Calculation of insertion losses of pipe lagging: A Matlab computer program

M. J. Lacis and S. Kanapathipillai

School of Mechanical and Manufacturing Engineering, The University of New South Wales, Sydney 2052, Australia

ABSTRACT

Excessive noise radiated by pipes consisting of air or steam are often lagged using porous materials of high flow resistivity and impervious sheets usually made from metals and plastics. This paper looks at the prediction of insertion loss associated with the lagging of cylindrical pipes. A method is described and a program to efficiently calculate the predicted insertion loss as a function of frequency is developed. Predicted values of the insertion loss are compared with measured values found in past literature. Accompanying this is a comparison of the predicted values compared with current recognised theoretical results. Finally an in-depth parametric study is presented.

INTRODUCTION

Noise control as with other environmental issues is an increasing concern to our society. The reduction of noise is essential for personnel working in industrial facilities, and for stress free living in nearby communities. In many industrial plants, according to an article published by the National Insulation Association (Miller 2001), piping can be the primary radiator of sound. Hence it is of great importance to effectively attenuate the noise produced from gas filled pipes. The usual methods to attenuate the noise radiated from gas filled pipes is to either insulate the pipe on the inside using a porous material or to wrap the outside of the pipe with porous and impervious sheets. The later method is considered in this paper.

While attempts have been made to theoretically predict the insertion loss associated with acoustically lagging pipes in the past, the majority of investigations have been experimental (Stevens 1998). The current paper looks at a number of theoretical methods that have been developed in an attempt to predict this insertion loss.

Insertion loss is commonly defined as the change in the sound pressure level at an observation point due to the introduction of some item in the sound field that alters the sound field. The representation of the insertion loss can be seen in Equation 1

$$IL = L_{p(\,no\ lagging\,)} - L_{p(\,lagged\,)} \tag{1}$$

where $L_{p\ (no\ lagging)}$ is the sound pressure level (dB) at the reference point in the absence of any lagging, and $L_{p\ (lagged)}$ is the sound pressure level (dB) at the observation point with some lagging in place. More simply the pipe insertion loss (IL) is a measure of the sound power radiated from an uninsulated pipe compared to the measured sound power once lagging has been applied.

Figure 1 is a representation of a simple lagged pipe. As shown in the figure the lagging is usually be constructed of a number of types of jackets. These jackets are air space(s), porous jacket(s) and impervious jacket(s).

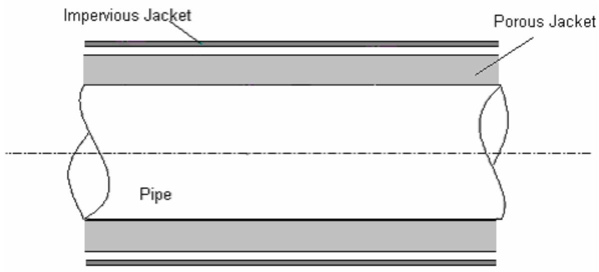

Figure 1. Representation of a Lagged Pipe

ANALYTICAL PREDICTION METHODS

For the prediction of the insertion loss of pipe laggings two in depth analytical techniques have been considered in the past (Kanapathipillai and Byrne 1996 and Munjal 1997). Both these methods consider the characteristics of the lagging materials and use cylindrical coordinates to solve the acoustic wave equation. The resulting solutions involve complex mathematics involving Bessels and Neumann functions.

Munjal 1997 attempted to analytically predict the insertion loss of acoustic laggings, with and without and impervious jacket, by making use of an impedance model developed on the basis of a transfer matrix approach and radiation impedance techniques. He derives a transfer matrix using the material properties of the lagging and uses the radial velocities of the bare pipe along with the outer jacket lagging and combines the respective radiation impedances to calculate the insertion loss. He went on to create a computer program in Fortran that made use of the procedures developed for the prediction on insertion loss. He considered only the breathing mode of pipe vibration for the calculation of the insertion loss, although bending mode is considered to be the major contributor to the noise (Kanapathipillai and Byrne 1996).

