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Efficacy of noise control measures at high noise zones from a copper mine in Zambia

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Abstract

Introduction: *it is estimated that about 30 million workers in the United States of America (USA) and 28% of the workers in Europe are exposed to high noise levels. In developing countries, occupational noise exposures are limited in the scientific literature due to lack of research being carried out in this field. We evaluated the efficacy of noise control measures at various sections at Konkola Copper Mine concentrator section in Zambia.* ***Methods:*** *we used a quantitative cross-sectional study to evaluate the efficacy of noise control measures at various sections of the concentrator. The study enumerated noise sources, noise release mechanisms and noise controls used. Noise levels without and with controls at each noise source were also measured using Optimus type1, model CR: 172B sound level meter.* ***Results:*** *seventeen noise generating equipment were identified with about 53% of the equipment operated at the crushing section, 18% operated at the flotation and filtration section respectively, and 11% at milling section. A substantial portion (65%) of the identified noise sources in the concentrator are not housed, and among these, 36% are mobile in nature. It was also found that none of the noise areas were demarcated. There are three types of noise release mechanism from the 17 machines identified at the sections of the concentrator. Eighty-two percent (82%) of the machines release noise by pulsation mechanism, 12% by jet and 6% by turbulence. Approximately, 76.5% (13) of the noise controls at the concentrator had efficacy strong enough to reduce noise levels to below the OEL while 23.5% (4) of the controls had weak efficacy that failed to reduce noise levels to below the OEL.* ***Conclusion:*** *there is a need to strengthen efficacy in areas where controls were found to be weak. There is need to sustain controls that were found to be strong to maintain their efficacy. About 75% (3 of the 4) of the controls with lower efficacy were from the crushing section while 25% (1 of the 4) were from the filtration section.*

Introduction

Hazardous noise exposure is associated with a wide range of health consequences of stress, poor concentration, communication difficulties, and fatigue from lack of sleep [1], and more serious issues such as cardiovascular disease [2], cognitive impairment, tinnitus [3] and NIHL [4]. About 30 million workers in the United States of America (USA) are exposed to time-weighted average (TWA) sound levels above the Occupational Exposure Limit (OEL) of 85 dB (A), resulting in about 10 million noise-induced hearing loss (NIHL) > 25 decibels (dB) [5]. Across Europe, 28% of workers surveyed reported that at least one-fourth of the time they work in high-noise areas, meaning that they are exposed to noise loud enough to raise their voices to hold a conversation, which translates to noise that is approximately 85-90 dB (A) [6]. In developing countries, occupational noise exposures are limited in the scientific literature, this is due to a lack of research being carried out in this field [7]. More emphasis is given to the correlation of noise exposure to health outcomes, with little attention on exposure assessment and exposure control activities. The mining industry worldwide is struggling with hearing loss and overexposure to noise. This is confirmed by an estimate that 70 to 90% of diagnosed miners are found to have NIHL significant enough to be classified as a hearing disability before their retirement age [8].

In a copper mining set-up, the concentrator section is assumed to be among high noise zones Where workers are exposed to noise above the occupational exposure limit (OEL) of 85 dB (A). These noise levels are high enough to cause noise impairment. High noise can also lead to productivity losses in the workplace [9] due to absenteeism. To reduce the negative health effects associated with exposures to noise, it is important to critically look at the sources of noise, noise release mechanisms, noise controls that are in place, and noise control efficacy. This study identified noise sources, noise release mechanism, and noise controls and assessed noise controls´ efficacy at the Konkola Concentrator. Noise control strategies follow the hierarchy of controls [10]. Elimination and substitution are mostly at the initial stage of the hierarchy of control. They entail the complete removal of the noise source or replacing a high noise emitting source with a lower-emitting process, respectively [11]. Engineering controls utilize a number of controls such as silencers, operator´s cabins, and control rooms that enclose workers from the source, use of sound absorbers, and proper maintenance of noise sources that ensures that sources maintain their normal noise rating. Administrative controls involve management decisions that affect worker noise exposure in a positive manner and may include shift scheduling to minimize exposure duration, re-allocation of noisy tasks to times when there are few workers, keeping workers away from unnecessary noise, and health education [12]. At the bottom of the hierarchy is the use of hearing protection devices (HPDs] that include earmuffs, ear blocks, and ear plugs. Hearing protection devices (HPDs] are considered the last resort due to their low noise reduction levels and high dependence on personal attitude [13].

