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TESTING THE PERFORMANCE OF A NEW FAN SILENCER PROTOTYPE FOR AUXILIARY VENTILATION

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INTRODUCTION

Mechanized underground mines often suffer from noise overexposure. Noise levels are usually above the Permissible Exposure Limit (PEL) where underground fans are used. Sound levels in active workings can reach 121 dB(A), especially when fans are not equipped with silencers. Use of silencers seldom ensure PEL for various reasons. Overexposure of noise induces permanent hearing loss among mine workers.

Recent field studies by a NIOSH-funded research project at six coal and non-coal mines revalidated the findings. The University of Utah has undertaken laboratory studies to reduce fan noise at the source. A new silencer prototype with varying noise dampening material has been designed and tested. The silencer and an associated extension which can be repacked with different dampening materials were used in various configurations. Attempts were made to simulate field conditions where installations are quick and not perfect. The test results are presented here.

NOISE IN UNDERGROUND MINES

Noise induced hearing loss (NIHL) is a chronic problem in the mining industry. In spite of regulations being in place and elaborate hearing protection programs under way, hearing loss is prevalent among the mine workers (Bise, 2001). All production and support machinery in mining generate loud noise often beyond the approved exposure level. Researchers in the U.S. have identified auxiliary fans as one of the major sources of noise that can create noise exposure levels up to 121 dB(A), which is one of the highest in the mining operation (Bauer, 2006). Studies have demonstrated substantial reduction of noise level by using silencers. Adequate fan selection and proper utilization of silencers in auxiliary fans have great potential of abating the problem.

In hard rock mines, auxiliary fans are used in blower configuration to ventilate development headings and large production stopes, and also to ventilate underground shops, crushers, conveyor transfer points, etc. Typical duct diameters in hard rock mines vary from 0.91 m to 1.21 m. Silencers are often omitted for cost reduction. In coal mines auxiliary fans are used in exhaust configuration with rigid ducts 0.61-0.76 m in diameter (Hagood, 1982 and Moreby, 2009) to ventilate working faces in gate-roads and main entry developments. Sometimes, stone dusters are added at the discharge end to dust the roof, ribs and floor.

AUXILIARY FANS AND SILENCERS

Auxiliary fans are relatively smaller in size than the main fans and often have high rotational speeds (1800 -3000 rpm). Fans are selected based on pressure-quantity requirements and space restrictions only. Noise emissions are rarely considered during the selection stage. Installation of fans, ducts and other accessories is mainly based on best practices, which often do not include noise control. As a result, the operation of an auxiliary or local ventilation system normally produces excessive noise.

A fan silencer is a noise reduction device placed in a duct or airway to absorb or attenuate the sound transmitted along the path while allowing the flow of air through the passage. Usually, they are placed at the fan inlet in a blower system or at the fan outlet in an exhaust system (Howes, 1989).

Two types of silencers are used with auxiliary fans: pod-less and pod type silencers. A pod-less type silencer consists of a tubular shell, an acoustical fill, and an outer shell (casing). The fill is usually 10 to 15 cm thick (Figure 1.a). To reduce shock losses, the silencer diameter is made equal to the fan diameter. This makes the casing to be at least 20 to 30 cm larger than the fan diameter. This requires an extra headroom in a drift to house the fan-silencer assembly. Due to this fact, these types of silencers are seldom used with auxiliary fans in underground mines. The alternative is to use a pod type silencer (Figure 1.b). In this case, to match the fan diameter, the thickness of the acoustical fill is usually reduced to a about of 5 cm. To compensate for the thickness reduction, a center pod wrapped with acoustical material is added to the silencer (Hurley, 2002). Although this improves the attenuation capacity of the silencer, it reduces the fan performance by increasing the static head loss.

