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Sound absorption of egg boxes and trays

António P. O. Carvalho [a)]
Sónia C. P. Vieira [b)]
Laboratory of Acoustics, Faculty of Engineering, University of Porto
4200-465 Porto, Portugal

It is not uncommon to find amateur music rehearsal rooms covered with egg boxes as it is an economical solution to allegedly improve the acoustics. This research characterizes acoustically the use of alveolar containers for storage and transportation of food supplies. Eight distinct types of boxes for eggs and trays for fruit were analyzed, in a total of 21 different arrangements and materials. The results of sound absorption coefficients (α_S) measured in a reverberant chamber are presented and discussed. In summary, NRC values between 0.20 and 0.70 were obtained.

1 INTRODUCTION

The first egg box (out of paper) was invented in the early 20th century but only in the 1950s today's most common egg cartons appeared. Regarding their use in acoustics, in our days, many places for music, especially those intended for domestic functions, such as test rooms of philharmonic bands, "garage bands" or recording studios, with low economic power, resort to improvised materials or systems, economic and easy to apply. A system that is widely used in such places is the "egg boxes".

The objective of this work is to characterize the acoustic performance of those alveolar containers for storage and transportation of food supplies (eggs and fruit) as an absorbing material[1].

2 METHODOLOGY

Sound absorption measurements were done in the Laboratory of Acoustics of the College of Engineering of the University of Porto 200 m^3 reverberation chamber using EN ISO 354[1,2]. Four positions source/microphone were used and, in each, three measurements, with a total of 48 measurements for each test. The samples used can be grouped in two materials: "paper" and "plastic" (Fig. 1). The paper alveolar containers are of molded cellulose and the ones in plastic

[a] carvalho@fe.up.pt
[b] ec09136@fe.up.pt

(foamed or clear plastic) are polypropylene (PP) or polystyrene (PS) (for egg cartons). Also used in one test, was a 30 mm thick polyurethane flexible foam board. In total, 21 situations were evaluated (including *open* and *closed* boxes and using their *normal* and *inverted* positions).

