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A STUDY OF ACRYLIC ENCLOSURES FOR NOISE CONTROL IN THE FOOD INDUSTRY

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INTRODUCTION

Within the food industry, empty bottles and cans in reverberent canning and bottling halls can lead to sound pressure levels exceeding 100dB(A) [1 and 2]. It is necessary to reduce these levels to an acceptable working level. Where treatment at source is not always possible, an enveloping enclosure would seem a logical consideration.

The Industry is governed by strict environmental and hygiene guidelines which must be borne in mind when considering the enclosure design:
- all surfaces must be smooth and 'hard' to enable them to withstand the most rigorous cleaning
- the conveyors and machinery must be completely visible.

The former criteria results in the bottling/canning halls having a high reverberation time resulting in the high noise levels.

This problem has been investigated at length with a view to assessing suitable materails for an enclosure. S.A. Waggoner [3] identifies acrylic as a material which satisfies the two main criteria and in fact he tests his recommendation using 300mm cube but does not indicate how the full-scale noise benefits are to be predicted. It was therefore decided to assess the full-scale benefits of a typical food industry enclosure using acrylic sheet.

ENCLOSURE DESIGN ASSESSMENT

An experimental enclosure using acrylic sheet should have the following features which would have to be adequately assessed prior to making any recommendations:
- the enclosure should be open topped.
- holes of varying sizes should be accommodated to permit the effects of entering conveyors and access opeinings to be accounted for.
- the enclosure should have a gap of about 150mm at the bottom to facilitate washdown and cleaning procedures.

The material used, as already identified is hard and non absorptive.

A perusal of existing theory was decided upon to establish whether or not an experimental rig was required in order to assess the benefits (or otherwise) of an acrylic noise enclosure.

THEORETICAL CONSIDERATIONS

Summary of existing Theory

P.P. Iyer [4] - developed a simple theoretical model to predict the effectiveness of enclosures for noise control. However this model does not allow for a typical enclosure for the food industry to be considered as it assumes that the enclosure is complete and located within an anechoic field. There is no provisions for assessing either an incomplete enclosure (being one open-topped and/or with access holes) or one located in a reverberent field.

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Kurze [5] - presents a paper evaluating previous work on this subject but limits his account to the anechoic field. However he concludes that Maekawa's Prediction chart [6] for barrier attenuation gives reliable data for predicting sound pressure levels in a barrier's shadow-zone.
Czarnecki [7] - assumes that the barrier surfaces are absorptive and that the height of the barrier is small compared with both the source/barrier distance and the wave length of the noise source.
Tweed and Tree [8] - compare the Jackson Theories [9 and 10] to Ver [11]. They conclude that, where Jackson considers that the enclosure and the source can be modelled as two infinitely rigid planes coupled by the spring stiffness of the intervening air cavity and Ver considers that the noise within the enclosure is diffuse, neither theory adequately predicts an enclosure's insertion loss with sufficient accuracy to be considered as a design tool.
Floyd [12] - makes the same assumption as Ver [11] and considers that an enveloping 'barrier' can "best be visualised as an enclosure without the roof". However in doing so he does not go on to consider the sound pressure build-up which is invetiable with a non-absorptive enveloping barrier. Consequently, although the comparison between his measured and computed results is very good, the paper concedes that in a typical industrial situation the predicted insertion loss would be greater than the measured insertion loss.
Moreland and Minto - [13] - offer an example of an actual working barrier. In their analysis they assume that the sound power of the source does not build-up with the inclusion of a barrier which is true where the barrier does not envelope the source. They also only consider the shadow-zone of the barrier where diffraction over the barriers does not affect the measured results and they do not make any allowance for the reverberant noise resulting from a non-anechoic location.
Junger [14] - takes Jackson's coupled model [9 and 10] and expands it to three dimensions which, in enhancing the mathematical analysis of the theory, results of greater accuracy but predicts slightly higher insertion losses.
Tweed and Tree [15] - in a follow up article, compare Junger's [14] theory to Jackson's [9 and 10] and Ver's [11] and develop their own model which despite being non-typical of an industrial situation gives similarity between measured and predicted results although the severity of the decrease in resonant insertion losses appears to be over estimated.

Conclusions
As the existing theory does not lend itself to the typical enclosure design proposed it seemed inevitable that an experimental rig had to be devised.