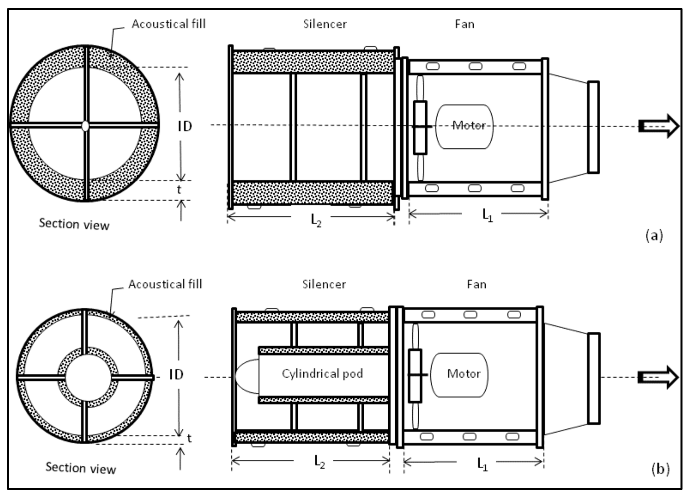


Figure 1. Schematic of fan silencers: (a) Pod-less type silencer, and (b) Pod type silencer.

NOISE SURVEY IN MINES

Sound level and fan performance tests were conducted at six (named A through F) US underground mines: three coal mines, two hard rock mines and one salt mine. In each mine, auxiliary fans are used to ventilate development headings, and fixed facilities. Sound levels were measured near the fans, along the ductwork, and near the working areas. Two Edge eg5 noise dosimeters were used to monitor the sound levels in all mines. An SE-400 Series SL meter was also used, except for two coal mine in which the use of the instrument was restricted to intake entries because it does not have a flame proof enclosure.

Table 1 shows a summary of sound level measurements and the prevailing ambient conditions in each mine. The sound levels around the auxiliary fans varied between 93 and 114.6 dB(A), depending on the size of the motor. In coal mines, where the fans were equipped with silencers, these readings fluctuated around 104 dB(A), substantially above the MSHA's prescribed level 90 dB(A). The sound levels at the working faces varied between 80 and 100 dB(A). Except for one case, the sound levels by the workings were above 87 dB(A).

Table 1. Sound Level Measurement Summary in Six Mines

Mine	Fan Details	Silencer	SL, dB(A)*	
			By Fan	By Face
A: Coal	2 x 75 kW, exhauster	Yes	105	
	2 x 75 kW, exhauster	Yes	106	100
B: Coal	2 x 75 kW, exhauster	Yes	106	98
C: Coal	1 x 93 kW, exhauster	Yes	104	87
	1 x 93 kW, exhauster	Yes	104	87
	1 x 37.5 kW, exhauster	No	107.5	87
D: Metal	1 x 75 kW, booster fan	Yes	103.5	
	1 x 112 kW, blower	No	101	90
E: Metal	1 x 30 kW, blower	No	110	98
	1 x 45 kW, Aux. booster	Yes	101	99
	1 x 45 kW, Aux. booster	Yes	102	100
F: Salt	1 x 3.5 kW, blower	No	93	80
	1 x 15 kW, Jet Fan	No	106	89
	2 x 93 kW, booster fan	No	114.6	104

**: Mining equipment down during survey*

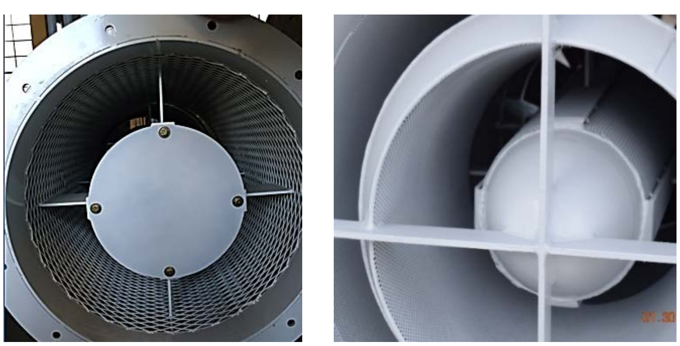
In non-coal mines, in addition to sound levels generated by auxiliary fans, decibels generated by booster fans were also monitored. Mines D and F used these type of fans. The sound levels around these fans were 103.5 and 114.6 dB(A) respectively. These levels are quite high even for intermittent noise which is limited to 100 dB(A).

The management teams at these mines were aware of the high noise levels and took measures by administrative control and/or by the use of Personal Protective Equipment (PPE) to comply with the regulatory requirements.