Kanapathipillai and Byrne 1996 developed a technique where the radial intensities are determined with and without the jackets. Once the intensities are found the insertion loss can be determined by taking the ratio of the sound intensity. The radial intensity, I_r at the reference point can be given by

$$I_r = 0.5\frac{|P|^2}{|z_r|^2} Re\{z_r\} \tag{2}$$

where

$$P = -jU_r \rho c \frac{k}{k_r} \frac{J_n(k_r r) - jN_n(k_r r)}{J'_n(k_r a_0) - jN'_n(k_r a_0)} \quad (3)$$

J_n - n[th] order Bessel function, N_n - n[th] order Newman function, ρ - density of air, U_r - radial particle velocity, c - speed of sound in air, k_r - acoustic wave number and a_o - pipe radius.

The determination of the radial intensity, at the reference point, when no lagging is present is relatively straightforward. Computation of the radial intensity when a limited number of jackets surround the pipe is a little more complicated. They got around this by first determining the characteristic impedance at the outer most jacket. This value is the same as that calculated when no lagging is present. Once this value is determined the calculation of the radial impedance can be found on the inner side of the impervious jacket with an impervious jacket transfer formula (Kanapathipillai and Byrne 1996). The process of determining the characteristic impedance on the inner side of a jacket once the impedance on the outer side of the jacket is known is used until the outer shell of the pipe is reached.

For the determination of the acoustic pressure, the technique used is the reverse of the technique used in the determination of the characteristic impedance. The acoustic pressure can be determined using Equation 3. From this point the acoustic pressure can be determined through use of the pressure relationship for a porous jacket (Kanapathipillai and Byrne 1996). The process of determining the pressure on the outer surface of a specific jacket, once the inner surface pressure is known, is used until the outer most jacket is reached. To ease the calculation difficulties a computer program, (Lacis 2005), was created in Matlab. This program incorporated three modes of pipe vibration (breathing, bending and ovalling modes).

COMPARISONS BETWEEN PREDICTION METHODS

The following section produces comparisons between the theoretical prediction method outlined in this paper and some experimental results obtained from Loney 1984. The two insertion loss figures were obtained through measurements and predictions made on a 304.8 mm diameter steel pipe of length 6705.6 mm. The impervious jacket is aluminium and is 0.254 mm thick. A flow resistivity for the porous jacket of

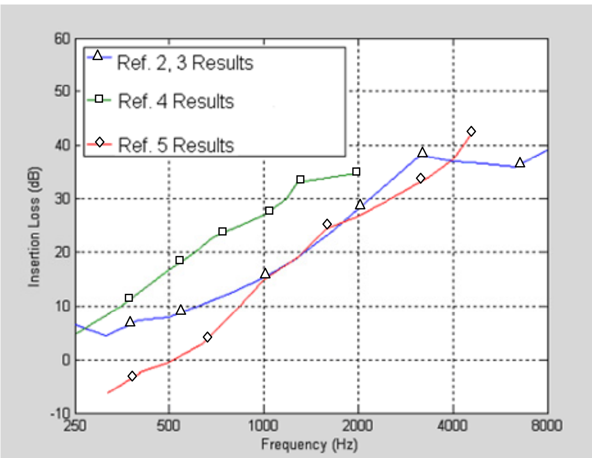

Figure 2. Experimentally observed values of insertion loss obtained from Loney 1984 (Ref 5), plotted against Munjal 1997 (Ref 4), Kanapathipillai and Lacis 2005 (Ref 2,3). Porous jacket 2 inches (50.8 mm) thick and aluminium jacket 0.254 mm thick

