CONTROL OF BOILER NOISE IN A HIGH RISE BUILDING

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ABSTRACT

A case study is presented concerning the control of low frequency noise from gas pulse-fired hot water boilers. Basic acoustic principles of open ended pipes and of expansion chamber mufflers have been used to assist in understanding the nature of the noise problem and devising a solution.

SOMMAIRE

On présente une étude sur le contrôle aux fréquences graves du bruit généré par deux chaudières à eau chauffées par gaz plusé. Les principes acoustiques de base des tuyaux à bout ouverts et des silencieux à chambres d'expansion aident à comprendre le problème et à trouver une solution.

1.0 INTRODUCTION

This case study has a very noisy and dramatic start, and, thankfully, a peaceful and satisfactory ending. The case is interesting in that it involved an innovative approach to noise control through some basic application of muffler theory.

The boilers supplying domestic hot water to a high rise apartment building had recently been replaced by two high-efficiency pulse-fired gas hot water boilers. The boilers are located in an equipment room in the basement of the building, with both fresh air supply and exhaust being catered for through a single 300 mm diameter duct with an in-line fan. Figure 1 shows the system as it was immediately after the installation of the new boilers. The 300 mm duct with its in-line fan drew fresh air from an external vented shaft and expelled a mixture of fresh air and boiler exhaust into an underground manhole, vented to the atmosphere at grade level.

The system had operated in this configuration for some weeks without significant problems or excessive noise. However, there was a concern that, in the event of heavy rains or a blockage, high water levels could block the system outlet in the storm water manhole. It was decided that the manhole should be extended vertically to approximately 2.4 m above ground level and that the system exhaust pipe would be extended to above ground level within the extended manhole as shown in Figure 2.

It was during the construction of the extension to the manhole that events took on a very dramatic turn. The extension was to be constructed of concrete blocks. As the contractor removed the manhole cover and started to lay the concrete blocks, noise from the boilers became louder and louder. Indeed the low frequency noise was so intense that it was shaking the mortar out of the fresh blockwork. Even though it was winter, the boilers had to be shut down for several hours to allow the construction of the manhole extension to be completed. Once the mortar was sufficiently set, the boilers were turned back on, restoring the supply of hot water for the residents of the high rise. However, the noise level from the system exhaust, i.e. the extended manhole, was very high and gave rise to complaints from neighbouring residents. It was described as sounding like a trumpet, or perhaps more accurately like a sousaphone or didgeridoo since the pitch of the noise was quite low.

At this point Technical Services staff of Ottawa-Carleton Housing, who manage the building, contacted the author to seek assistance in diagnosing the problem and controlling the noise.

2.0 INITIAL INVESTIGATION AND ANALYSIS

During the initial site visit, the boilers and associated ductwork were inspected and sound pressure measurements were made at a distance of 10.4 m from the system exhaust outlet, i.e. 10.4 m horizontally from the top of the manhole. The noise had a strong low frequency tone. This is illustrated by the noise spectrum, see Figure 3, which shows strong peaks in the 40 and 50 Hz 1/3-octave bands. When both boilers were operating, the low frequency tone exhibited a distinct beating at a period of approximately 1.5 seconds. The beating did not occur when either of the boilers was operated separately. The level of the exhaust noise could be reduced