AUXILIARY VENTILATION SYSTEM LAB MODEL AT THE UNIVERSITY OF UTAH

The University of Utah ventilation lab was geared up to conduct noise attenuation tests for auxiliary ventilation system. An auxiliary ventilation system model was set up in exhaust configuration to emulate what are used in coal mines. It includes a 7.5 kW axial fan, a silencer, 0.51 m diameter ductwork, and a damper. The fan is installed with a fiberglass ductwork attached to its inlet and a ring style silencer at its outlet. The inlet is equipped with a damper to simulate ducts of longer length, and a variable frequency drive to change the fan speed between 0 and 1800 RPM (0-60 Hz). Several fan performance tests were conducted for different fan-silencer combinations. Additional tests were conducted for different damper positions and fan speeds. For each condition, sound levels were monitored at various stations using a noise dosimeter and a sound level meter. The collected data was processed and the results were used to generate sound level spectra needed for further studies.

In early 2016, one strut type and one ring type silencer were procured, and tested in conjunction with the fan system. Figure 2 shows the images of the two silencers.



(a) (b)

Figure 2. a) Strut type silencer; b) Ring type silencer

The lab facility was then modified to include a new silencer which consisted of two sections: a modified ring style silencer and a re-packable silencer in which the sound absorbing material can be retrieved and replaced (Figure 3).

Figure 3. Re-packable extension used in 2017 experiments.

Initially, both the ring style silencer and the re-packable silencer were filled with standard ProRox SL960 sound absorbing material. Subsequently the dampening material in the re-packable silencer extension was changed to ROXUL AFB and ROXUL CurtainRock80 (CR80). These materials are made up of a fibrous porous mineral wool that has been bonded together with a high temperature binder. The material is fire and water resistant, and mostly resistant to any fungi growth. Figure 4 shows a schematic of the modified ring style (conical pod) silencer attached to a re-packable silencer extension (cylindrical pod).

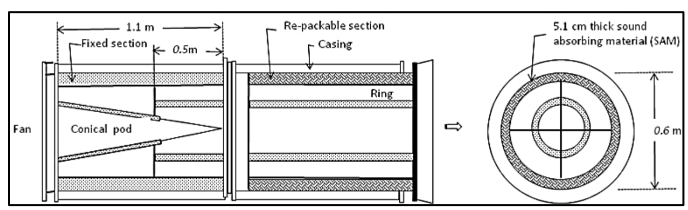


Figure 4. Modified ring style silencer showing two major components: fixed section that includes a conical pod and re-packable section where the sound absorbing material can be replaced (not to scale)

The auxiliary ventilation system model was tested at the maximum fan speed of 1800 rpm with the inlet duct damper wide open. Then, the tests were repeated after the damper cross-sectional area was reduced by 25% increments to simulate longer ducts. The testing setup and sampling points are shown in Figure 5. a and 5.b.

SILENCER ATTENUATION TESTING IN LAB

Sound attenuations tests were conducted at the University of Utah's auxiliary ventilation model. The re-packable silencer was used to test three types of sound absorbing material (SAM) in the ventilation model: ProRox SL960, ROXUL AFB and CR80. The products were made of the same material and had the same thickness, but different packing density. The SAMs are shown in Figure 6.

Tests were conducted under controlled conditions. A-weighted sound levels were monitored at various stations using a SE-400 sound level meter and the exposure level using an Edge eg5 noise dosimeter. The collected data was then downloaded to an SLM software to determine a composite sound levels in dB(A) for each station. Then, the sound absorbing materials were ranked based on their effectiveness in reducing noise.

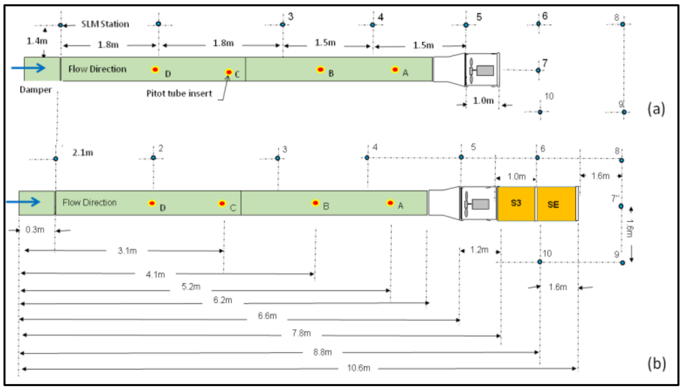


Figure 5. Layout of laboratory test arrangements for noise testing – (a) fan only; (b) with silencer and extension.

