Controlling Low Frequency Noise Using a Passive Silencer

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INTRODUCTION

The Petroleum industry is an integral part of Canada's economic engine providing approximately 15% of the country's Gross Domestic Product [1]. In fact Canada is the third-largest producer of natural gas and the seventh-largest producer of crude oil in the world. Further the upstream sector is the largest single private sector investor in Canada and in 2006, the oil and gas industry contributed an estimated $27 billion to government revenues in the form of royalty payments, bonus payments and income taxes. The crude oil and natural gas trade surplus contributed 80 per cent of Canada's merchandise trade balance in 2006 [2]. The following table provides additional perspective into the size and importance of this industrial sector.

2006 Petroleum Industry Statistics

Capital Spending:		**$52.9 billion**
Industry Revenues:	Oil, Gas & By-products	**$106.5 billion**
Payments to Governments:	Royalties, Bonuses, Fees & Income Taxes	**$27.0 billion**
Employment:	Direct and Indirect	**365,000**
	Total Employment Impact	**500,000**

Why are these statistics significant? Simply, that given this level of importance to the economy many Canadians believe that the oil and gas industry is not concerned about impacts of its operations on the public and that regulators are soft on that sector. It is no wonder many are surprised to learn that the energy industry spends the most of any industrial sector in Canada on environmental protection with noise from exploration, production, processing and transportation activities being one key issue where leadership and innovation are evident. In fact nowhere in Canada is this more apparent than in the Province of Alberta. Nearly 85% of all the oil and natural gas recovered in Canada comes from Alberta [2]. This in turn puts a tremendous onus on the prime energy industry regulators in Alberta, the Energy Resources Conservation Board (ERCB) and Alberta Utilities Commission (AUC), to ensure the development of the province's energy resources is undertaken in a responsible manner.

Environmental noise, as one key indicator of responsible development, is regulated by the ERCB & AUC through its Noise Control Directive D 038. Operators of energy facilities in Alberta that emit environmental noise must meet the Permissible Sound Level (PSL) established for industrial facilities that are established for receptor locations such as nearby residences. Noise control must be adopted as required therefore to keep facility noise below the PSL or the facility is in a non-compliance status and subject to punitive enforcement action by the ERCB [3].

Normally, the process of determining compliance is rather straightforward where a post start-up Sound Pressure Level monitoring survey is performed using the A-weighted energy equivalent (L_Aeq) metric to measure noise from the new facility at the nearest or most impacted receptor.

The results are then compared against the PSL. If below the PSL the facility is allowed to proceed, if the PSL is exceeded then additional noise control or changes to operational conditions are required.

Despite this standard approach to managing facility noise a small but persistent number of complaints from nearby residents continue to occur even if the facility is in compliance. The reason for this is that with the receptor being some distance from the energy industry noise source, the high and mid frequency components can decay or be absorbed by air and ground conditions over this distance leaving mostly Low Frequency Noise (LFN) at the residence. The significance of this LFN and how some facility operators are dealing with this problem will be explored further in this paper.

EFFECTS OF ENERGY INDUSTRY LFN ON PEOPLE

Exploring the relationship between LFN and annoyance, at levels that cause people to complain, is the first step to understanding the issue and developing effective solutions.
A review of the scientific literature on the effects of LFN on humans indicates that the impacts can range from: creating a sensation of pressure in the ear; disturbing normal conversation; to creating secondary vibrating effects within homes. If severe enough it can also result in potential behavioral dysfunction including task performance deterioration, reduced wakefulness, sleep disturbance, headaches, and irritation [4].

Overall however, the fundamental characteristic of petroleum industry LFN is that of "intrusiveness" [5] contributing to annoyance by [6]:

- creating a sensation of pressure in the ear,
- periodically masking effects on medium to high frequency sound with a strong modulation effect that can disturb normal conversation, and
- by creating secondary vibrating effects typically experienced within homes

Further, LFN does not need to have high amplitude or considered "loud" for it to cause such forms of annoyance and irritation and sufferers of LFN annoyance describe it as [5]:

- omnipresent,
- impossible to ignore,
- worse indoors (due to the effects of vibration),
- unable to accurately locate, and
- difficult to tune out

Unlike higher frequency noise, LFN is very difficult to suppress. Closing doors and windows in an attempt to diminish the effects of LFN sometimes makes the noise worse, because of the propagation characteristics of LFN and the low-pass filtering effect of structures [5]. Individuals often become irrational and anxious as attempts to control LFN fails, serving only to increase the individual's awareness of the noise accelerating the above symptoms.