DETAILS OF EXPERIMENTAL RIG

The basis of the experiments was a simulated noise source consisting of a Bruel and Kjaer random noise generator, a peak amplifier and a Nairn loudspeaker. The loudspeaker was placed within air tight cubical boxes of three sizes (600mm, 1200mm, 2000mm) in order to:
- simulate 'typical' machine sizes.
- investigate any coupling effects between the source and the enclosure.
- establish any differences between a point and a plane source.

The acrylic enclosure was constructed of 13mm thick 'acrylic' sheet 2600mm squre by 2500mm high into one side of which square holes of 3 sizes (150mm, 300mm, 600mm) could be introduced. An acrylic ceiling could be attached to the box, to which absorbent tiles could be fixed if required. The whole enclosure could be raised by 150mm and air tight gasketing could be removed. The rig was located, for the purposes of the experiment, in a partially empty warehouse which had a critical reverberation time of 2.67 secs at 1kHz. This is typical of reverberation times measured within canning/bottling halls.

Secondary tests were carried out in a semi-anechoic area of a car park to compare some of the measured results. Weather prevented a full comparison to take place.

MEASUREMENTS AND THEIR ANALYSIS

Presentation of Data
Measurements were taken with and without the enclosure in position so that simple subtraction would give the insertion loss of the enclosure.

The measurements were taken from positions 1m, 3m, and 5m from each of the 4 faces of the enclosure as well as 1m above the level of the top of the enclosure.

To simplify the presentation of data, the readings at each of the distances has been averaged over the four faces. The standard deviation of this averaging has been assessed and the 95% confidence limits has been identified in the tabulated results that follow.

Analysis
The following discussions are based mainly on a comparison of the insertion losses in order to discover the predominant factors in the determination of insertion losses. The discussions are generally based on the 2000mm plywood source unless otherwise identified in the tables.
Size of Noise Source - A comparison of the results obtained from altering the size of the noise source indicates that on a purely dB(A) basis there is no significant variation between box sizes. However when the octave bands were analysed there was a significant increase in insertion loss at 250Hz using the largest source while at 8kHz the insertion loss was detectably decreased. This trend would be expected from normal barrier theory.
Introducing a ceiling - Adding an acrylic ceiling to the basic enclosure gave an expected increase in the insertion loss. The addition of absorbent tiles gave a further increase in the losses. Two reasons for this were considered: i) the increase in the mass of the ceiling would enhance the transmission loss of the ceiling: ii) the absorbency of the tiles might go someway to reducing the pressure build up within the enclosure.
Pressure build up within the enclosure - Although incidental to the purposes of the research, consideration was given to an assessment of the pressure build up within the enclosure. Without a ceiling this pressure build up seemed to be about 6dB(A), and with the ceiling, the inclusion of absorbent tiles seemed to reduce a build up by 4-5dB at the higher frequencies. From this it was deduced that the pressure build up within an enclosure can be significant.
Raising the enclosure - A straight comparison of the effects of raising the enclosure by 150mm show that there is little effect at 1m, no effect a 5m, but has the greatest effect at 3m. - Without a ceiling this can be explained by the fact that the reverberant noise through the top of the enclosure predominates and this is substantiated when the 8dB(A) decrease with the ceiling

in place is noted.

Within the semi-anechoic field a similar test indicated that raising the enclosure decreased the insertion loss by 4dB(A) at all 3 distances.
Introducing Holes - As expected, the nearer the receiver is to the holes, the greater the reduction in insertion loss of the enclosure and with an open topped enclosure there is no significant reduction at distances greater than 1m. When a ceiling is put in the adverse effects of adding holes is quite severe, although a detectable insertion loss is still maintained 1m from a 600mm square hole.

(Note, when considering the effects of holes, only the readings taken at the face containing the holes were considered).
Reverberant and Semi-Anechoic Comparison - As a general overview of the data gathered, the semi anechoic results give a more distinct picture of the effects of an open topped enclosure. However it is clear that this could not subsequently be applied with confidence to the reverberent conditions found in industry.

CONCLUSIONS

Despite the inability to adequately assess the effects of the sound pressure build up within an enclosure, there seems to be a definite case for optimising the design of an enclosure as opposed to altering the acoustics of the space it inhabits. Given a basic open topped acrylic enclosure the most efficient way of increasing the insertion loss would be to add a ceiling even of a non absorbent material such as acrylic. Unfortunately there is resistance within the food and drinks industry to having enclosures with ceilings due to the possibility of condensation dripping into up turned cans/bottles. This in turn could be overcome by creating a mansard or pitched roofed enclosure.