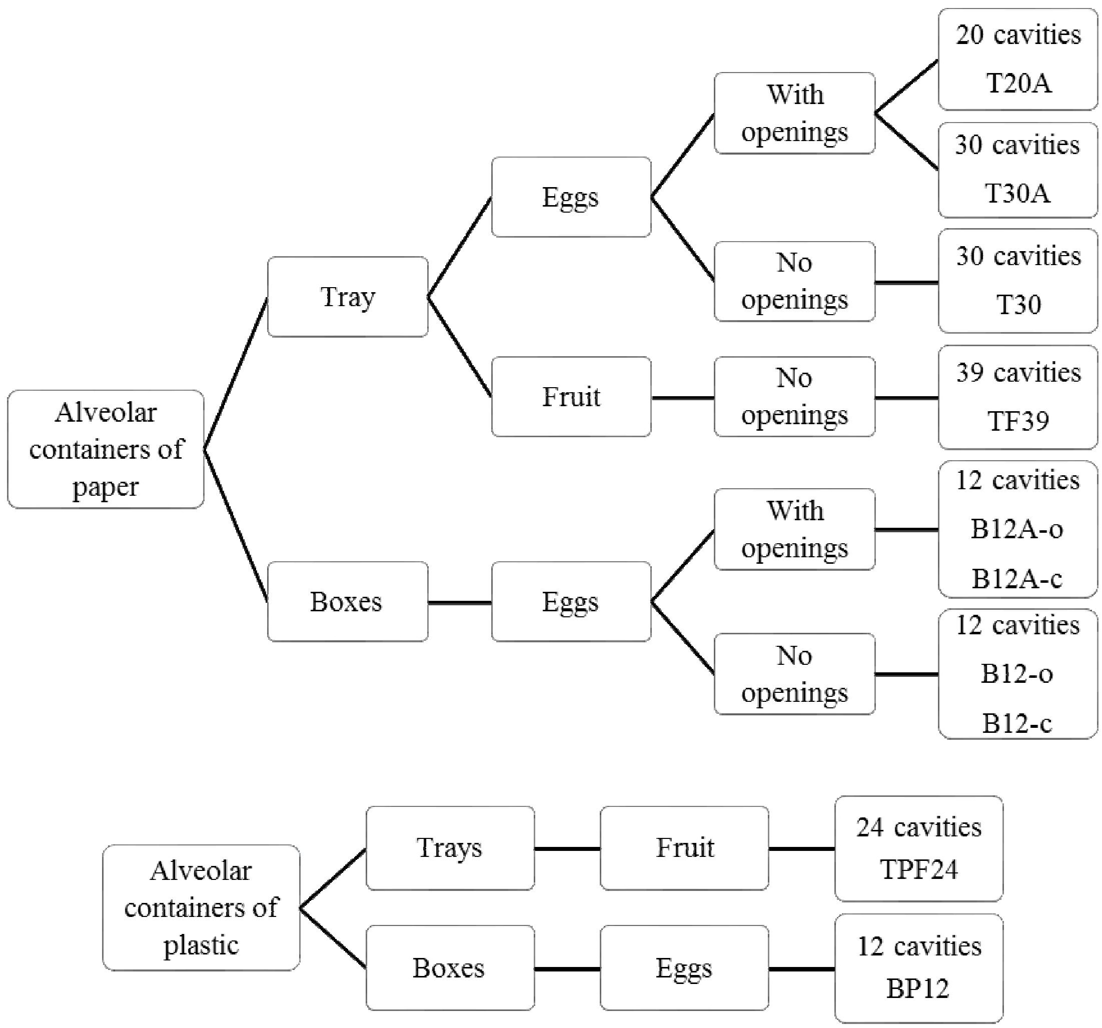

Fig. 1 – Alveolar containers of paper (top) and plastic (below) analysed (T - Trays, B - Boxes/paper; A - with small Apertures, o - open, c - closed, F - Fruit, P - Plastic).

3 RESULTS

3.1 Paper Alveolar Containers

3.1.1 Samples T20A and T30A

The T20A sample is composed of trays of molded cellulose for 20 eggs with small apertures (Fig. 2). Two surface positions, regarding the exposure to sound, were tested: normal (-n) and inverse (or upside down) (-i). There are differences in the sound absorption coefficient values using the *normal* and *inverse* surface of the trays (Fig. 14). However, there are only differences in the middle and high frequency bands. In the low frequencies practically does not exist sound absorption.

The sound absorption coefficient results of sample T20A-i (inverse surface) are a little superior in most frequencies and this is due, mainly, to the fact that the area exposed to sound waves is superior with the inverse surface of the trays, as the small apertures are “covered” by the reverberation chamber floor, that is, having a more exposed area the energy of sound waves dissipate faster.

In medium and high frequency bands, a translation is seen (Fig. 14) between the results from the 500 Hz, when the T20A-i (inverse surface) test results are more to the left. This happens as there are small openings in the trays. When the trays are with the normal face in contact with the floor, the openings are "covered" by floor and are not directly exposed to sound waves, but if the position of the trays is the opposite, the openings are directly exposed to sound waves and there is an air box up to pavement (reflector) that could act as a resonator. However, contrary than expected, the small openings maybe not function as resonators (when the trays are on reflector material) and make the results of the T20A-n (normal surface) to be more to the right of the T20A-i (inverse surface) results.

The T30A is composed of trays of molded cellulose for 30 eggs with small apertures and were tested in both surfaces: normal (-n) and inverse (-i) (Fig. 3). The Fig. 14 presents the results of the sound absorption coefficient values of the two surfaces and there are differences, similar to those in sample T20A and the reasons are the same as those then stated.

As this sample T30A had small openings, such as T20A, and as they do not act as resonators on its normal surface (when the trays were on reflector material) as one would expect, the normal surface of the sample T30A was also tested but now over 30 mm thick polyurethane flexible foam boards (Fig. 4) to see if the openings had an acoustically positive effect. In Fig. 14 it is shown that at medium frequencies there is a steeper peak that can support the conclusion that the trays' small openings might work as resonators (acting in the medium frequency bands) on their normal surface but being placed over an absorbent material.

