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Performance of a New Fan Silencer Prototype for Auxiliary Ventilation

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Abstract

Mechanized underground mines suffer from noise overexposure. Noise levels are often above the Permissible Exposure Limit (PEL) where underground fans are used. Sound levels in active workings can reach up to 121 A-weighted decibels (dB(A)), especially when fans are not equipped with silencers. Use of silencers seldom ensures PEL. Overexposure of noise induces permanent hearing loss among mine workers. A NIOSH-funded research project and field studies at six coal and non-coal mines revalidated the findings. The University of Utah undertook laboratory studies to reduce fan noise at the source. A new silencer prototype with varying noise dampening material was designed and tested. The silencer and associated extension can be repacked with different dampening materials. The silencer and the extension were used in various configurations. Attempts were also made to simulate field conditions. The tests demonstrated a maximum sound level attenuation of about 14 dB(A) at the fan discharge. A properly designed silencer offers lesser resistance and thereby better fan performance and lower energy cost. The re-packable silencer is more likely to be maintained properly. Lowering of noise level happens in audible frequencies (4000 to 8000 Hz) which are important in A-weighting.

Keywords Mining · Engineering · Health · Safety · Mine ventilation · Auxiliary fan · Noise induced hearing loss (NIHL)

1 Noise Sources 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 [1]. The Code of Federal Regulation 30CFR Part 30 §62.110 sets 8-h' time-weighted average (TWA_8) PEL of noise at 90 dB(A) for all mine workers. All production and support machinery in mining generate loud noise often beyond the PEL. Researchers in the USA have identified auxiliary fans as one of the major sources of noise. These fans can create noise exposure levels up to 121 dB(A), which is one of the highest in mining operation [2]. Studies have demonstrated substantial reduction of noise level by using silencers. Appropriate 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 to ventilate underground maintenance workshops, crushers, conveyor transfer points, etc. Typical duct diameters in hard rock mines vary from 0.91 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 [3] to ventilate working faces in gate-roads and main entry developments. Sometimes, rock dusters are added at the discharge end to dust the roof, ribs, and floor.

2 Auxiliary Fans and Fan Silencers

Auxiliary fans are relatively smaller in size than the main fans and often have high rotational speeds (1800–3000 rpm). These fans are selected based on pressure-quantity requirements and space restrictions only. Noise emissions are rarely considered during the selection stage. Installation of fans,

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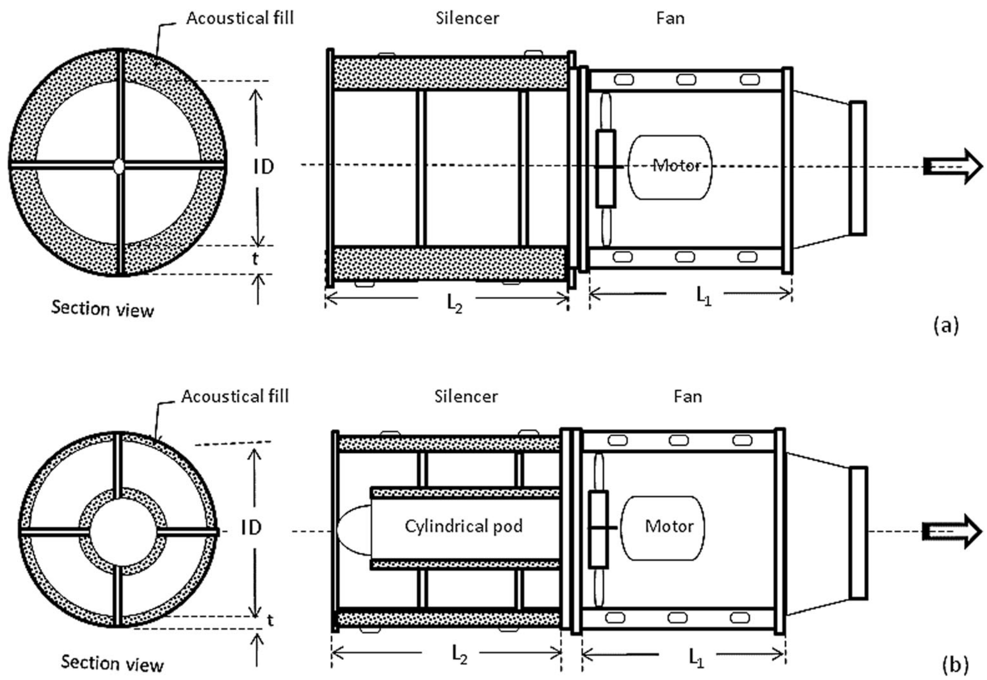