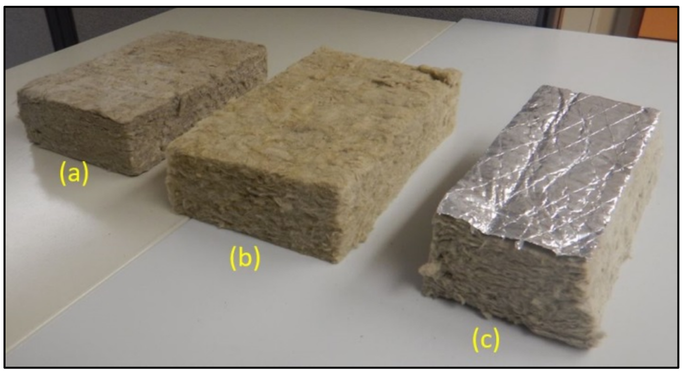


Figure 6. Sound Absorbing Materials: (a) ProRox SL960, (b) ROXUL AFB, and (c) ROXUL CR80.

TEST RESULTS

Four cases of fan performance and sound attenuation tests are presented in this paper. The cases are:

1. Fan system without silencer or extension
2. Fan system with a new ring style silencer and extension with ProRox SL960
3. Fan system with a new ring style silencer and extension with ROXUL AFB.
4. Fan system with a new ring style silencer and extension with ROXUL CR80.

Figure 5.a shows a schematic of the University of Utah lab model illustrating the locations where the air pressure and sound level measurements were taken for test 1, fan system without silencer. Figure 5.b shows a schematic of the exhaust fan system illustrating the location of the silencer extension (SE) in relation to the new ring style silencer (S3). While the insulation material in the ring style silencer was unchanged (SL960), this was changed in the silencer extension. The following insulation materials were used in the silencer extension: SL960, AFB and RC80. For each test the damper cross-sectional area was set to 100% open and the fan operated at full speed (60Hz).

Instrumentation such as Pitot tubes and manometers was used to measure the fan performance. An SE-400 Series SLM was used to measure sound pressure levels, and two Edge eg5 noise dosimeters, for exposure levels.

The sound level meter was held near waist height at various stations near and around the fan, and the relevant parameters recorded for each system configuration.

Test 1. Fan System without Silencer

Following the laboratory safety procedures, the damper was set at position '0' (damper 100% open), the fan started and the prevailing ambient conditions were recorded. This was followed by fan performance tests and sound level measurements. Based on the barometric pressure (86070 Pa) and an air temperature (25 °C), the air density was estimated at 1.0 kg/m^3.

The fan performance was determined from static and velocity pressure measurements. Static pressures were measured at three stations along the duct (A, B, and C in Figure 5a). The measurements at the stations were used to determine the fan static pressure. The velocity pressures were measured across the duct diameter at station A. These measurements, together with the air density were used to calculate the air quantity in the duct. Based on these measurements, the fan operating point was given by:

Quantity = 4.39 m^3/s (9340 cfm)
Total Pressure = 375 Pa (1.50 in. w.g.)

For this condition, the fan input power was estimated at 3.0 kW (4.0 HP).

Sound levels were monitored using a SE-400 Series sound level meter. Measurements were taken for five minutes at each station and the instrument recorded the parameters of interest. The collected data was then downloaded to 3M's DM software to determine a composite sound level for each station. A wind screen was used throughout the test to reduce the effect of wind on the microphone. Table 2 shows the average A-weighted sound levels, Lavg, for the 10 measuring stations. These ranged between 82 and 89 dB(A). The highest sound level was recorded by the fan discharge (station 10).

Table 2. Summary of sound level measurements at the U. of Utah lab model - Fan system with fan only.