The concentrator receives copper ore from mining operations and mills it into smaller particles to produce concentrate used at the smelter to produce copper anodes. Anodes are subsequently transported to the refinery for further processing to produce cathodes (copper metal) at 99.99% purity. Konkola Concentrator is a 6 million tons per annum capacity copper concentrate processing plant. The process cycle from copper ore feed to concentrate takes about 2 hours. The normal work shift for workers at the concentrator is 8 hours, and the plant operations run continuously to maximize on production. A detailed process involves receiving ore on conveyor belts and conveying it to the stockpile where it is fed into secondary crushers for crushing via chutes. The crushed ore is conveyed and fed into wet mills to make a slurry. The slurry is pumped to flotation tanks where sodium isopropyl xanthate (SIPX), frother, and sodium hydrosulphide are added to separate the copper and other metals. The chemicals act as collectors for copper minerals in slurry. This product is then pumped to the filtration section to remove excess water to produce the concentrate. In this study, we evaluated the efficacy of noise control measures in the various areas in the concentrator section. Furthermore, the study firstly identified noise sources in the four sections within the concentrator; secondly described noise release mechanisms in four sections within the concentrator in a copper mine in Zambia in 2022; thirdly described the noise controls that have been put in place at the four sections within the concentrator, and lastly, we assessed the efficacy of noise control measures at the four sections within the concentrator.

Methods

Study design: this is a quantitative cross-sectional study to evaluate the efficacy of noise control measures.

Study area: the study was conducted at Konkola Copper Mines (KCM) plc´s Konkola Business Unit (KBU) in Chililabombwe District in the Copperbelt Province of Zambia. This study was carried out at the concentrator area as it is considered one of the high noise emitting units of the mine.

Description of the sampling equipment: sound level meter (SLM) Optimus type1, model CR: 172B, manufactured by Cirrus Research Plc in the United Kingdom, was used to monitor noise. This instrument has a detection range of 20 dB (A) to 140dB (A) and up to 143dB (C). This SLM is fitted with MK: 224 microphones and the calibration level must be stable to within ±0.075 dB for 5 minutes.

Sampling arrangement and duration: a walk-through survey was conducted to collect information to describe the operations, identify noise sources, understand noise release mechanisms of noise sources, and describe noise control measures. Information obtained during the walk-through survey was recorded and used to inform the noise mapping and sampling plan.

Monitoring: noise measurements were collected at four different sections in the concentrator (namely; stockpile/crushing, milling, flotation, and filtration/concentrate shed sections). The sound level meter was calibrated to 94 dB @ 1khz before and after noise measurement to check the accuracy of the microphone using a calibrator supplied by the manufacturer. Before field-based monitoring, background noise levels were taken over 20 minutes in the absence of any operating process, to ascertain that there was significant noise influence from plant process activities. Monitoring was done three times per location to reduce uncertainty. Field-based monitoring was conducted at a distance of 1.2 m from any noise-reflecting surface per monitored location. The monitoring height of the SLM was 1.5 m above ground to take care of the hearing circumference of the receptor for a standing worker and 0.9 m for a seated working operation. The SLM was fitted with windshield foam to compensate for wind variations to avoid any noise obstruction or absorption by the data collector. To find the actual noise level per location, the three noise readings taken per sampling location were added and then averaged to get the noise level reading at a particular point.

Processing of raw data/data analysis: noise monitoring readings from the sound level meter were manually recorded in the checklist specifically designed for the study and subsequently transferred into an Excel spreadsheet for further processing. The noise monitoring instrument used can give noise readings in time-weighted equivalent in A, B, and C. For this study, A weighting that mimics the human ear was used during noise monitoring, and $L_{ex.8h}$ view was used to extrapolate would exposure for 8 hours. Alternatively, acquired sound pressure level readings could be used to calculate a time-weighted equivalent concentration using equation 1 and 2 [14].

$$\mathrm{TWA_{Laeq}} = 10\log\left(\frac{\mathrm{t_1} \times 10^{\mathrm{db}/10} + \mathrm{t_2} \times 10^{\mathrm{db}/10}}{\text{Total time (T)}}\right)$$

