transmits it to the wine cooler wall, radiating noise to the environment.

Looking at the temperatures obtained during the wine cooler sound power measurement, it was noticed that there was a significant difference between the temperature of the middle of the condenser and the filter dryer: according to Espindola *et al* (2016), the bigger this difference the bigger the possibility of having non-condensable gases in the refrigeration circuit. Besides, a non-condensable gas can potentially affect the system operation, impacting its thermodynamic efficiency and creating the flow noise. One of the main causes of the presence of non-condensable gases mixed with refrigerant is a bad quality of the evacuation process on the production line, so it was decided to remove all the refrigerant from the unit and recharging following good practices related to the evacuation process.

After reprocessing the wine cooler with the original refrigerant charge, the sound power level was re-measured. In Figure 12 it is verified some improvement in terms of sound level and in Figure 13 is shown the reduction of the temperature difference between the middle of the condenser and the filter dryer in one of the circuits.

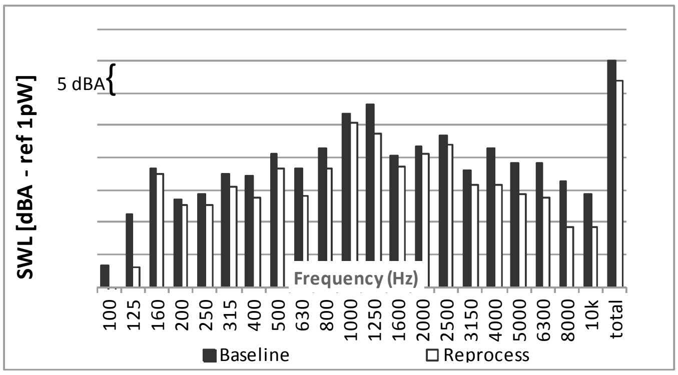


**Figure 12:** Comparison between noisy wine cooler before and after reprocessing gas charge.

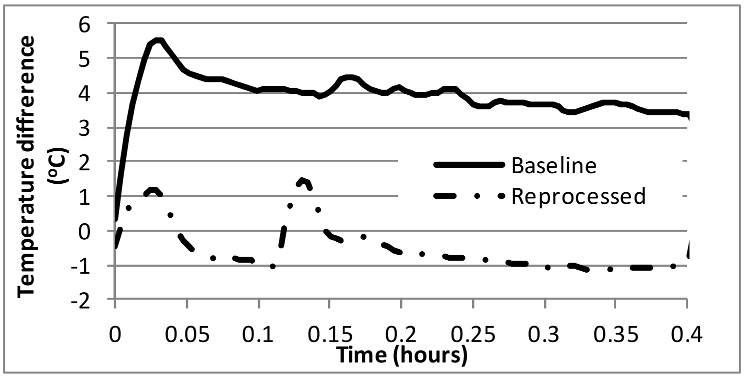


**Figure 13:** Difference of the temperature between the middle of the condenser and the filter dryer.

Despite the noise reduction shown in Figure 12, customer requested help to reduce even more the wine cooler sound level, so some other techniques of noise reduction were evaluated.

### 3.3 Noise optimization

Even reprocessing the refrigerant charge, the wine cooler sound still presented the flow noise radiated in the region of the capillary tubes. In order to avoid big modifications in unit components and refrigerant charge and due to the request of the customer of reducing the sound level in 5 dBA compared to the baseline, it was decided to evaluate some passive noise reduction technique.

As a result of some internal discussions, mastic material was placed in condenser region with the goal of damping the system wall radiation. This action was taken because capillary tubes and evaporators were inside the wall behind condensers, exciting it during refrigerant expansion and due to the fact that the redesign of the capillary tubes would be much more difficult. Figure 14 shows the rear part of the wine cooler, considering baseline and the configuration with mastic material.

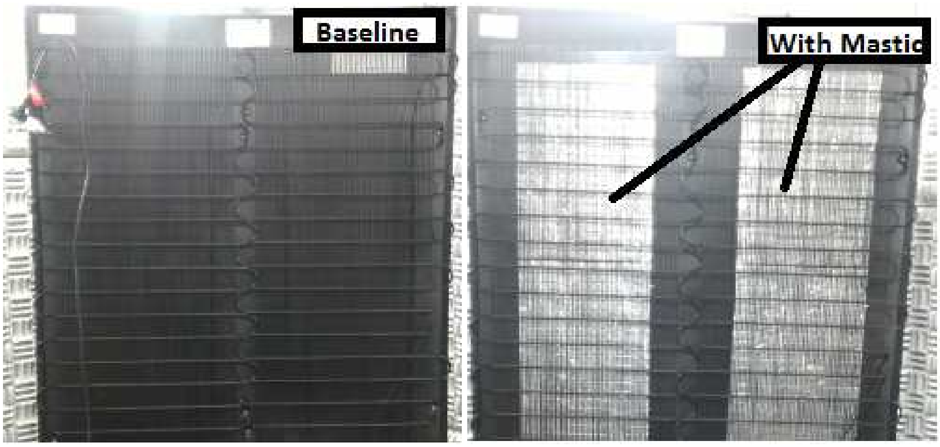


**Figure 14:** Rear part of wine cooler without and with mastic material.

After obtaining positive results in energy consumption and verifying small impact in the refrigeration capacity, sound power evaluations were carried out. Figure 15 illustrates a comparison of the overall sound levels among the baseline, the reprocessed and the optimized (with mastic material) configurations during the first three hours of working. Huge improvement along first 80 minutes has been observed.