Fig. 1 Schematic of fan silencers for a blower auxiliary fan system. **a** Pod-less type silencer, and **b** Pod type silencer (ID, internal diameter; t, thickness of acoustical fill; L_1, L_2, lengths)

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 [4].

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 in thickness (Fig. 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 (Fig. 1 b). In this case, to match the fan diameter, the thickness of the acoustical fill is usually reduced to about 5 cm. To compensate for the thickness reduction, a center pod wrapped with acoustical material is added to the silencer [5]. Although this improves the attenuation capacity of the silencer, it reduces the fan performance by increasing the static head loss [6]. However, researchers in the past have experimented with even two flexible silencers coupled to both ends [7] of the fan [8].

3 Noise Survey in Mines

Studies have identified limited success of hearing protection measures in the mines [9]. Sound level and fan performance tests were conducted as part of this research work at six (named A through F) US underground mines: three coal mines, two hard rock mines, and one salt mine. Researchers use both noise dosimeters and sound level meters in similar noise surveys [10]. In each mine, auxiliary fans are used to

Table 1 Sound level (SL) measurement summary in six mines

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

*Mining equipment down during survey

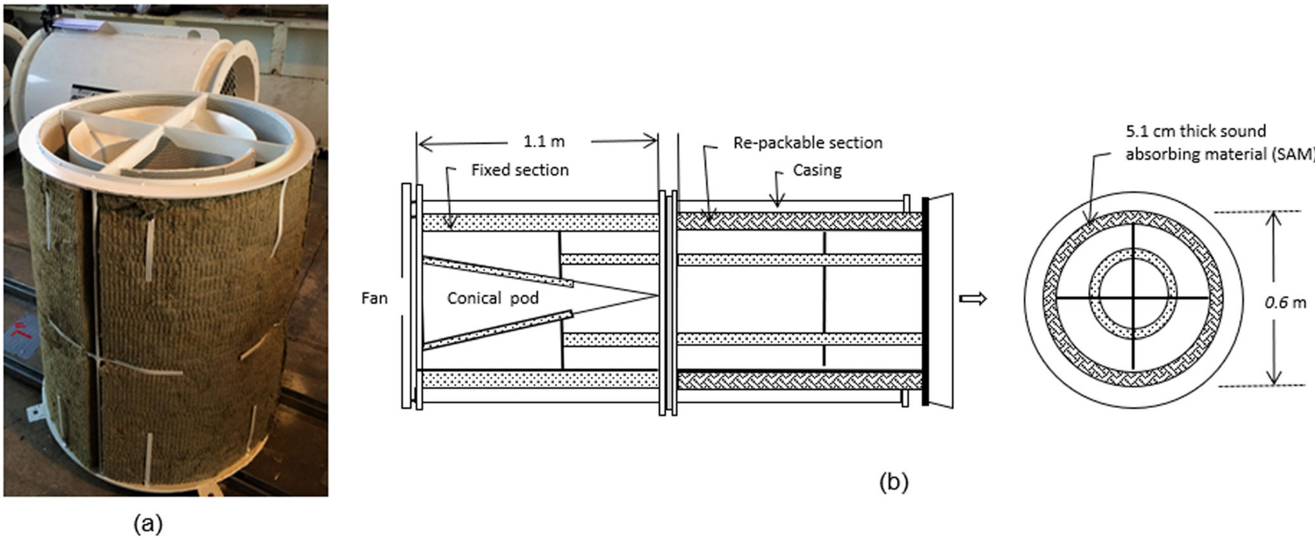

Fig. 2 New ring style silencer and silencer extension. **a** Re-packable section, and **b** Modified ring style silencer showing two major components: fixed section that includes a conical pod and re-packable section where the sound absorbing material can be replaced (not to scale)

ventilate development headings and fixed facilities. Coal mines are known to rely mostly of axial flow fans, and at high rotational speed, those are very noisy [11]. There are many advances in ventilation measurement technologies [12, 13] in the mines. 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 six mines. An SE-400 Series sound level (SL) meter was also used, except for two coal mines in which the use of the SL meter was restricted to intake entries.