Analyzing the three tests of sample T30A (Fig. 14) it is observed that the sample placed on 30 mm polyurethane foam boards (absorbent surface) has a much better effect in the low and mid frequencies, and the small apertures have the expected effect. With regard to the high frequencies, the results of the three tests are not very different. From the 1250 Hz frequency band the sound absorption coefficient results of sample T30A-n-ABS descend to similar values as T30A-n, where once again it can be seen that these openings might work as resonators (when the trays are on absorbent material), and these only act on medium frequencies.

Fig. 2 and 3 - T20A - Tray for 20 eggs (with small apertures) when the normal surface is facing up; T30A - Tray for 30 eggs (with small apertures) when the normal surface is facing up.

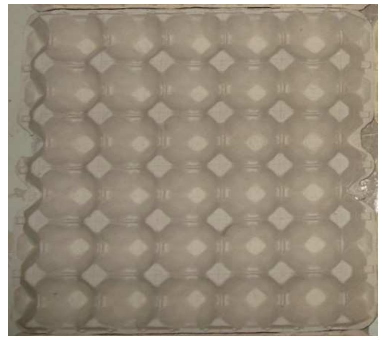

Fig. 4 and 5 – T30A-n-ABS (left) - Trays for 30 eggs with small apertures (when the normal surface is facing up) on absorptive polyurethane foam boards 30 mm thick; T30-n (rigth) - Trays for 30 eggs when the normal surface is facing up.

Fig. 6 and 7 – (left) B12A-o - Boxes (open) to 12 eggs (with small apertures) when the normal surface is facing up; (right) B12A-c – Boxes (closed) for 12 eggs (with small apertures) when the normal surface is facing up.

Fig. 8 and 9 – (left) B12A-o-n-WL – Boxes (open) for 12 eggs (with small apertures) without lids with the normal surface facing up (normal surface about the lids); (right) B12-o – Boxes (open) for 12 eggs when the inverse surface is facing up.

Fig. 10 and 11 – (left) B12-c - closed Boxes to 12 eggs when the normal surface is facing up; (right) TF39 - Trays of fruit with 39 cavities when the normal surface is facing up.

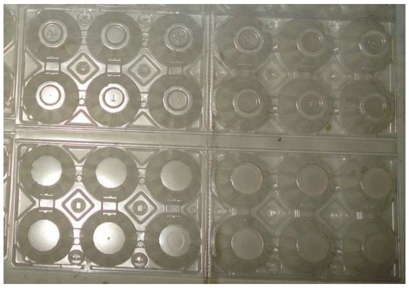

Fig. 12 and 13 – (left) BP12 - Boxes of plastic for 12 eggs when the inverse surface is facing up; (right) TPF24 - Trays of plastic for fruit with 24 cavities when the normal surface is facing up.

3.1.2 Sample T30

Sample T30 is composed of trays of molded cellulose for 30 eggs (Fig. 5). Two surfaces' positions were tested regarding exposure to sound: normal (-n) and inverse (-i).

Sample T30 in both surfaces (normal (-n) and inverse (-i)), as the T20A (trays of molded cellulose for 20 eggs with small apertures) and T30A (trays of molded cellulose for 30 eggs with small apertures) practically does not present absorption in the low frequencies and there are differences in the results achieved at normal and inverse surfaces in middle and high frequency bands (Fig. 14). These differences could be due to the difference in the amount of area exposed to sound waves but in this case the normal and inverse surfaces areas are apparently equal and thus differences are possibly due that the inverse surface is rough.

It is seen that the sound absorption coefficient test results to sample T30A-i (inverse surface) are a bit higher in most frequencies and this may be due to the roughness that exists in the inverse surface of the trays, this is, being the surface rougher the energy of sound waves dissipates more quickly, as in samples T20A and T30A (Fig. 14).