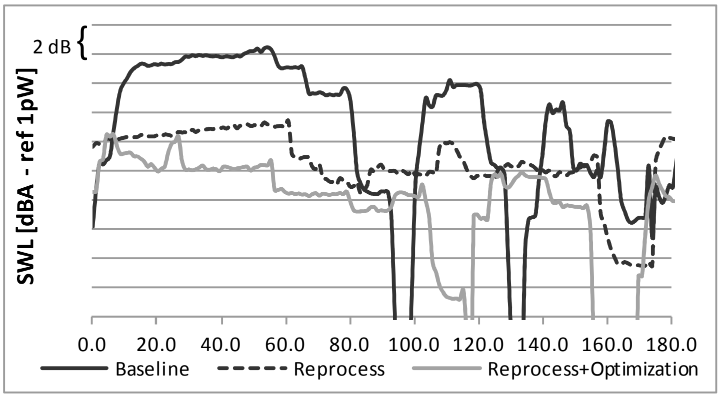


**Figure 15:** wine cooler overall sound level during first three hours working.

Figure 16 includes in the chart presented in Figure 12 the spectrum of the optimized configuration.

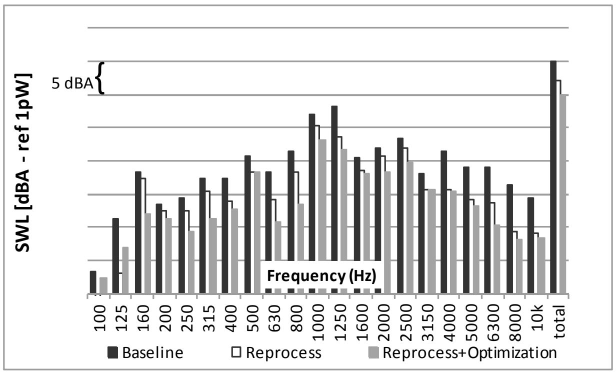


**Figure 16:** spectra of noisy wine cooler compared in three different configurations.

It is concluded that the improvements evaluated in the unit provided 5 dBA of noise reduction compared to the baseline, meeting the criteria set by the manufacturer. Besides, the sound quality improved drastically, since the flow noise reduced even more. With the optimization of the sound level and the sound quality and verifying only small impacts in the cabinet power consumption and in the compressors capacity, it was decided to implement the process and the product solutions.

## 4. CONCLUSIONS

This paper presented two cases that the refrigerant flow created increase of sound level, with serious impact in the sound quality, generating complaints of the final users: one of them was related to a drinking fountain and the other one to a wine cooler.

The problem related to the drinking fountain impacted particularly frequencies over 2500Hz; therefore, the conclusion was the main source of the noise had at least partial relationship with the radiation coming from the compressor enclosure. Due to this fact, the use of an asphalt blanket sheet on the compressor cover helped to reduce the noise as a preliminary solution for the complaint.

In order to better understand what was increasing the sound level of the drinking fountain five minutes after draining two liters of cool water, three thermocouples and two pressure transducers were installed in the suction and the discharge tubes. With these transducers, it has been identified that with the regular refrigerant charge, the refrigerant was completing the transformation to superheated vapor very close to the compressor, exciting its cavity. Reducing in 15% the refrigerant charge, it was assured that the refrigerant was in vapor state inside the compressor, solving the noise problem.

A wine cooler with very high flow noise was also analyzed after customer requested 5dBA of noise reduction: first of all, temperatures were measured and it was noticed big temperature difference between environment and condenser which, according to some references, could be related to the presence of non-condensable gas.

After recharging the wine cooler with the same refrigerant charge, it was verified a huge improvement in terms of noise, but still not meeting customer´s target, so an additional action was taken: asphalt blanket sheets were placed in unit´s wall, near capillary tubes. Due to this, wine cooler sound level reached the requirement requested by the customer.

The two cases studied in this work showed two different situations of high noise and poor sound quality: one of them impacting the high frequencies of a drinking fountain and the other one affecting the mid frequencies of a wine cooler. Asphalt blanket sheets helped to improve the sound level but only using transducers to better understand the refrigeration cycles, it was possible to redefine refrigerant charge in both units, solving the customer complaints.

## NOMENCLATURE

| | | |
|---|---|---|
| SWL | Sound Power Level | (dB - ref. 1pW) |
| ref. | reference | (–) |
| Evap | evaporator | |

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