Where TWA is the average noise level over the sampling period, t is the time taken to collect noise sample, db is the sound pressure level and T is the total sampling time.

$$\mathrm{TWA_{Laeq}} = \mathrm{TWA} + 10\log\left(\frac{t}{\mathrm{T}}\right)$$

A weighted average sound pressure level is equivalent to the noise exposure normalized to a specific time and when no subscript appears, base 10 is assumed. T represents a time duration of 8 hours, while t represents the actual monitoring duration. The total amount of noise per section was calculated using equation 3.

$$\mathrm{TWA_{Laeq}} = \mathrm{TWA} + 10\log\left(\frac{t}{\mathrm{T}}\right)$$

[15].

The efficacy of the noise control measure was derived by using equation 4.

$$\text{Efficacy} = \left(\frac{\mathrm{B} - \mathrm{A}}{\mathrm{B}}\right) \times 100$$

Where B is the highest concentration (noise level reading before controls) and A is the lowest concentration (noise level reading after the controls). Reduced noise was calculated by multiplying the B with efficacy converted to percentage to obtain the noise level figure. The obtained figure was subtracted from B and the difference was the noise reduction. To obtain the efficacy of hearing protection devices (HPDs), equation 5 was used to calculate the lower value, which is the noise level under the protector needed, or the lower concentration required for calculating efficacy for HPDs [16].

$$HPDs = LAeq, 8 - [(NRR - 7) X\, 0.5]$$

Where LAeq 8 is A weighted continuous noise for 8 hours and NRR is the noise reduction rating for the HPD in use. Monitoring at each location was done in triplicate using an instrument with a valid annual calibration certificate. Pre- and post-field calibration was performed on the instrument on each day of monitoring to ensure that the readings obtained were accurate. An ethical waiver W-CBP-230428-01 was granted as this study did not involve animal or human subjects but only area noise monitoring using a CR: 172B SLM. Specifically designed noise survey and measurement data extraction checklists were completed during the walk-through survey and actual noise measurement phases. The walk-through survey was done to familiarize myself with the activities at the concentrator such as process flow, various equipment used, and installed noise control measures.

Quality control: monitoring at each location was done in triplicate using an instrument with a valid annual calibration certificate. Pre- and post-field calibration was performed on the instrument on each day of monitoring to ensure that the readings obtained were accurate. The steps above are a prerequisite for authentic noise readings. An ethical waiver W-CBP-230428-01 was granted as this study did not involve animal or human subjects but only area noise monitoring using a CR: 172B SLM.

Results

Description of noise zones: results presented in Table 1 show the number of noise areas in various parts of the concentrator. Four different areas performing various activities were identified as noise areas. From the walkthrough survey, a total of 17 noise-generating equipment were identified, with about 53% of the equipment operated at the crushing area. It was also found that none of the noise areas were demarcated.

Noise release mechanisms for the different areas: there are three noise release mechanisms in the four sections, distributed as shown in Table 2. Crushing, flotation, and filtration sections have two types of noise release mechanisms each, while milling has only one. Different equipment has different noise release mechanisms, as shown in Table 3. The noise release mechanism is influenced by the activity or the equipment output. The three noise release mechanisms are in line with the ones highlighted in the literature. The known noise release mechanisms are pulsation, turbulence, and jet. The pulsation release mechanism is found in compressors, while turbulence is found in fans and jets and is associated with compressed air [15]. Once noise/stressor is released from a source, it will emit to the adjacent media, which could be air, liquid, or solid. Noise emitted into the air will travel with it until it is emitted to the receptor through contact. The sound emitted into the air may encounter barriers like walls, trees, liquids, or engineered attenuation material along its transmission pathways. These barriers will lead to reduced noise intensity at the receptor [16]. Sound emitted to solids will travel in the solids, and air, and finally immit at the receptor. The sound exposure pathway involves release from the source and emission into the transport media (air, liquid, and solid) for transmission to the receptor for it to constitute an emission [17]. Barriers along the transmission pathway and the distance of the receptor from the source determine the amount of sound available for an exposure event [18].