As for the translation that occurs in samples T20A and T30A results, in this sample (T30) that does not happen, because the only difference between the two sides is the roughness that changes.

3.1.3 Sample B12A

The sample B12A it composed of boxes of molded cellulose for 12 eggs with small apertures (Fig. 6 and 7). This sample was tested by the normal (-n) and inverse (-i) surfaces when the boxes were open (-o) or closed (-c).

The results show (Fig. 15) significant differences in the high and medium frequencies, and between the two surfaces, while at low frequencies practically does not exist sound absorption. It is not easy to assess the reasons why the results vary because they have very different configurations on both sides (Fig. 6 and 7), being more roughened by the normal part when the boxes are open. However, it can be observed (Fig 15) that the results to the inverse surface, in addition of growing faster, also fluctuate more often. This may be due to the most robust form that the box has in its inverse surface. On the normal surface, the peak value around the 1250 Hz frequency band maybe due to the protrusions (where the small apertures are) that the box has in its constitution (Fig. 6), but it is not a very high value, maybe because the floor material of the reverberation chamber is reflector.

The Fig. 15 also presents sample B12A by normal (-n) and inverse (-i) surface when the boxes were closed (c) and also with the boxes without lids (WL) (Fig. 7 and 8). Analyzing only the results on the "normal" and "inverse" surfaces when the boxes were closed, it is shown that the measured sound absorption coefficient (α_S) exceeds 1.0 at 500 and 630 Hz, which is not physically possible to the α (the theoretical value). This happens because only the area in horizontal projection is accounted for, that is, it is not considered the actual area including the 3D relief of the boxes (in inverse surface) nor the lateral area of the samples (in inverse and normal surface) which are significant due to the height of the closed boxes (Fig. 7).

The peak in the 500 Hz (both in B12A-c-n and -i) is mainly due to the height of the sample elements (Fig. 7). By Fig. 15 it is observed that there are significant differences between the results of tests to the closed boxes when the normal and inverse surface is facing up, mostly from the 1 kHz frequency, while in low and medium frequencies practically there are no differences. Those disparities are perhaps due to the fact that on the "inverse" surface there is relief while when "normal" surface is facing up, it is smooth.

The test results of these boxes without lids have a peak at 800 Hz and from there the values decrease up to 2500 Hz (Fig. 15). The peak is perhaps due to the protrusions that have an opening and act as resonators when they are placed over the lids.

The Fig. 15 also presents the results of the sound absorption coefficient of the five tests of sample B12A where B12A-c-i has the best results (from 315 to 3150 Hz the values are greater than 0.60).

Comparing B12A-o-n-WL and B12A-o-n (Fig. 15), the first has the peak at 800 Hz while B12A-o-n has it at 1250 Hz. This difference is perhaps due that B12A-o-n-WL has the protrusions with small openings over absorptive material and that the boxes, superimposed over the lids, have a greater height.

3.1.4 Sample B12

The sample B12 it composed of boxes of molded cellulose for 12 eggs (Fig. 9 and 10). The normal (-n) and inverse (-i) surfaces were tested when the boxes were open (-o) and closed (-c).

As in the previous samples, differences exist in mid and high frequencies, between exposure in the normal (-n) and inverse (-i) surface of the sample (Fig. 15). The reason why there are these dissimilarities is not easy to state because there are many differences in the normal and the inverted surface. However, at high frequency bands, the results despite oscillating more when the sample is at its inverse surface, do it in small variations and their values are higher in all frequencies. This is perhaps due because the inverse surface is more robust (with more relief). Regarding the fact that the results of the inverse surface are more to the left (that is, to increase faster) this is due perhaps that the boxes' openings are covered by the pavement of the reverberation chamber, as was the case T20A (trays of molded cellulose for 20 eggs with small apertures) and T30A (trays of molded cellulose for 30 eggs with small apertures).