Station	1	2	3	4	5	6	7	8	9	10
dB(A)	85.5	81.9	83	82.9	84.2	88.6	87.9	85.5	87.5	88.7

See Figure 5.a for station locations

Noise levels were also recorded during the test using an Edge eg5 noise dosimeter. The readings were taken for approximately fifty minutes while the fan was running at full speed. Background noise was measured for five minutes before the fan was turned on and for five minutes after the fan was turned off. The samples ranged from minimum, maximum, and peak values. Figure 7 shows the maximum and overall average sound levels collected during the test. Time intervals A through J represent the time spent when the noise dosimeter was held at the sound level stations for five minutes. During the test, the dosimeter was moved from the system inlet (interval A) to the fan discharge (interval J). In this Figure, the blue line represents maximum sound levels (Lasmx) recorded at each interval and the green line the sound level average (Lavg), which includes all sample averages of max, min, and peak sound levels. Based on Figure 7, the average background noise level fluctuated around 63 dB(A). The sound level increased to 83 dB(A) when the fan was switched on. The highest overall noise level, 88.7 dB(A), was recorded during interval G, which was due to the proximity of the noise dosimeter to the fan outlet.

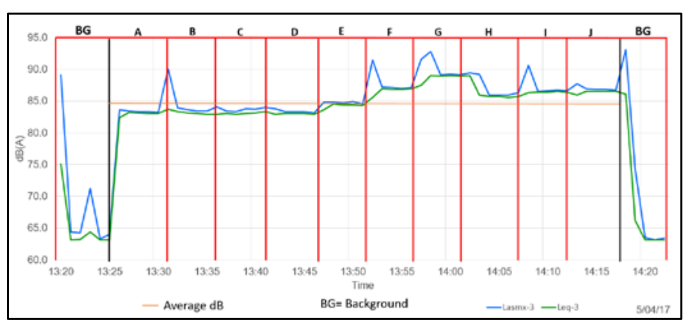


Figure 7. Sound spectra showing the maximum (blue) and the equivalent average sound levels (green) for Test 1.

Test 2. Fan System with SL960 in Silencer Extension

Once the sound absorbing material was changed to SL 960 in the silencer extension and the cartridge retrofitted, the system was inspected and found to be in good standing, the fan was started and operated at full speed (1800 rpm). Then, the prevailing ambient conditions were recorded and the air density was calculated (0.99 kg/m^3). This was followed by air pressure surveys and sound level measurements. Based on these measurements, the fan operating point was given by:

Quantity = 4.20 m^3/s (8895 cfm)
Total Pressure = 363 Pa (1.45 in. w.g.)

For this condition, the fan input power was estimated at 2.63 kW (3.5 HP).

Sound levels were measured at 10 stations around the fan system. As in previous case, measurements were taken using an SE-400 sound level meter set for A-weighting. The collected data was then downloaded and processed. Table 3 shows a summary of composite sound levels for the ten measuring stations. These ranged between 74 and 79 dB(A). Compared to that of test 1, on the average, the silencers provide a total protection of about 10 dB(A).

Table 3. Summary of sound level measurements – Silencer extension with SL960 material.

Station	1	2	3	4	5	6	7	8	9	10
dB(A)	78.7	77	75.6	75.4	75.3	74	74.1	74	74.1	74.5

See Figure 5b for station locations

Noise levels were recorded using an Edge eg5 noise dosimeter. Samples were taken for approximately 70 min while the fan was running at full speed. Once started, the instrument was moved from the duct inlet towards the system outlet. During the process, the background averaged 63.1 dB(A), Then, the sound level increased to a maximum of 78.4 dB(A), when the fan was started, and stabilized at 74.8 dB(A) by the system discharge. Figure 8 shows the details of noise exposure rates and average sound levels for this test.

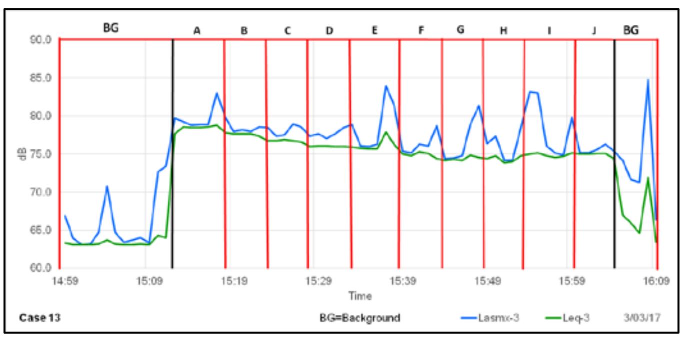


Figure 8. Sound spectra showing the maximum (blue) and the equivalent average sound levels (green) for Test 2.