However a typical open-topped enclosure raised 150mm from floor level would give an insertion loss of 4dB(A) at 1m.

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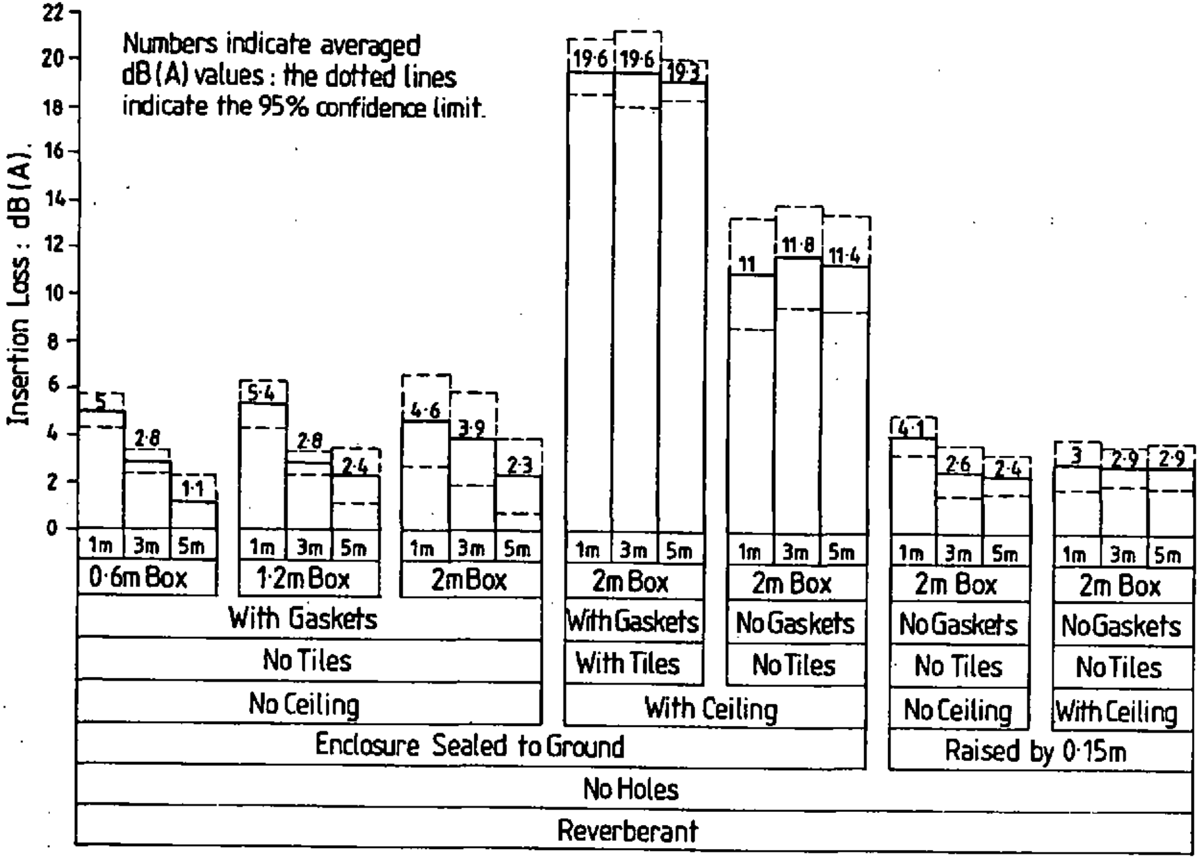
Numbers indicate averaged dB(A) values : the dotted lines indicate the 95% confidence limit.
Insertion Loss : dB(A).
22
20
18
16
14
12
10
8
6
4
2
0
5
2·8
1·1
5·4
2·8
2·4
4·6
3·9
2·3
19·6
19·6
19·3
11
11·8
11·4
4·1
2·6
2·4
3
2·9
2·9
1m
3m
5m
0·6m Box
1·2m Box
2m Box
With Gaskets
No Tiles
No Ceiling
2m Box
With Gaskets
With Tiles
2m Box
No Gaskets
No Tiles
With Ceiling
Enclosure Sealed to Ground
2m Box
No Gaskets
No Tiles
No Ceiling
2m Box
No Gaskets
No Tiles
With Ceiling
Raised by 0·15m
No Holes
Reverberant

Table 1.