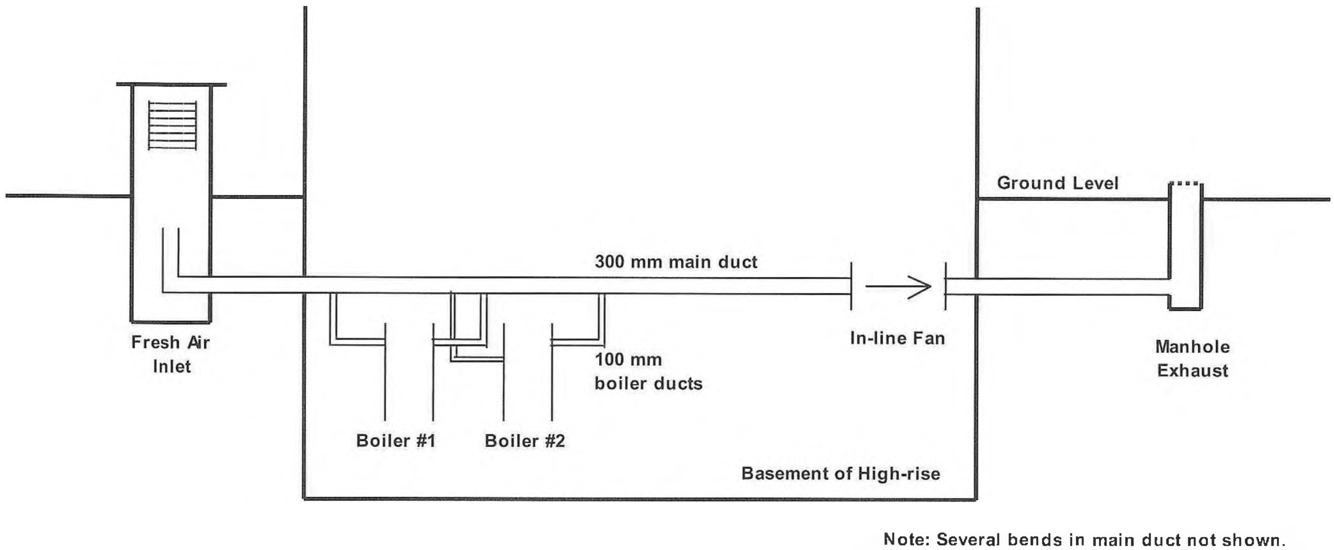

Figure 1. Schematic Diagram of Boiler System.

by about 6 dB by partially covering the opening at the top of the manhole, however the low frequency noise was still quite noticeable.

It was suspected that the source of the noise was the pulse firing of the boilers. On contacting the manufacturers of the boilers, it was found that the firing rate was indeed 44 Hz. 44 Hz is on the border between the 40 and 50 Hz 1/3-octave bands, which explains why sound levels in both bands are high.

The beating of the sound when both boilers are operating is also explained by a small difference in the firing rates of the two boilers. It immediately sprung to mind that if the boilers firing cycles could be locked 180° out of phase, then the sound could be minimised. Unfortunately, the boiler manufacturer said that this was not possible with their firing control systems.

The question still remained as to why the noise from the boilers had increased so markedly when the exhaust arrangements were altered. It seemed likely that duct system was resonating in some way and that quite likely the exhaust arrangement had something to do with this resonance. In air, 44 Hz sound waves have a wavelength, λ, of 7.8 m. The length of the extended manhole is 5.6 m, which is approximately $3\lambda/4$. This turned out to be a critical relationship as discussed below.

A pipe with one end open and the other closed has acoustic resonances at a series of frequencies which are related to the effective length of the pipe[1]. The effective length, L', is the actual length of the pipe, L, plus an end correction which for a straight pipe is $0.3D$, D being the diameter of the pipe, i.e. $L' = L + 0.3D$. For the manhole this yields the following.

$$L' = 5.6 + 0.3*0.95 = 5.9 \text{ m}$$

A series of resonances occur when the effective length of the pipe coincides with one of the following multiples of the wavelength of the sound.

$$\lambda/4,\ 3\lambda/4,\ 5\lambda/4,\ \ldots.$$

It can be seen that the effective length of the extended manhole is very near to being equal to $3\lambda/4$ or 5.85 m, which is the second in the above series of resonances for sound with a frequency of 44 Hz. Given the presence of other complicating factors, such as the entry pipe at the bottom of the manhole, it seems highly likely that this explains why the

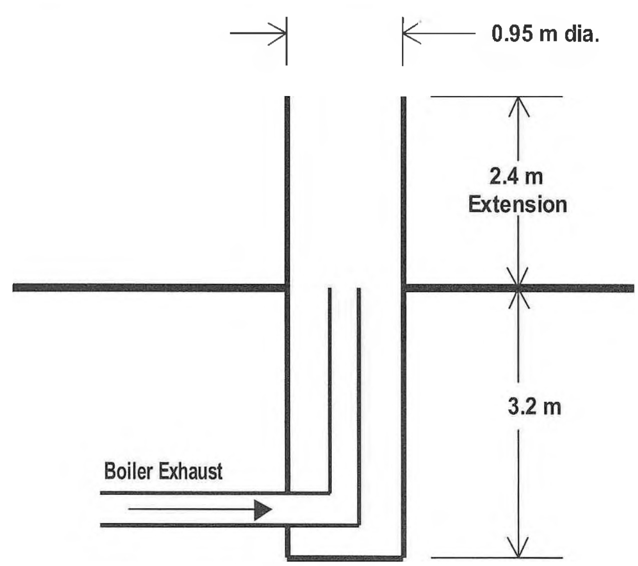

Figure 2. Initial Change to Exhaust Arrangement (manhole extended above ground)