Test 3. Fan System with AFB in Silencer Extension

The procedure used in test 2 was repeated for another model condition in which the standard SL960 insulation in silencer extension was replaced by the ROXUL AFB. For the new condition, the fan performance tests yielded the following results:

Quantity = 4.17 m^3/s (8820 cfm)
Total Pressure = 375 Pa (1.5 in. w.g.)

For this condition, the fan input power was estimated at 2.63 kW (3.5 HP).

Sound levels were also measured using a SE-400 sound level meter set for A-weighting. The collected data was then downloaded and processed. Table 4 shows a summary of composite sound levels. Comparted to that of test 1, the silencers reduced the sound level at station 5 by about 9 dB(A), indicating that the AFB insulation material was one decibel less effective as the SL960.

Table 4. Summary of sound level measurements– Silencer extension with AFB material.

Station	1	2	3	4	5	6	7	8	9	10
dB(A)	80	78.1	76.5	76.3	75.5	74.7	74.3	74.3	75	74.7

As in previous tests, noise levels were recorded using an Edge eg5 noise dosimeter. Samples were taken for about 60 min while the fan was running at full speed. The background sound level fluctuated around 63.7 dB(A). When the fan was started, the sound level increased to a maximum of 80.1 dB(A) by the duct inlet, then, declined slowly when the instrument was moved towards the fan, and stabilized at 76dB(A) by the system discharge

Test 4. Fan System with CR 80 in Silencer Extension

For the new condition, the fan performance tests yielded the following results:

Quantity = 4.14 m^3/s (8755 cfm)
Total Pressure = 400 Pa (1.6 in. w.g.)

For this condition, the fan input power was estimated at 2.75 kW (3.7 HP).

Sound levels were also measured using a SE-400 SL meter set for A-weighting. As in previous case, measurements were taken at 10 stations around the system. The collected data was the downloaded and processed. Table 5 shows a summary of composite sound levels for the ten measuring stations. These ranged between 74 and 79.5 dB(A). Compared to that of test 1, this alternative provides a total protection of 10 dB(A).

Table 5. Summary of sound level measurements – Silencer extension with CR 80 material.

Station	1	2	3	4	5	6	7	8	9	10
dB(A)	79.5	78.4	77	76	75.4	74.2	74.3	74	74.3	74.5

Noise levels were also recorded during the test using the same instrumentation and procedure as in previous tests. Measurements were taken at ten stations for about 70 minutes. During the test, the background sound level fluctuated around 64 dB(A). When the fan was started, the sound level increased to a maximum of 79.7 dB(A) by the duct inlet, then, declined slowly, when the instrument was moved towards the fan, and stabilized at 78 dB(A) by the system discharge.

ANALYSIS OF RESULTS AND DISCUSSIONS

Four tests were conducted to evaluate the effect of silencers on fan noise reduction. The first test, fan system without silencer (base case), was conducted to determine the maximum sound level distribution in the lab. The following three tests were conducted to evaluate the effect of two silencers on fan noise reduction. In each test, the new ring silencer and a silencer extension were attached to the exhaust fan system. While the insulation material in the ring style silencer remained fixed (SL960), this was changed in the silencer extension. The following materials were tested: SL960, AFB and RC80. Comparative sound level graphs, for homologous stations, were used to determine an order of magnitude of noise reduction produced by the two silencers.

Figure 9 shows a comparison of average sound levels for the four tests presented in this study. These were developed based on the average sound levels shown in tables 2 through 5. Based on this Figure it can be concluded the utilization of these silencers reduced the noise level by about 7 dB(A), at station 1, near the system inlet, and by about 14 dB(A) at the system discharge (station 7). A close look at the histograms show that the silencer with SL 960 insulation material provides a better protection than the other materials.