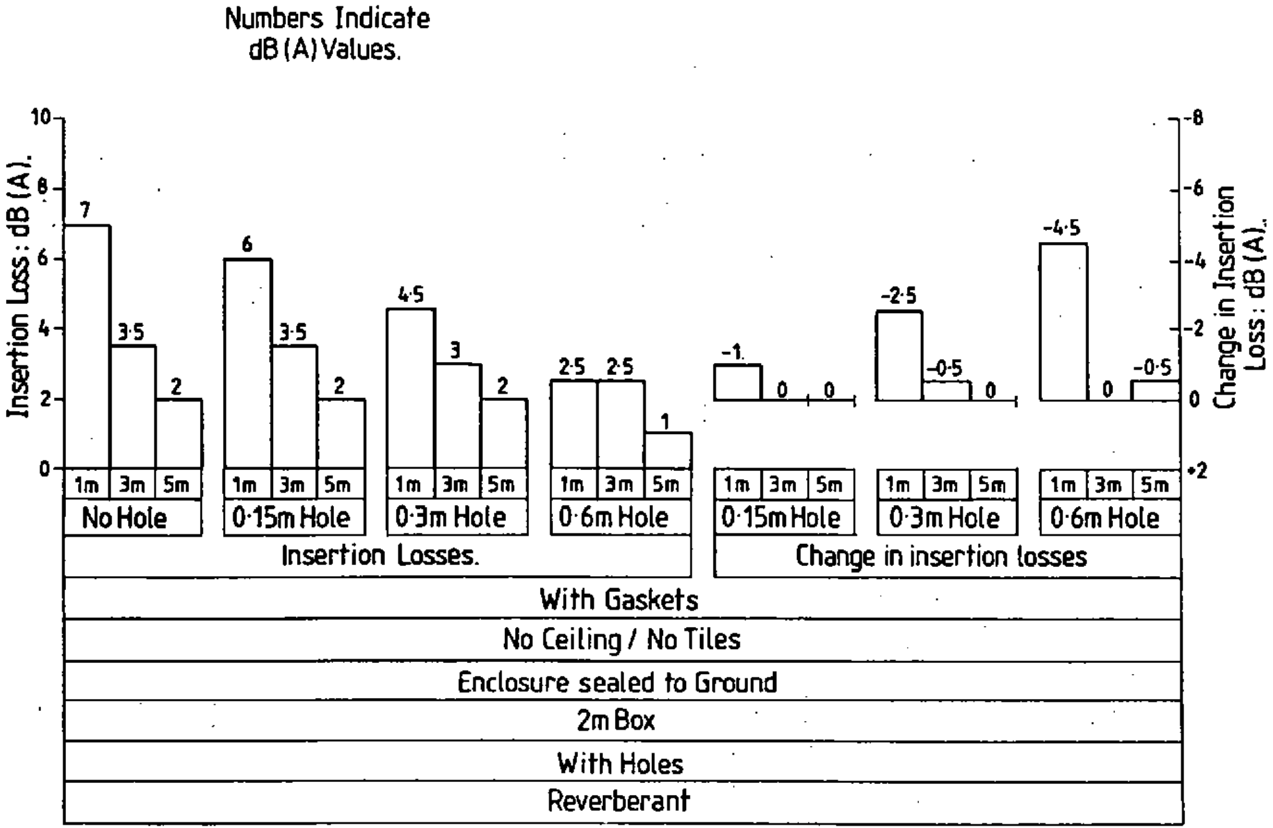
Numbers Indicate
dB (A) Values.
Insertion Loss : dB (A).
Change in Insertion
Loss : dB (A).
7
3·5
2
6
3·5
2
4·5
3
2
2·5
2·5
1
-1
0
0
-2·5
-0·5
0
-4·5
0
-0·5
1m
3m
5m
No Hole
0·15m Hole
0·3m Hole
0·6m Hole
Insertion Losses.
Change in insertion losses
With Gaskets
No Ceiling / No Tiles
Enclosure sealed to Ground
2m Box
With Holes
Reverberant

Table 2.