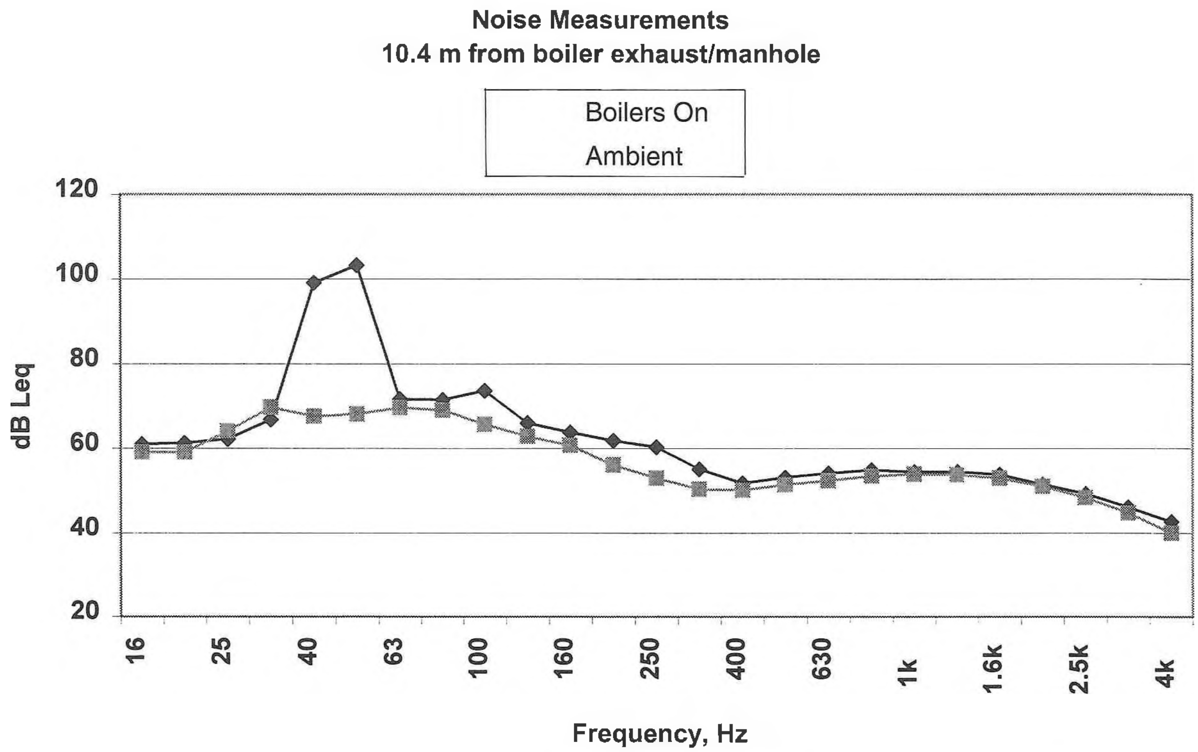

Figure 3 Noise Spectrum, L_{EQ}, of Boiler Exhaust with Manhole Extende (Please see Figure 2).

exhaust noise became so loud when the manhole was extended.

In simple terms it appears that a near perfect organ pipe or didgeridoo had been inadvertently created for the boilers firing at 44 Hz.

3.0 Design and Testing of a Temporary Muffler

Because of the disturbance caused by the noise in the neighbourhood, something had to be done quickly. Two options were available.

Option 1, Manufacturer's Mufflers: The manufacturer of the boilers said they could supply mufflers which would fit in the 100 mm inlet and exhaust ducts which connect the boilers to the larger 300 mm duct, see Figure 1. Four mufflers would be required for the two boilers, one in each inlet duct and one in each exhaust duct. The manufacturer's mufflers were expansion chamber type mufflers, approximately 1.2 m long by 200 mm diameter with internal absorptive lining.

The author had a degree of doubt about the likely effectiveness these mufflers in this situation. The mufflers seemed rather short considering the wavelength of the sound, 7.8 m. The manufacturer of the boilers was able to supply some data on the attenuation performance of the proposed mufflers, however, the data had some inconsistencies in the frequency bands of interest and the tests had been conducted under quite different ducting arrangements.

Option 2, In-situ Muffler: It occurred to the author that it would be relatively simple to convert the manhole into an expansion chamber type muffler as shown in Figure 4.

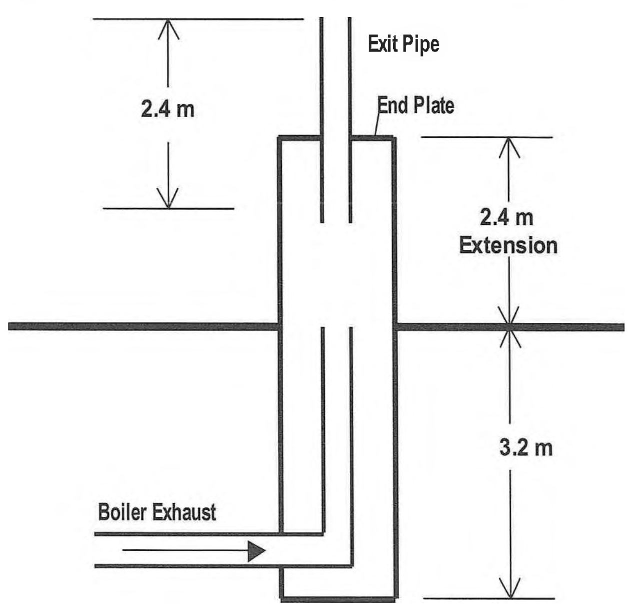

Figure 4. Temporary In-situ Muffler.