Table 1 shows the summary of sound level measurements in each mine. Sound level around the auxiliary and booster 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 at the workings were above 87 dB(A).

In non-coal mines, in addition to sound levels generated by auxiliary fans, noise generated by booster fans was also monitored. Mines D and F used booster 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 had taken measures by administrative control and by using Personal Protective Equipment (PPE) to comply with the regulatory requirements.

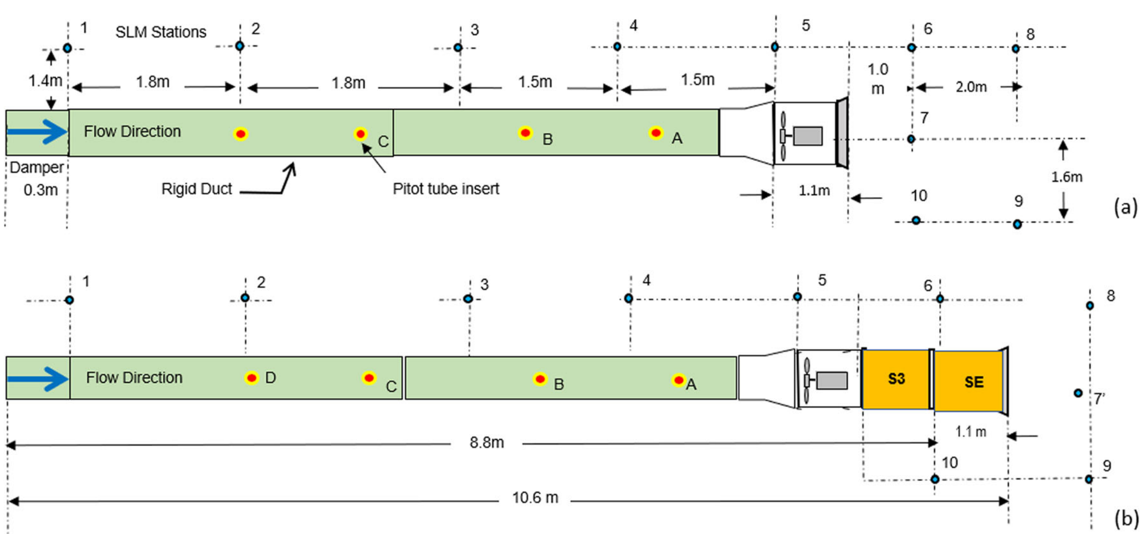

Fig. 3 Laboratory test layout for noise testing. **a** Fan only. **b** With silencer and extension

Table 2 Summary of sound level measurements at the University of Utah lab model—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

4 Auxiliary Ventilation System Lab Model at the University of Utah

An auxiliary ventilation system model was set up at the University of Utah ventilation laboratory in exhaust configuration to emulate coal mines. The system includes a 7.5-kW axial flow fan, a silencer, a 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.

The lab model included a prototype 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 (Fig. 2 a). 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 (CR 80). 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 2 b shows a schematic of the modified ring style (conical pod) silencer attached to a re-packable silencer extension (cylindrical pod). 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 Fig. 3 a, b.

5 Silencer Attenuation Testing in the University of Utah Lab

Several sound attenuations tests were carried out in the University of Utah lab model. The re-packable silencer was used to test three types of sound absorbing material (SAM): ProRox SL960, ROXUL AFB, and CR 80. 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 level in dB(A) for each station. Then, the sound absorbing materials were ranked based on their effectiveness in reducing noise.