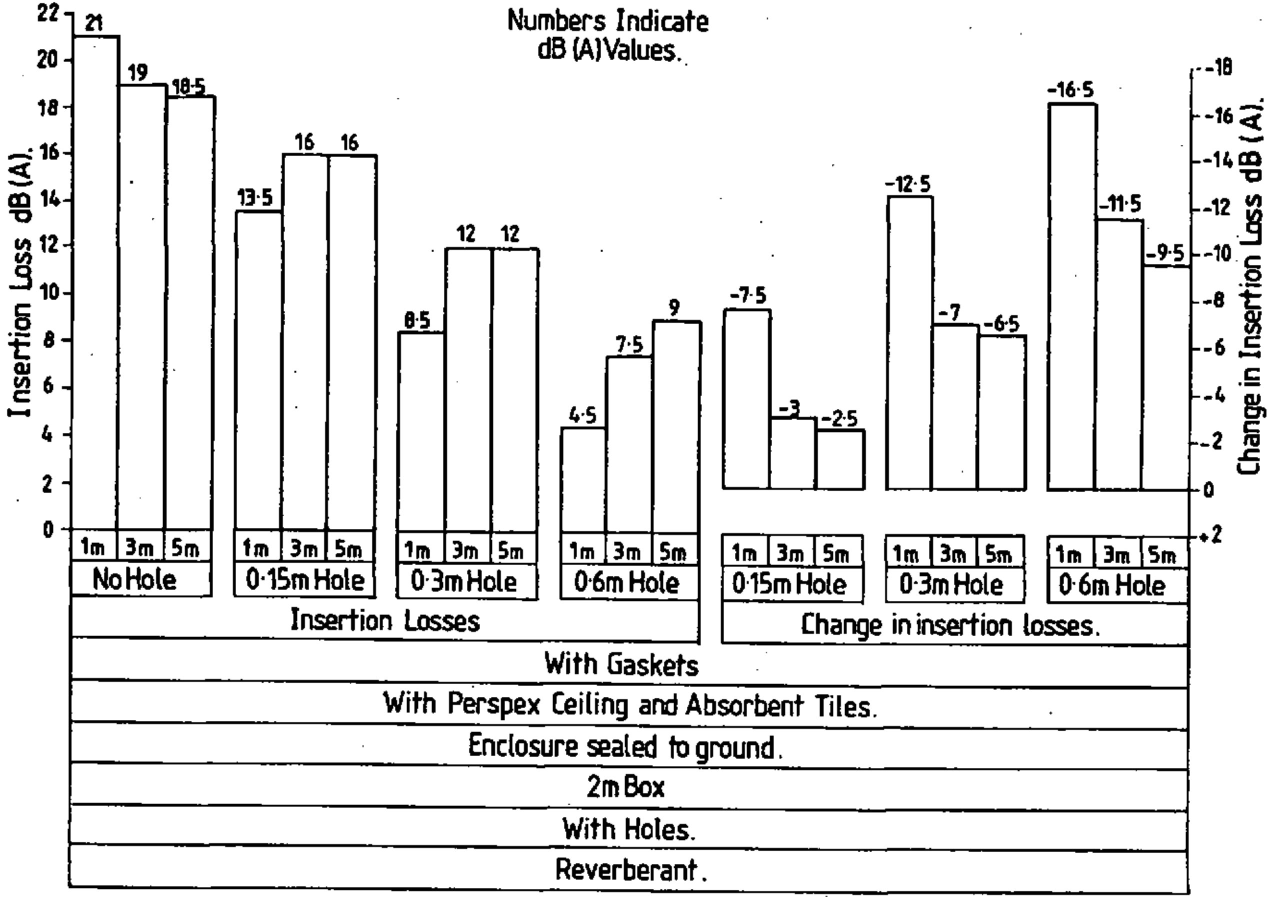
Numbers Indicate dB (A) Values.
Insertion Loss dB (A).
Change in Insertion Loss dB (A).
21
19
18·5
13·5
16
16
8·5
12
12
4·5
7·5
9
-7·5
-3
-2·5
-12·5
-7
-6·5
-16·5
-11·5
-9·5
1m 3m 5m
No Hole
0·15m Hole
0·3m Hole
0·6m Hole
0·15m Hole
0·3m Hole
0·6m Hole
Insertion Losses
Change in insertion losses.
With Gaskets
With Perspex Ceiling and Absorbent Tiles.
Enclosure sealed to ground.
2m Box
With Holes.
Reverberant.

Table 3.

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