Description of noise sources in sections: there are nine different types of machines in the crushing section emitting different ranges of noise from the lowest noise level of 77.4 dB (A) to the highest noise level of 92.3 dB (A). The noise at the crushing section had five different noise categories (77-80, 80-83, 83-86, 86-89 & 89-92), and of these, three are above OEL. The total noise emitted from the crushing section of the concentrator is 98.0 dB (A). Different noise sources in the crushing section and the levels of noise they emit before the implementation of controls include crushers, C4-conveyor, C5-conveyor, vent fan, pumps, loader-L03, loader-L04, loader-L12, and vibration feeders.

There are two (2) different types of machines in the milling section, emitting noise at 85.7 dB (A) and 88.9 dB (A). This results in one noise category (85.7-88.7) in the milling section. The total noise emitted from the milling section of the concentrator is 90.6 dB (A). The two noise sources in the milling section and the levels of noise they emitted before the implementation of controls are semi-autogenous grinding (SAG) mills and ball mills. There are three (3) different types of machines in the flotation section emitting different ranges of noise from the lowest of 78.5 dB (A) to the highest of 89.2 dB (A). This represents four different noise categories (77.5-81.5, 81.5-84.5, 84.5-87.5 & 87.5-89.5) with two categories above the OEL. The total noise emitted from the milling section of the concentrator is 89.9 dB (A). Different noise sources and levels of noise they emit before the implementation of controls include agitators, pumps, and compressors. The filtration section has three (3) different types of machines emitting different ranges of noise from the lowest noise level of 82 dB (A) to the highest noise level of 87.8 dB (A). This represents two different noise categories (82-85 & 85-87.8) with one category above the OEL. The total noise emitted from the milling section of the concentrator is 90.3 dB (A). Different noise sources and levels of noise they emitted before the implementation of controls were press filters, thickeners, and loader -L09.

Description of noise controls in sections: there are three types of noise control measures in the different sections of the concentrator, as shown in Table 4. Enclosure of the receptor from the noise source is the commonly used noise control measure at 52.94%, followed by HPDs at 41.17% and the least used one is silencers at 5.88%. These controls are consistent with the research entitled, ´engineering noise control for mines: Lessons from the world´ conducted in South Africa [19].

Description of noise after controls in sections: there are different levels of noise emitted from nine different machines in the crushing section after controls. The lowest noise level after controls is 64.9 dB (A) from conveyor rollers-C5 while the highest is 85.9 dB (A) from the crusher compared to the lowest of 77.4 dB (A) and the highest of 92.3 dB (A) before controls from the same machines. Different levels of noise emitted by different machines after control are shown in Figure 1. The crushing sections have seven different noise categories (64.9-67.9, 67.9-70.9, 70.9-73.9, 73.9-76.9, 76.9-79.9, 79.9-82.9 and 82.9-85.9) after controls were implemented compared to five noise categories before controls. Of the seven noise categories after controls, only one category was above the OEL compared to three noise categories that were above before controls were implemented. The total noise level in the crushing sections after controls is 91.8 dB(A) compared to 98.0 dB (A) before controls were implemented. Noise after controls in the milling section ranges from the lowest of 70.1 dB (A) from the SAG mills to the highest of 75 dB (A) from the ball mills compared to the lowest of 85.7 dB (A) and the highest of 88.9 dB (A) without controls from the same machines. There are two different noise categories (70.1-73.1 and 73.1 -75) after controls in the milling section compared to only one noise zone before controls. The two noise zones after controls are all below OEL. The total noise level in the milling section after controls is 76.2 dB (A).

Noise after controls in the Flotation section ranges from the lowest of 66 dB (A) from the pumps to the highest of 87.9 dB (A) from the compressors compared to the lowest of 78.5 dB (A) to the highest of 89.2 dB (A) from the same machines without controls. The noise level after controls at the milling section. There are seven different noise categories (66-69, 69-72, 72-75, 75-78, 78-81, 81-84 and 84-87) after controls in the flotation section compared to four noise zones before controls. One noise of the seven noise zones after controls is above OEL while two are above OEL before controls. The total noise level in the flotation section after controls is 87.9 dB (A). Noise after controls in the filtration section ranges from the lowest noise level of 72.6 dB (A) from the press filter to the highest noise level of 82.6 dB (A) from loader - L09 compared to the lowest noise level of 82 dB (A) from the thickeners to the highest noise level of 87.8 dB (A) from loader-L09. There are four different noise categories (72.6-75.6, 75.6-78.6, 78.6-81.6 and 81.6-82.6) after controls in the filtration section. None of the four noise categories after controls was above the OEL while one of the two noise categories was above the OEL before controls in this section. The total noise level after control is 85.7 dB (A).