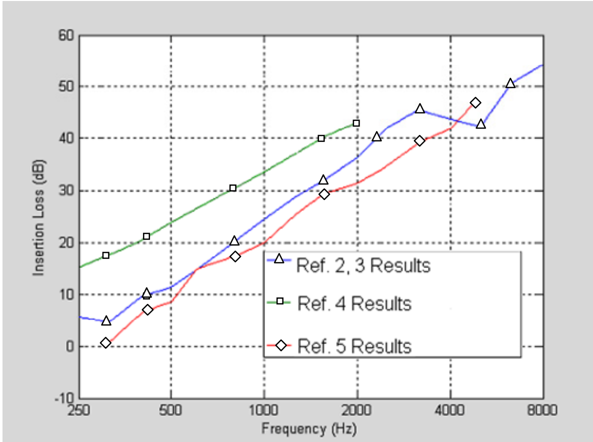

Figure 3. Experimentally observed values of insertion loss obtained from Loney 1984 (Ref. 5), plotted against Munjal 1997 (Ref.4) and Kanapathipillai & Lacis 2005 (Ref. 2,3). Porous jacket 4 inches (101.6 mm) thick and aluminium jacket 0.254 mm thick

10,000 rayls/m is assumed. Standard air, steel and aluminium properties have been used.

Neither techniques show complete accuracy to the experimental results presented in Loney 1984, the method produced by Kanapathipillai and Byrne shows significant agreement, particularly in the mid frequency range. Possibly the reason for the improved accuracy of the step-wise procedure compared to the matrix prediction method could be due to the inclusion of all the main modes of pipe vibration that result in audible radiation, (Lacis 2005). If Munjal 1997 were to consider the bending and ovalling modes of pipe vibration it would be likely to improve the agreement with Loney's experimental results.

PARAMETRIC STUDY

The subsequent plots based on the model developed by Kanapathipillai and Byrne 1996 show four different comparisons; variations to the pipe diameter, porous jacket thickness, impervious jacket thickness and differing impervious jackets. Appendix A shows tabulated values of these plots for readability.

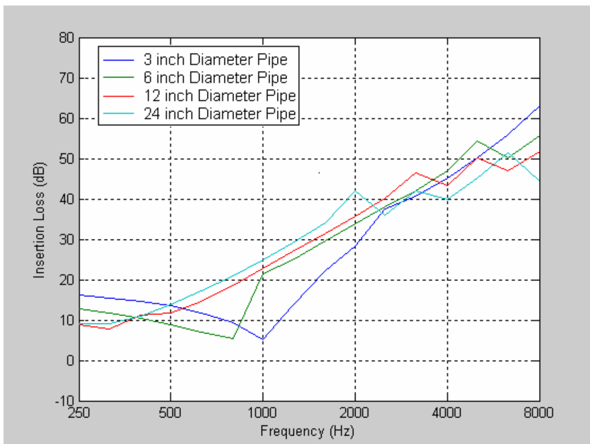

Figure 4. Insertion loss results as a function of frequency for different pipe diameters. Porous jacket of 50 mm thickness and flow resistivity 30,000 rayls/m, aluminium jacket 0.254 mm thick

A number of points can be taken for the above figures:

- As porous jacket lagging thickness is increased the insertion loss generally increases (dependant on impedance effects);

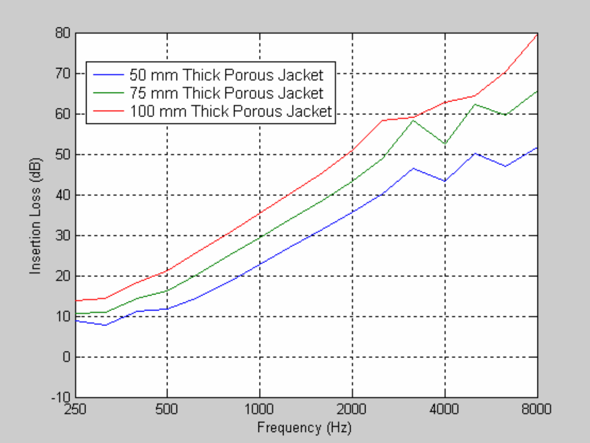

Figure 5. Insertion loss results for different porous jacket thicknesses as a function of frequency for a12 inch (304.8 mm) diameter pipe with flow resistivity 30,000 rayls/m and aluminium impervious jacket 0.254 mm thick