Research has also shown quite a significant difference between genders in their response to loudness [7]. Experiments conducted by N. Broner and H. G. Leventhall concluded that males tend to react to loudness with a significantly higher response than females do. The annoyance response remains similar between genders, although males seem to be less sensitive to low noise levels and more sensitive to high noise levels than females. This again is consistent with the ERCB noise complaint files where middle aged females were the most affected by the LFN [8].

REGULATORY REQUIREMENTS

While LFN is recognized in many areas around the world as potentially problematic there is no single definition or interpretation of what constitutes LFN. Rather what is more common is the general agreement among acousticians that LFN can impact people and should be identified and if determined to be problematic controlled when possible.

The ERCB and the energy industry in Alberta first became aware of Low Frequency Noise (LFN) as a potential problem area in the early 1990's. At that time there seemed to be a growing disconnect between the level of annoyance being expressed by some residents and the measured night-time sound levels taken at those residences in A weighted Level Equivalent ($L_A$eq).

The ERCB Noise Control Directive D 038 uses an A-weighted energy equivalent ($L_A$eq) to measure energy industry facility sound levels. These sound level readings are compared to the Permissible Sound Level (PSL) established for a residence and can determine if the facility noise level is in compliance with the ERCB guidelines. A major part of the success of D 038 is the use of a Noise Impact Assessment (NIA) at the design stage of an application. An NIA predicts sound levels from the proposed facility at the nearest or most impacted residence. Industry must complete an NIA prior to application submission for any new permanent facilities having a continuous noise source or for modifications to existing permanent facilities. The ERCB believes that by completing an NIA the licensees consider possible noise impacts before a facility is constructed or in operation. In fact, it is suggested that a facility be designed 5 dB $L_A$eq below the PSL to account for worst-case situations, possible low frequency noise and inability of noise mitigation measures to meet performance levels.

Although A-weighting best approximates human hearing, it tends to discount the presence of LFN, typically below the 250 Hz range, especially when an industrial source is a significant distance (i.e., more then 1000m) from nearby residents. In a few of these cases, the A-weighted sound pressure level from industrial facilities measured at the residence did not correlate with expected annoyance levels. In most cases, a night time sound level of 40 dB $L_A$eq or less at the resident's home should not create any significant annoyance levels as these levels should result in acceptable indoor noise conditions [4].

Difficulties arise when a resident has excessive annoyance due to LFN yet the industrial source is in compliance with the conventional test in D 038 based only on the $L_A$eq results. In these cases where the level of annoyance expressed by residents is not consistent with the norm for the $L_A$eq in question the presence of potential LFN must be investigated.

ANALYTICAL PROCESS FOR LFN

The methodologies shown below focus on the nighttime periods and are guidelines provided by the ERCB but do not restrict the methods of a qualified investigator or acoustical consultant. The first step is the pre-evaluation by the investigator of a potential LFN problem by determining the quality of the noise as described by the affected resident(s) and assess whether the noise problem is intermittent or continuous.

If there is an LFN concern and it is continuous, the levels should be measured over the entire nighttime period in terms of the 1/3 octave Leq and statistical levels (L10, L50, L90, or some combination). The difference in the Leq (equivalent-continuous) levels for adjacent spectral bands should be graphed in order to demonstrate whether there is a clear tonal component. If the difference in the levels varies over the nighttime, this will be evident from such a graph. When measurements are taken over the entire period of the nighttime, the measurement subinterval should be a maximum of one minute. In this case, the statistical levels are valuable to show any shorter term fluctuations in levels.

If the suspected LFN is intermittent, then short-term measurements should be taken at times when the low frequency sound is present, and the assessment of the presence of a tonal component should be restricted to times when the sound is present. A high-quality audio recording of the sound over the period of concern may need to be taken for later analysis and identification of the duration and intensity of the LFN. If the timing of the intermittent periods is not regular, a continuous measurement may be required to obtain sufficient evidence of the presence or absence of a tone.

In this case, the spectral analysis can be done as a short-term Leq or a "slow" weighted sound level. Many instruments do allow simultaneous measurements of the 1/3 octave Leq levels. If meters cannot track all the 1/3 octave frequency bands at the same time, the tonal components can be assessed by running a taped signal through an analyzer a number of times to get the levels of all the frequency bands of interest. The analyzer would be for "slow response" and the recordings run with different 1/3 octave band settings until all bands between 20 and 250 Hz have been analyzed.