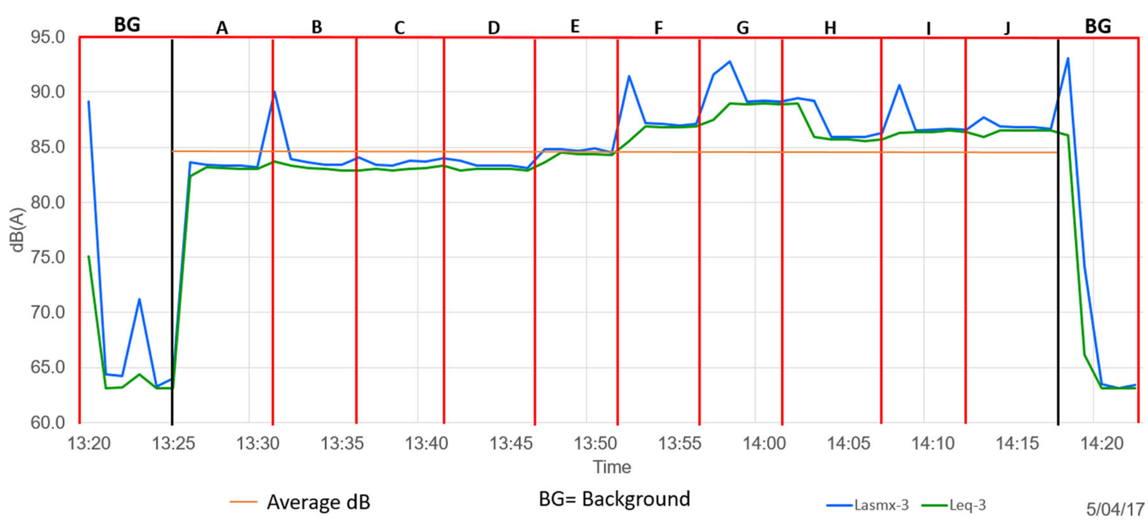

Fig. 4 Sound spectra for test 1. blue—maximum, green—equivalent average sound levels

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

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

6 Test Results

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

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 CR 80

Figure 3.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 3 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 CR 80.

For each test laboratory, safety procedures were followed; the damper cross-sectional area was set to 100% open, and the fan was operated at full speed (60 Hz). 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 for 5 min at each station, 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 were recorded for each system configuration. A wind screen was used throughout the test to reduce the effect of wind on the microphone.

6.1 Test 1—Fan System Without Silencer

Ambient conditions: barometric pressure 86,070 Pa, air temperature 25 °C, estimated air density1.0 kg/m^3

Fan performance: static pressure measured along the duct at points A, B, C, and D (Fig. 3 a) was used to determine the fan static pressure. The velocity pressures were measured across the duct diameter at station A. Fan operating point: quantity = 4.39 m^3/s (9340 cfm); total pressure = 375 Pa (1.50 in. w.g.). The fan input power was estimated at 3.0 kW (4.0 HP).

Sound level data were collected by SLM and then downloaded to 3 M's DM software to determine a composite sound level for each station. Table 2 shows the average A-weighted sound levels, Lavg, for the ten measuring stations. These ranged between 82 and 89 dB(A). The highest sound level was recorded by the fan discharge (station 10).