In order to gain additional information on sound level distribution for different frequency bands, the raw data generated by the sound level meter was re-evaluated. Figure 10 shows sound level histograms for the last three tests when the sound level monitor was held at station 7. Based on these histograms it can be concludes that the three insulation materials have practically the same noise absorbing characteristics. A closed look however, shows that RC 80 outperforms the other materials in the low frequency bands. Figure 10 also show the equivalent sound levels in dB(A) for the frequencies at which humans can hear the best. A comparison of sound levels in the 4000 Hz -8000 Hz range (red box) reveals that SL 960 outperforms AFB and CR 80 by about 2dB(A).

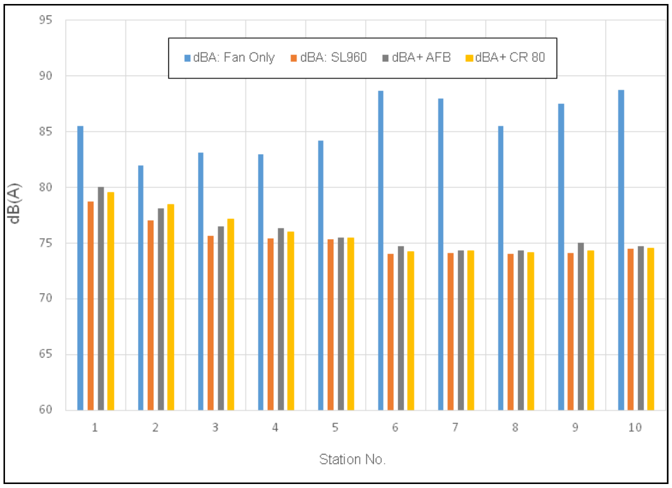


Figure 9. Comparison of sound levels for four fan-silencer configurations: fan only, and fan system with three different insulation materials in the silencer extension.

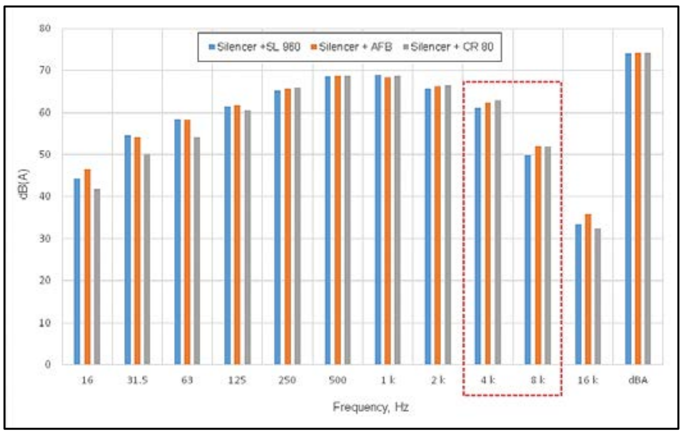


Figure 10. Comparison of sound levels for different frequency bands for samples collected at station 7. The red box shows the frequencies at which hearing loss begins.

Among other findings, this study showed that, compared to the base case (test 1), the utilization of the ring style silencers reduced the fan capacity by about 5 % and increased the fan pressure by about 8%, regardless the type of material used. This is explained by the additional resistance to airflow caused by the pod type silencers.

CONCLUSION

This study brought out some important findings. First, despite decades of regulations and hearing protection programs, almost all mines have potential of exposure to above PEL of noise from auxiliary ventilation systems. Mine authorities are aware of the situations on most occasions and administrative controls and/or personal protective equipment (PPE) are utilized to comply with regulations. However, engineering control has taken a back seat. Hard rock mines use numerous auxiliary and booster fans and often omit silencers for cost reasons. In underground, coal mines use auxiliary fans only. On most instances some form of attenuating devices are attached to these fans. But, the silencers are very rarely maintained enough to attenuate noise below PEL. The silencers used also have significant room for improvements.

The silencers used in the tests have demonstrated attenuation of about 14 dB(A). On the other hand, a properly designed silencer will offer lesser resistance. That will ensure better fan performance and will save energy cost over long period of time.

The re-packable silencer offers the unique opportunity of fast and effective maintenance. Changing the SAM will require very low skill level. So, there will be more likelihood of good maintenance of the silencers. The well maintained silencers will provide excellent engineering control of the noise overexposure problem. Another important aspect of this engineering control is that lowering of noise level in audible frequencies (4000 to 8000 Hz) important in A-weighting.

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