If it is determined that the potential for LFN does exist, measurements must be conducted in both C and A weighted networks concurrently. Measurements may be made using two concurrently monitoring sound level meters, a dual-channel capable sound level meter, or other equipment capable of obtaining both the C and A weighting sound levels simultaneously.

An LFN complaint condition may exist when:

- the isolated (i.e., non-facility noise, such as wind noise, has been removed) time-weighted average dBC – dBA value for the measured day or nighttime period is equal to or greater than 20 dB, and
- a clear tonal component exists at a frequency below 250 hertz (Hz).

If LFN is confirmed to exist, a 5 dB $L_A$eq penalty will be added to the appropriate CSL results. If this value exceeds the PSL, the licensees will be required to identify the potential source and outline an action plan to address the issue in a timely way [3].

RESEARCH & DEVELOPMENT

With LFN clearly an issue the big hurdle for industry was to not only ensure that their facilities would be able to meet the applicable PSL but also to have some assurance that LFN would not jeopardize their compliance status. Looking at the situation engineers at Noise Solutions Inc. determined that one of the most likely sources of LFN at a typical energy facility was the exhaust from natural gas compressors. According to ERCB records there are approximately 12000 compressor stations in Alberta the majority of which are in relatively close proximity to rural residents. It was clear that a suitable exhaust silencer or muffler could help to not only reduce overall noise levels but would target the low end of the frequency spectrum to systematically reduce LFN.

The Noise Solutions Inc. Project Team decided to undertake a multi-phased approach to come up with the most effective LFN silencer using best practical technology and materials that used the following steps:

- Identify the most popular types of drivers (engines) used to power the natural gas compressors and obtain any relevant manufacturer LFN noise emission data.
- Conduct a review of monitoring data from compressor station sound surveys to augment manufacturer data base.
- Plot all data and determine dominant frequencies
- Complete engineering design to target dominant frequencies, build and test units in the field.

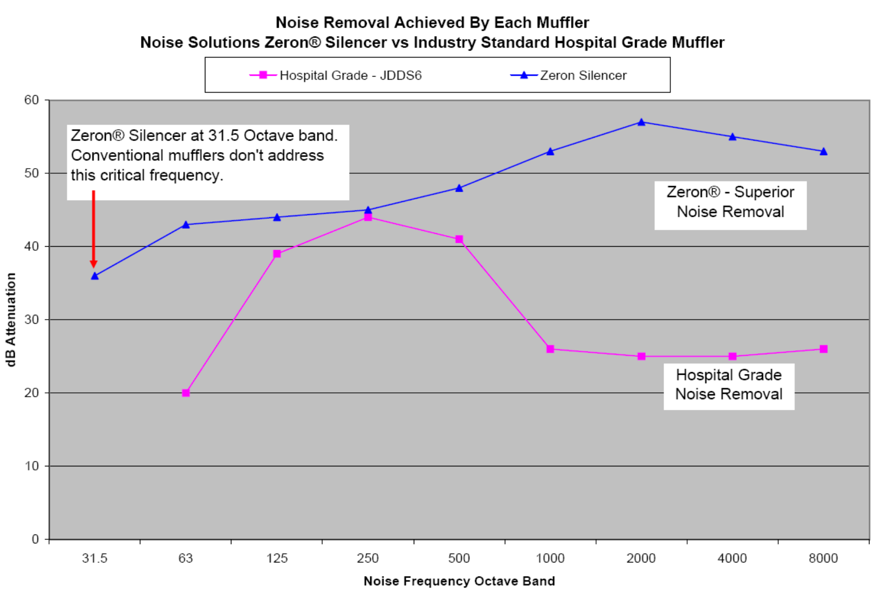
As part of the Research and Development process the Project Team established some parameters and other measures of success for the LFN silencers including:

- The resulting LFN silencer could to be built by Noise Solutions Inc. Manufacturing Division.
- The materials to be used should be from existing materials used in current manufacturing product lines or if new the materials must be compatible with the existing process machinery and technical abilities of shop staff.
- That the units have minimal heat radiation to the shell.
- That the process of controlling LFN does not allow for less attenuation of mid and high frequency noise.
- That the overall attenuation be greater than 10 dBC overall.
- That the silencer illuminate any LFN tonal components.

The following table represents the Dynamic Insertion Loss obtained by the silencer under the trade name Zeron™ Exhaust Silencer.