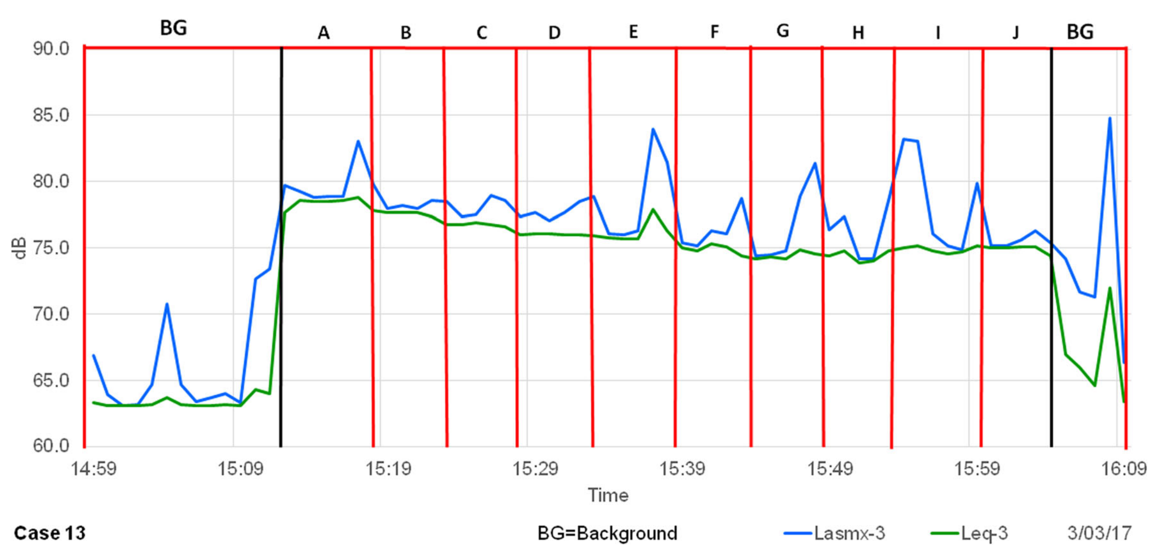

Fig. 5 Sound spectra for test 2. Blue—maximum, green—equivalent average sound levels

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

See Fig. 3 a for station locations.

Noise levels were also recorded for 50 min while the fan was running at full speed using an Edge eg5 noise dosimeter. Background noise was measured for 5 min before the fan was turned on and for 5 min after the fan was turned off. Figure 4 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 1 through 10 for 54 min. 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 Fig. 4, 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.

6.2 Test 2. Fan System with SL960 in Silencer Extension

Ambient conditions: Air density 0.99 kg/m^3

Fan operating point: quantity = 4.20 m^3/s (8895 cfm), total pressure = 363 Pa (1.45 in. w.g.). The fan input power was estimated at 2.63 kW (3.5 HP).

Sound levels were measured at ten stations around the fan system using SE-400 SLM. Table 3 shows a summary of composite sound levels. These ranged between 74 and 79 dB(A). Compared to that of test 1, on the average, the silencers provided a total protection of about 10 dB(A).

See Fig. 3 b for station locations.

Noise levels were recorded using an Edge eg5 noise dosimeter for approximately 70 min while the fan was running. The background averaged 63.1 dB(A). The sound level increased to a maximum of 78.4 dB(A) near station 1 when the fan was started. The recorded sound level by the fan discharge area was about 74.8 dB(A). Figure 5 shows the maximum and overall average sound levels collected during this test. Time intervals A through J represent the time spent when the noise dosimeter was held at the sound level stations 1 through 10 for 5 min. 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.

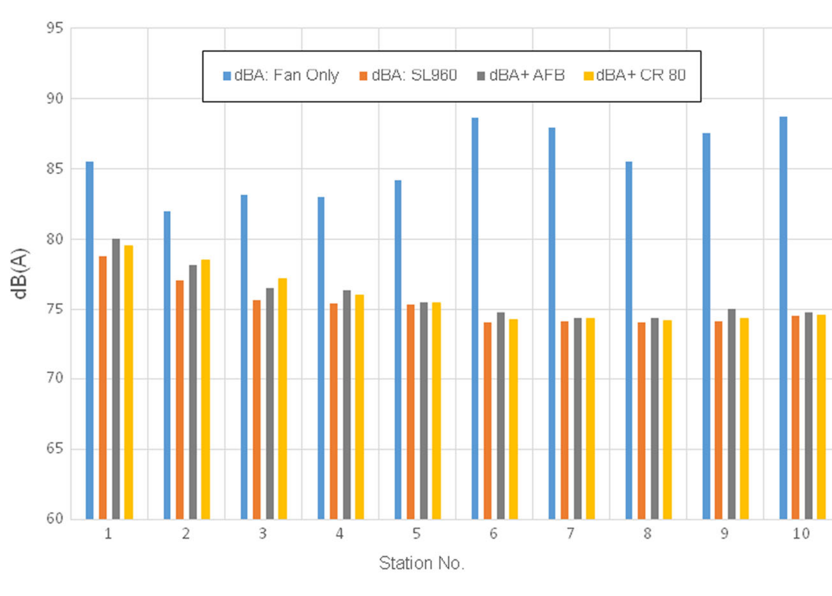

Fig. 6 Comparison of sound levels for four fan-silencer configurations

6.3 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.

Fan performance: quantity = 4.17 m^3/s (8820 cfm); total pressure = 375 Pa (1.5 in. w.g. The fan input power was estimated at 2.63 kW (3.5 HP).