As with the results of the previous samples there is also a peak at B12-c-n (Fig. 15). This happens because there are some openings at the box lids and, as the boxes are closed and the carton material is absorbent, they may act as resonators, with its frequency of maximum effectiveness at 800 Hz. This peak is not as pronounced as in other cases and this is possibly due to the fact that the openings are large. Comparing the three tests of sample B12 (Fig. 15) it can be seen that in low frequencies does not exist practically absorption in both surfaces of exposure ("normal" and "inverse") when the boxes are open. However, the sample with the closed boxes already shows sound absorption although is minimal. It can also be seen that the results with the closed boxes are better at medium frequencies and grow faster.

3.1.5 Sample TF39

The sample TF39 it composed of trays for fruit with 39 cavities of molded cellulose (Fig. 11) and were tested both surfaces: normal (-n) and inverse (-i).

There are differences in the medium and high frequencies between the exposures of "normal" and "inverse" surfaces and at the low frequencies practically there is no sound absorption (Fig. 14). These differences in medium and high frequencies are due to the fact the exposed area to sound waves is superior in the inverse surface of the trays (that is, having a larger exposed area the energy of sound waves dissipate faster).

The results in high and medium frequency bands show that with the inverse surface the peak of sound absorption coefficient lies in the 1 kHz and then descends to a minimum of 2 kHz, while in the normal surface the peak lies at 1250 Hz and then descends to a minimum at 2500 Hz. That is, there is a translation of the results between the two exposure sides and always with the same frequency difference. This happens maybe because the inverse surface has a greater relief (largest area exposed to sound waves).

3.2 Plastic Alveolar Containers

The sample BP12 it composed by boxes of plastic (polystyrene - PS) for 12 eggs (Fig. 12) and were tested by its normal (-n) and inverse (-i) surfaces, with the open boxes (-o). There are differences in the medium and high frequency bands between the exposure at "normal" and at the "inverse" surface and on the low frequencies practically does not exist sound absorption (Fig. 15). These differences in medium and high frequencies are due perhaps to the fact that the inverse surface has a greater relief exposed to sound waves.

The sample TPF24 it composed of trays of plastic (polypropylene - PP) for fruit with 24 cavities (Fig. 12) and were tested on both surfaces of sound exposure: normal (-n) and inverse (-i). There are differences in medium and high frequencies between the exposures by the normal and the inverse surfaces, and at the low frequency bands practically does not exist sound absorption (Fig. 14). These differences in medium and high frequencies are due to the fact that the inverse surface has a greater relief exposed to sound waves. As the sample material is plastic and very light, it was not expected to have any sound absorption, but it exists and it is significant in some frequencies. This is possibly due as the elements are very light and vibrate with the sound waves, dissipating this way some of the energy.

3.3 Summary of Results

The Fig. 14 presents the sound absorption coefficient (α_S) results of all tests to trays for eggs or fruit. Analyzing these results (excluding sample T30A-n-ABS: trays for 30 eggs with small apertures exposed to the sound by the normal surface over absorptive foam, there is a difference in the frequency where the maximum value of the sound absorption coefficient is.

When the trays have small apertures (A) and with the normal surface (-n) facing up, the peak value is further to the right (higher frequencies) and has a slightly lower α_s value than when the trays had the normal face facing down. This means that the openings may not function as resonators and even when they are in contact with the floor of the reverberation chamber the results are a little better. But the small apertures do not work as resonators perhaps because the floor of the reverberation chamber is reflector. This was verified by sample T30A-n-ABS, as the results of sound absorption coefficients were far superior to the values of T30A-n (trays for 30 eggs with small apertures exposed in the normal surface) and from all other samples of trays for eggs.