A simple theory for expansion chamber mufflers suggests that the performance is dependent on the following parameters.

A	=	cross sectional area of the exit pipe
l	=	length of the exit pipe
d	=	diameter of the exit pipe
l'	=	effective length of the exit pipe
	=	$l + 0.6d$
V	=	volume of the chamber
c	=	speed of sound, 344 m/s in air
f	=	exciting frequency, 44 Hz (firing rate)
f_o	=	chamber resonance frequency, Hz

$$f_o = \frac{c}{2\pi}\sqrt{\frac{A}{l'V}}$$

IL	=	insertion loss of muffler,

$$IL \approx 40Log_{10}\left(\frac{f}{f_o}\right) \quad \text{for} \quad f >> f_0$$

It was decided to construct and test a temporary version of the in-situ muffler since this could be readily constructed from available materials. A 2.4 m length of 300 mm diameter PVC pipe was used as the exit pipe with a steel plate acting as an end plate, see Figure 4. Approximately half of the end pipe protruded above the end plate.

Using the above relationships, this configuration gives the following theoretical results.

f_o	=	4.55 Hz
IL	=	39.4 dB

The results of sound level measurements made with and without the in-situ muffler in place are shown in Table 1. It can be see that with the in-situ muffler in place, the sound has been attenuated by 25 to 30 dB, i.e. very close to background levels. Background levels are quite high because the high-rise building is located adjacent to a busy urban road.

	1/3 octave band	
	40 Hz	**50 Hz**
No Muffler (as per Figure 2)	99 dB	103 dB
In-situ Muffler (as per Figure 3)	74 dB	72 dB

Table 1 Measured Sound Pressure Level, L_{eq}
(10.4 m from manhole)

It was not expected that the insertion loss calculated by the above simple theory would be directly applicable to the boiler exhaust system. The construction of the temporary muffler is in effect a replacement of a resonant end pipe with a muffler. If anything one might expect a better performance than the calculated insertion loss.

The above temporary in-situ muffler was left in place for a number of weeks until a longer term solution to the problem could be put in place. This simple arrangement could not be a permanent solution because condensation in the boiler exhaust soaked the concrete blocks in the manhole. With the freezing and thawing cycles of the Ottawa winters, all this moisture would eventually fracture the walls of the manhole.

4.0 A Longer Term Solution

Either of the above two options could have been pursued as longer term solutions. If the in-situ muffler was to last in the long term, it would need to be made of more durable materials. One suggestion was to construct the in-situ muffler from PVC pipes of various sizes, making it just small enough to fit within the existing manhole.

It was decided instead to try the boiler manufacturer's mufflers. If these worked satisfactorily, then they had the advantage of being off-the-shelf items, which would be housed in the equipment room within the high-rise building.

One inlet muffler and one exhaust muffler were first tested on one of the boilers. Despite the author's doubt about the effectiveness of these mufflers, they performed well.

Manufacturer's mufflers were then fitted to both boilers and at the same time, the 300 mm exhaust pipe was extended completely through the manhole to a height of approximately 1.5 m above the end plate. With both boilers operating, this arrangement led to sound pressure levels of 76 and 78 dB in the 40 and 50 Hz 1/3-octave bands respectively. Although this performance is not quite as good as the temporary in-situ muffler, the attenuation is still enough to prevent complaints from neighbours.

5.0 Conclusions

The case study did have a satisfactory ending in that noise from the boilers was controlled and the neighbours satisfied. It was also pleasing to find that basic acoustical principles of pipe resonances and of expansion chamber mufflers could be successfully applied.

The case study also illustrates that simple prediction methods should be applied with caution. Although the theoretical results discussed above predicted the general trends, the detailed results were not accurately predicted.

6.0 Acknowledgements

The author wishes to thank George Kinnear, Director of Technical Services, Ottawa-Carleton Housing, for his support and permission to publish this case study. The important roles of the following people in carrying out the project is also gratefully acknowledged: Roger Tuttle and Andy Mutch of Ottawa-Carleton Housing and Walter Liston of Baxtec Mechanical Services.

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