Table 1, Zeron™ Exhaust Silencer									
Octave Band Centre Frequency (Hertz)									
Dynamic Insertion Loss (dB)									
Octave Band	31.5	63	125	250	500	1000	2000	4000	8000
Provided DIL	36	43	44	45	48	53	57	55	53

This table shows the performance of the Zeron™ Exhaust Silencer against a Hospital grade version provided by another manufacturer.



CASE STUDY

1. The Challenge of Noise

Noise Solutions Inc was first approached with an inquiry from the Hunt Oil Company in regards to their Caroline Compressor site in the winter of 2006. Hunt Oil, "one of the world's leading independent energy companies" and global petroleum exploration and production innovator, was planning to install a new compressor on the Caroline Site. For the surrounding community however, this posed a serious noise problem. A concerned community group known as SPOG (The Sundre Petroleum Operators Group), created in 1992 to address oil and gas industry-related concerns of communities in the Sundre-Caroline area, expressed unease with Hunt's potential site development. Being conscientious of their affect on the environment and the surrounding population, Hunt agreed to SPOG's terms of development. According to the requirements, Hunt Oil's new compressor unit was allowed to be developed so long as it had absolutely *no* additional noise impact whatsoever on the area. Thus, Noise Solutions' unique services were requested. Not only was complete noise attenuation required in this case, but the ventilation system would have to be reworked due to the sour gas on the site. The entire noise-suppression unit would have to be specially designed in order to compensate for the sheer size of the compressor building. Luckily, Noise Solutions Inc was ready to undertake this challenge.

2. High-Quality Noise Suppression Equipment

In an effort to fully attenuate both the high frequency noise (dBA) and the low frequency noise (dBC) of the new compressor unit, Noise Solutions and Hunt Oil agreed that a significant level of sound-suppression would be necessary. The Air-X-Changer 168EF Cooler had a 14 foot wide fan; one of the largest Noise Solutions Inc had ever worked on. This posed both design and shipping challenges, though these were quickly overcome. To remedy the noise produced by this fan, Noise Solutions used a customized Cooler Silencer Package, including a Cooler Inlet and Outlet Silencer complete with Cooler Plenum Walls to trap any exterior noise that could potentially escape. The compressor engine, a Waukesha L5794LT rated at 1,445 HP @ 1,200 RPM, was also equipped with customized Noise Suppression Equipment. This included a full Zeron® Engine Exhaust Silencer package, Induced Draft Acoustical Building Inlet Ventilation and Fan Forced Acoustical Building Outlet Ventilation, as well as an Acoustical Building Enclosure. The use of this powerful noise suppression equipment would be necessary to bring the compressor under the EUB and SPOG regulations.

3. Attention to Service

To ensure the success of this project, great attention was made to provide quality customer service from beginning to end. This service included, but was by no means limited to, pre-job site visits as well as mid and post job evaluations. Open, two way communication with Hunt Oil throughout the process of analysis, design, manufacturing, shipping, and installation of the equipment were key goals. Many parts of the equipment itself were custom designed to meet the unique requirements of the client's machinery and process layout. A direct and amenable approach to the challenges faced at Hunt Oil's Caroline Gas Compressor Site allowed for quick and efficient problem solving of issues that arose during the shipping, delivery and installation processes ultimately assuring customer satisfaction and the complete success of the project.

4. Superior Results

Effective research and development programs can and will result in expert design of nise suppression equipment such as compressor silencers whereby the performance expectations for Hunt Oil's Caroline Gas Compressor Site was fully met and surpassed the regulatory and community targets set forth by SPOG and the ERCB. Because of the compliance managed with the new compressor unit, Hunt Oil was able to operate harmoniously with the surrounding community, ensuring that no damage or annoyance was caused by the noise level of their site. In fact, the success in reducing LFN on the project even led to the Energy and Utilities Boards participation in a site tour confirming the project's success.

CONCLUSIONS

While it is not possible to completely illuminate LFN from an internal combustion engine using a passive type silencer it can be significantly suppressed allowing for both regulatory compliance, safety of workers, and maintaining an acceptable quality of life for nearby residents. Using a rigorous four point program of accurate analysis of the noise including LFN being generated combined with effective engineering and design, followed by quality controlled manufacturing of the noise suppression equipment, concluding in experienced installation will get the results needed by operators to meet stakeholder expectations. Any shortcuts, to save time or money, can and will likely result in failure to meet those expectations resulting in higher costs in the end not to mention the incalculable cost of lost credibility and confidence by the local community which could be reflected in a backlash to further development in the region.

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