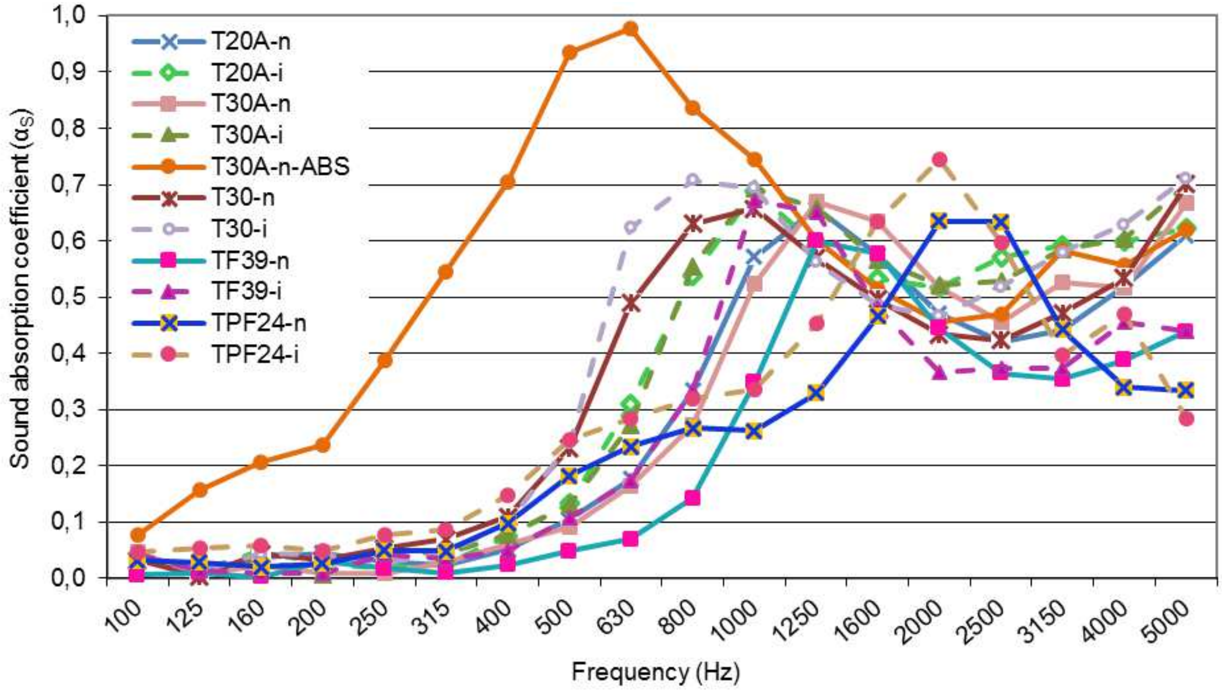

Fig. 14 – Sound absorption coefficient (α_S) for trays for eggs and fruit (T - Trays, A - with small Apertures, n - normal surface, i - inverse surface, ABS - absorptive polyurethane foam boards, F - Fruit, P - Plastic).