Table 4 shows a summary of composite sound levels. Compared 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 1 dB less effective as the SL960.

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. The recorded sound level by the fan discharge area was about 76 dB(A).

6.4 Test 4. Fan System with CR 80 in Silencer Extension

Fan performance: quantity = 4.14 m^3/s (8755 cfm); total pressure = 400 Pa (1.6 in. w.g.); and the fan input power was estimated at 2.75 kW (3.7 HP).

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).

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 min. 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. The recorded sound level by the fan discharge area was about 78 dB(A).

7 Analysis of Results

Comparative sound level graphs, for homologous stations, were used to determine an order of magnitude noise reduction produced by the two silencers for the four tests conducted.

Figure 6 shows a comparison of average sound levels for the four tests presented in this study. These average sound levels were calculated based on the sound levels shown in Tables 2, 3, 4, and 5. Based on this figure, it can be concluded that 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 shows 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 7 shows sound level histograms for the last three tests when the sound

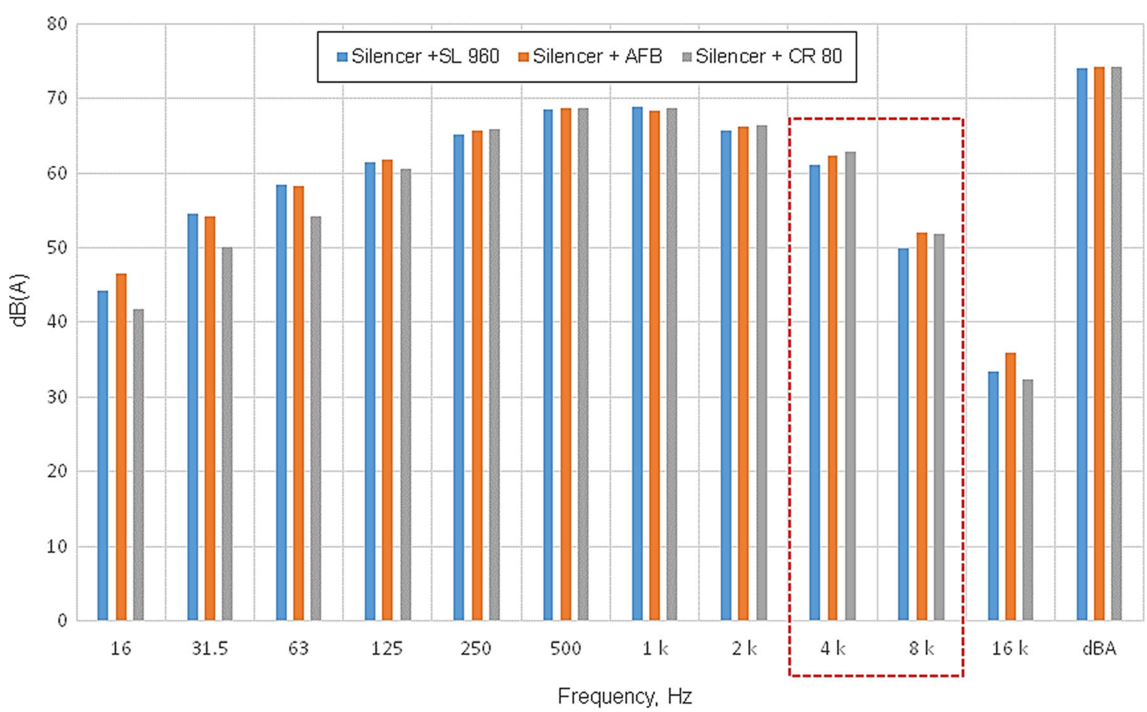

Fig. 7 Comparison of sound levels for different frequency bands for samples collected at station 7. The red box shows the frequencies at which hearing loss begins

level monitor was held at station 7. Based on these histograms, it can be concluded that the three insulation materials have practically the same noise absorbing characteristics. A closed look, however, shows that CR 80 outperforms the other materials in the low frequency bands. Figure 7 also shows the equivalent sound levels in dB(A) for the frequencies at which humans can hear the best. A comparison of sound levels in the 4000–8000 Hz range (red box) reveals that SL 960 outperforms AFB and CR 80 by about 2 dB(A).