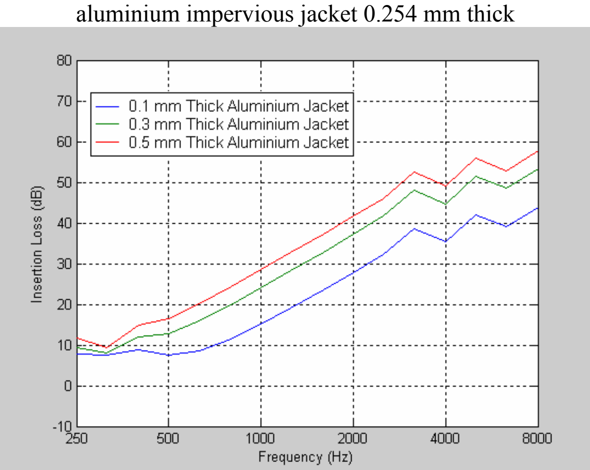

Figure 6. Insertion loss results for different aluminium jacket thicknesses as a function of frequency for a 12 inch (304.8 mm) diameter pipe with a porous jacket 50 mm thick and flow resistivity 30,000 rayls/m

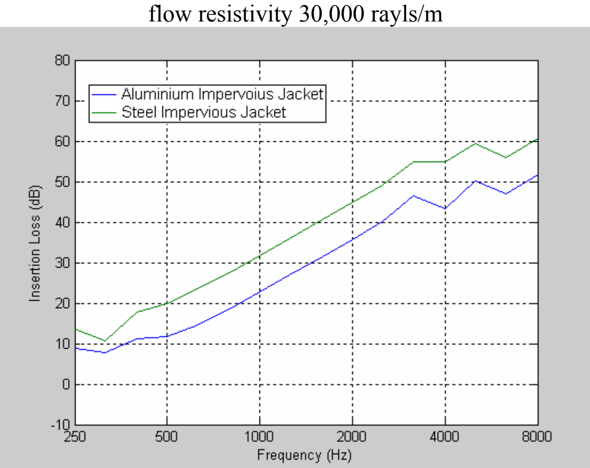

Figure 7. Insertion loss results for different impervious jackets as a function of frequency for a 12 inch (304.8 mm) diameter pipe with a porous jacket 50 mm thick and flow resistivity 30,000 rayls/m. impervious jacket thickness 0.254 mm

- increasing the density and stiffness of the impervious jacket increases the insertion loss;
- as the flow resistivity increases the insertion loss increases;
- insertion loss varies considerably depending of the pipe diameter.

The results found in the above plots have all been extracted from the user-friendly program created in Lacis 2005. This program is available through the School of Mechanical and Manufacturing Engineering, The University of New South Wales. This simple to use program prompts the user for various lagging and pipe characteristics and prints a plot similar to that found in Figures 2 through 7.

CONCLUSIONS

A user friendly Matlab program that effectively predicts the insertion loss associated with pipe laggings has been developed. The program has enabled the authors to make some useful comparison of the models found in past literature. Although the aim of this paper is not directed towards comparing experimental results with available theoretical models, the program has provided some results for future research in this topic.

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APPENDIX A

Lagging and Pipe Variation

The following table presents an in-depth look at variations in insertion loss when varying the lagging parameters. For readability the third octave band results were converted to their octave band equivalent. The results have been grouped to allow for ease of comparison. The octave band results were achieved by taking the logarithmic average of the third octave band values. While the octave band technique does eliminate a large amount of detail the general trend can be still seen.