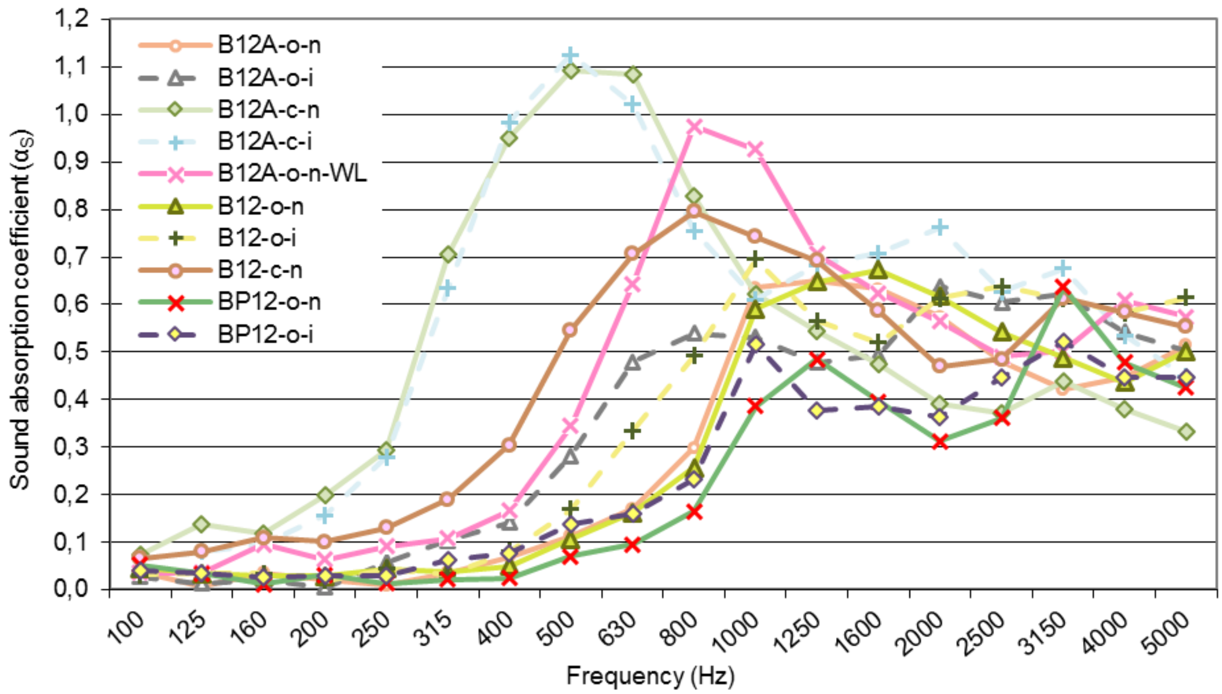

Fig. 15 – Sound absorption coefficient (α_S) for boxes for eggs (B - Box, A - with small Apertures, o - open, c - closed, n - normal surface, i - inverse surface, WL - Without Lid, P - Plastic).

Comparing the α_S results of trays for eggs (T20/30) and fruit (TF) it can be observed that they are very different. The trays for fruit reach the peak at higher frequencies but with similar values to the peak values for trays for eggs (excluding the sample T30A-n-ABS which has a much more pronounced peak).

In spite similar values for the peaks of sound absorption coefficients, the TPF24-i has its best performance between 1600 and 2500 Hz and the worst performance between 500 and 1600 Hz or between 2500 and 5000 Hz. In contrast with T30-i the reverse happens. But the differences on the values of the sound absorption coefficients between T30-i (paper trays) and TPF24-i (plastic trays) in the frequency range where TPF24-i has the best performance, are lower than the differences in the frequency intervals where TPF24-i has the worst results. Therefore the T30-i (paper tray) (excluding T30A-n-ABS which is the sample with the best results of all trays) has better results than the trays for fruit (TF).

Concerning fruit trays (TF), the plastic trays have the peaks at higher frequencies than those of molded cellulose. And the plastic trays for fruit exposed by the inverse surface (TPF24-i) have better sound absorption coefficient values than trays of molded cellulose for fruit (TF39) in almost all tested frequency bands.

Fig. 15 shows the results for boxes for eggs or fruit. The differences are significant among the results of the boxes when they are open or closed. It shows that the peak for the open boxes to 12 eggs (excluding B12A-o-n-WL that despite being open behaves identically as the closed boxes) is almost always inferior and is at higher frequency that the boxes for 12 eggs when closed. In the frequencies between 160 and 630 Hz, the B12A-c exposed by its normal and inverse surface, continues to have better results, but from 1 kHz is B12A-c exposed by its inverse surface, that has higher values almost always.

In relation to the open boxes (except B12A-o-n-WL that behaves similarly to the closed boxes) the results are distinct in terms of results' evolution (growth and decrease, maximum values rightmost or leftmost, etc.). The reasons are not clear as the boxes have very different geometries and even in each box they do not have exactly the same geometry. None of the open boxes stands out positively but the BP12-o (open box in plastic for 12 eggs) sticks out negatively because in almost all the frequencies, has lower values than the other samples. Therefore, the paper boxes for 12 eggs (open or closed) are better than the plastic box for 12 eggs open.

It should be noted that closed boxes for 12 eggs (mainly the B12A-c exposed by its inverse surface) have better performance than the open boxes for 12 eggs.