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.

8 Conclusion

This study brought out some important findings. First, despite decades of regulations and hearing protection programs, almost all mines have the potential of exposure to above PEL of noise from auxiliary ventilation systems. Administrative controls and personal protective equipment (PPE) are often utilized to comply with regulations. 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 optimally to attenuate noise below PEL. The silencers used also have significant room for improvements.

The laboratory tests demonstrated a maximum sound level attenuation of about 14 dB(A) at the fan discharge. A recent study in China [14] had similar improvement using attenuators. A properly designed silencer will offer lesser resistance. A silencer is an obstruction to the airflow; therefore, it increases the shock loss. The sharper the obstruction, the higher the loss. The new model included a conical pod instead of a cylindrical. An aerodynamic pod will cut the shock loss. That will ensure better fan performance and will save energy cost over long periods of time.

The re-packable silencer offers the 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 happens in audible frequencies (4000 to 8000 Hz) which are important in A-weighting and will help protect human hearing the most.

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Compliance with Ethical Standards

Conflict of Interest The author declares that he has no conflict of interest.

Disclaimer The views, opinions, and recommendations expressed herein are solely those of the authors and do not imply any endorsement by the NIOSH, its directors and staff.

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Search

The National Institute for Occupational Safety and Health (NIOSH)

Keywords: Auxiliary ventilation | Hearing loss | Noise

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[redacted]	
Start Date	9/1/2015
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Research Concept	This technology will focus on developing auxiliary ventilation systems that can still provide the necessary air flow without generating noise levels that create overexposure to mine workers.
[redacted]	Hearing Loss Prevention Overview

Contract Status & Impact

This contract is complete. To receive a copy of the final report, send a request to mining@cdc.gov.

This contract aims to reduce noise exposure in underground mines by improving auxiliary ventilation technologies. Noise-induced hearing loss (NIHL) is an inherent health hazard in the mining industry, specifically in mines where heavy pieces of equipment are being utilized. Reduction of noise generated by mine fans can prove to be a significant step towards addressing this problem. While mine equipment is being operated, noise levels are elevated by the use of portable auxiliary fans, which are used to keep the mine ventilated. At times, multiple fans in series are used, further enhancing the noise level. Ventilation systems are usually designed for high efficiency with minimal emphasis placed on noise reduction. Sound attenuating devices are used, but are bulky, inefficient, and often omitted. This research will develop and test improved fan silencers.

In underground mines, working areas can be filled with extensive and damaging noise. When portable underground fans are used, either as auxiliary or booster fans, noise usually comes from two sources: fan motor and impeller blades. Without the presence of silencers, sound pressure at hazardous levels in excess of 100 dB(A) have been measured. Research has shown that the noise level can be reduced when flexible silencers are connected to both ends of the fan. However, the silencers can become clogged and ineffective if not properly maintained.

Under this contract, the University of Utah has assembled an auxiliary ventilation model equipped with flexible couplings and silencers to reduce noise level. This model has currently been upgraded to include two axial fans of 0.45-m-diameter ductwork in series. A 10 HP fan with two types of silencers has been purchased. This fan was tested in the field using three configurations: alone without a silencer, with a strut silencer, and with a ring silencer. To date, the ring silencer has provided the best noise reduction. In addition, the newly redesigned silencers have a potential for commercialization since they constitute an add-on feature to the portable ventilation fans.

See Also

- Development and Evaluation of a Urethane Jacketed Tail Roller for Continuous Mining Machines
- Noise and Hearing Protection: Development of Two Training Exercises for Drillers
- Noise Exposure in Longwall Mining and Engineering Controls Research
- Noise Source Identification on a Continuous Mining Machine
- Noise Source Identification on a Horizontal Vibrating Screen
- Snapshot of Noise and Worker Exposures in Sand and Gravel Operations
- A Technique for Estimating the Sound Power Level Radiated by Pneumatic Rock Drills and the Evaluation of a CSIR Prototype Rock Drill with Engineering Noise Controls
- Water Well Safety Bits: Health And Safety Information For The Water Well Industry
- What Does a Hearing Loss Sound Like?
- Working in Noise with a Hearing Loss: Perceptions from Workers, Supervisors, and Hearing Conservation Program Managers