	Porous Jacket		Impervious Jacket		Insertion Loss (dB)					
Nominal Pipe Size (inch)	Flow Resis-tivity (Rayls/m)	Thickness (mm)	Type	Thickness (mm)	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
3	30 000	50	Aluminium	0.254	16	13	11	33	47	61
3	30 000	75	Aluminium	0.254	16	15	21	42	59	70
3	30 000	100	Aluminium	0.254	18	16	29	58	73	79
6	30 000	50	Aluminium	0.254	13	9	22	35	51	54
6	30 000	75	Aluminium	0.254	14	11	29	43	59	62
6	30 000	100	Aluminium	0.254	16	14	35	51	69	76
12	30 000	50	Aluminium	0.254	9	13	24	37	47	50
12	30 000	75	Aluminium	0.254	11	18	31	45	59	64
12	30 000	100	Aluminium	0.254	14	23	37	54	63	77
18	30 000	50	Aluminium	0.254	9	14	25	41	44	54
18	30 000	75	Aluminium	0.254	12	19	32	50	55	63
18	30 000	100	Aluminium	0.254	15	24	38	53	61	76
24	30 000	50	Aluminium	0.254	9	15	26	39	43	49
24	30 000	75	Aluminium	0.254	12	20	33	47	53	56
24	30 000	100	Aluminium	0.254	15	25	39	52	59	39
3	15 000	50	Aluminium	0.254	15	10	6	28	40	52
3	30 000	50	Aluminium	0.254	16	13	11	33	47	61
3	60 000	50	Aluminium	0.254	19	18	17	42	57	74
6	15 000	50	Aluminium	0.254	12	6	16	30	43	45
6	30 000	50	Aluminium	0.254	13	9	22	35	51	54
6	60 000	50	Aluminium	0.254	16	14	29	43	61	67
12	15 000	50	Aluminium	0.254	7	10	19	32	41	42
12	30 000	50	Aluminium	0.254	9	13	24	37	47	50
12	60 000	50	Aluminium	0.254	12	18	31	45	58	63
18	15 000	50	Aluminium	0.254	6	11	20	36	37	45
18	30 000	50	Aluminium	0.254	9	14	25	41	44	54
18	60 000	50	Aluminium	0.254	14	19	32	49	51	< 0
24	15 000	50	Aluminium	0.254	6	12	21	34	36	45
24	30 000	50	Aluminium	0.254	9	15	26	39	43	49
24	60 000	50	Aluminium	0.254	14	20	33	45	< 0	< 0
3	30 000	50	Aluminium	0.1	11	9	6	25	39	53
3	30 000	50	Aluminium	0.3	17	15	12	35	48	62
3	30 000	50	Aluminium	0.5	21	18	15	39	53	67
6	30 000	50	Aluminium	0.1	9	8	14	27	42	46
6	30 000	50	Aluminium	0.3	14	10	23	36	52	55
6	30 000	50	Aluminium	0.5	18	12	28	41	56	60
12	30 000	50	Aluminium	0.1	8	8	16	29	39	42
12	30 000	50	Aluminium	0.3	9	14	25	39	49	51
12	30 000	50	Aluminium	0.5	12	18	30	43	53	56
18	30 000	50	Aluminium	0.1	8	8	17	33	36	46
18	30 000	50	Aluminium	0.3	10	15	26	42	45	55
18	30 000	50	Aluminium	0.5	12	19	31	47	50	59
24	30 000	50	Aluminium	0.1	8	9	18	31	35	41
24	30 000	50	Aluminium	0.3	10	16	27	40	44	50
24	30 000	50	Aluminium	0.5	12	20	32	45	49	55
3	30 000	50	Aluminium	0.254	16	13	11	33	47	61
3	30 000	50	Steel	0.254	24	21	18	43	56	71
6	30 000	50	Aluminium	0.254	13	9	22	35	51	54
6	30 000	50	Steel	0.254	20	14	31	44	59	63
12	30 000	50	Aluminium	0.254	9	13	24	37	47	50
12	30 000	50	Steel	0.254	14	21	33	46	57	59
18	30 000	50	Aluminium	0.254	9	14	25	41	44	54
18	30 000	50	Steel	0.254	14	22	34	49	53	63

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Nominal Pipe Size (inch)	Flow Resis-tivity (Rayls/m)	Thickness (mm)	Type	Thickness (mm)	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
24	30 000	50	Aluminium	0.254	9	15	26	39	43	49
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3	30 000	50	Aluminium	0.254	16	13	11	33	47	61
6	30 000	50	Aluminium	0.254	13	9	22	35	51	54
12	30 000	50	Aluminium	0.254	9	13	24	37	47	50
18	30 000	50	Aluminium	0.254	9	14	25	41	44	54
24	30 000	50	Aluminium	0.254	9	15	26	39	43	49

Table 1. Various insertion loss results for a porous and impervious jacket