Analyzing the measured sound absorption coefficients (α_S), in Fig. 15 it can be seen that they are larger to 1.0 in the 500 and 630 Hz, what is not physically possible for α (theoretical value). This happens because only the area in its horizontal projection is considered, that is, it does not account for the actual exposed area including the boxes' relief (in inverse surface). Also not considered is the lateral area of the lips of the samples (in inverse and normal surface) which is significant due to the height of the closed boxes.

In Fig. 14 and 15 the samples with higher sound absorption coefficients are B12A-c, B12A-o-n-WL and T30A-n-ABS. The B12A-c-i is the one that has the best performance in spite that at the frequency of its maximum effectiveness the measured sound absorption coefficient (α_S) is theoretically impossible to reach in α (theoretical value) as the values are greater than the unity. The TF39-n and BP12-o-n are the ones that have worse results in nearly all frequencies.

The Fig. 16 presents the results of tests to all alveolar containers for the NRC (Noise Reduction Coefficient as in ASTM C423-90A[3]). The B12A-c, T30A-n-ABS, B12A-o-n-WL and B12-c-n are the ones with the best values.

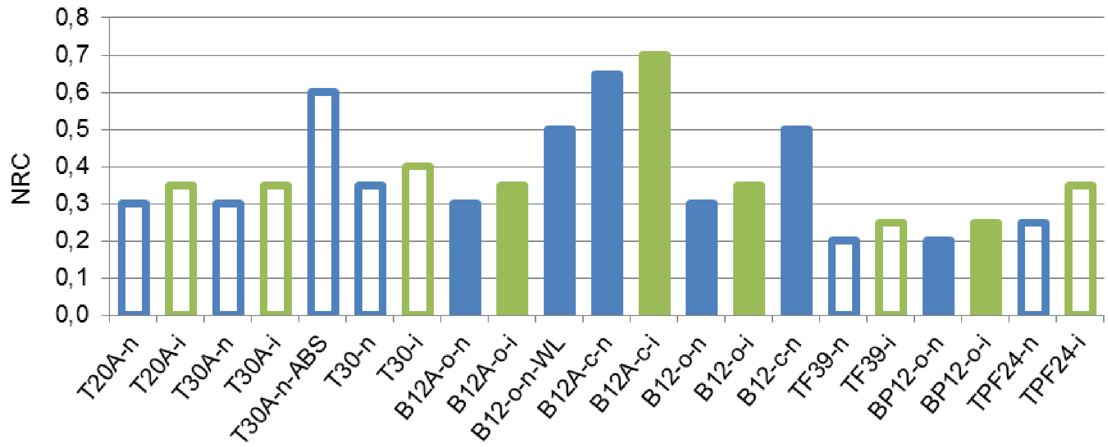

Fig. 16 – NRC of all alveolar containers (T - Trays, B - Boxes, A – with small Apertures, ABS - absorptive polyurethane foam boards, o – open, c – closed, n – normal surface, i – inverse surface, WL - Without Lid, F – Fruit, P – Plastic).

4 CONCLUSIONS

The values of the index *NRC* vary between 0.20 and 0.70. The B12A-c-i is the sample that stands out from all others with the best sound absorption performance and the BP12 and TF39 are the worst. The list below presents the main conclusions drawn (in each type of comparable situation, row-by-row).

- Trays without openings (best) vs. Trays with openings (excluding T30A-n-ABS) (worst);
- Trays of paper for eggs (best) vs. Trays of paper for plastic (worst);
- Trays of plastic for fruit (best) vs. Trays of paper for fruit (worst);
- Sample T30A-n-ABS (best) vs. Other samples of trays and boxes (open) for 12 eggs (worst);
- Closed boxes for eggs (best) vs. Open boxes for eggs (worst);
- Boxes (open or closed) of paper for eggs (best) vs. Box of plastic for eggs (worst);
- Closed boxes for eggs (best) vs. Trays for eggs and fruit (worst);
- Trays of plastic for fruit (best) vs. Box of plastic for eggs (worst);
- Sample exposed by inverse surface (best) vs. Sample exposed by normal surface (worst);
- Sample B12A-c-i (best) vs. All other samples (worst).

5 REFERENCES

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