Assessment of the efficacy of noise control measures: the efficacy of noise control measures at the four sections within the study area ranged from the lowest of 1.3% at Loader-L03 in the crushing section to the highest of 18.2% at the SAG Mills in the Milling section. Thirteen (13) machines representing 76.5% of the noise emitting machines had their noise control efficacy strong enough to reduce noise to levels below the OEL while 4 machines representing 23.5% of noise emitting machines had noise control efficacy not strong enough to reduce noise levels to below OEL. The efficacy of controls for different machines in the Concentrator and residual noise levels are shown in Table 5. The efficacy of noise control measures ranged from 1.4 to 22.3. Efficacy of 1.4, 3.4, and 7.9 from the crushing section and 1.5 from the flotation section failed to attenuate noise levels to below the OEL in 4 of the 17 monitored locations.

Discussion

The results of this study found that 17 noise sources in the concentrator´s four sections were crushing, milling, flotation, and filtration. The noise sources found in this study are similar to the ones reported in the literature [16]. The crushing section has the highest number of noise sources at 53%. It is followed by the filtration and the flotation sections with 18% each. The milling section has the least number of noise sources at 11%. The noise sources identified at the concentrator are conveyor belts (C4 and C5), vent fan, pumps, loaders (L03, L04, L09, and L012), vibration feeders, SAG mills, ball mills, agitators, auxiliary pumps, compressors, press filter/larox filter and thickeners, similarly to findings to a similar study [20]. Susanto *et al*. [21] mention that the SAG mills, ball mills, and agitators are also sources of noise while Steenkamp [22], highlights production machinery and process activities as noise sources, including fans, stators, gears, vibrating panels, turbulent fluid flow, electrical machines, process impacts, and internal combustion engines.

Results in Table 1 summarize the distribution of noise-generating machines across the concentrator, while Table 3 specifies machines that emit noise in the sections of the concentrator apart from showing noise release mechanisms from these machines. Thirty-five percent (35%) of the 17 sources at the concentrator are in some form of enclosure/housing, while 65% of the 17 sources are not. Thirty-six percent (36%) of the 65% of noise sources that are not housed are mobile. The three types of noise release mechanisms are pulsation, turbulence, and jet. Eighty-two percent (82%) of the machines release noise by pulsation mechanism, 12% by jet, and 6% by turbulence. The different equipment in the sections of the concentrator have different noise release mechanisms, as shown in Table 3. The noise release mechanism is influenced by the activity or the equipment output. The noise release mechanisms at the concentrator are in line with Elkoumy [23] unlike Steenkamp [22], who talks about noise release but does not specify noise release mechanisms.

There are three types of noise controls (enclosure, silencer and HPD) that are in use at the concentrator. They fall into two categories of the hierarchy of controls, namely; engineering and PPE. Out of the nine noise sources at the crushing section, 56% (5 of the 9) utilized enclosure as control, 33% (3 of the 9) had HPDs as control, and 11% (1 of the 9) source was installed with a silencer as a control. Enclosure is utilized to control noise from the two sources found in the milling section, while HPDs and enclosure are the noise control measures in use at both the flotation and filtration sections of the concentrator. Enclosure is the most available control in the concentrator at 53%, followed by HPDs at 41%, and the least available is the silencer at 6%. One study, confirms that silencers and vibration isolation are used to control high noise [21]. Engineering out the noise entails controlling the noise at the source by utilizing a number of engineering approaches such as barriers, enclosures, dissipative mufflers, lined duets, reverberation control, and installing sound-absorbing material [22].

About 76.5% (13) of the controls had efficacy strong enough to reduce noise levels to below the OEL while 23.5% (4) of the controls had weak efficacy that failed to reduce noise levels to below the OEL. However, 75% (3 of the 4) of the controls with lower efficacy were from the crushing section, while 25% (1 of the 4) were from the Filtration section. The crushing section and filtration are the sections with some controls with weak efficacy, while all the controls in the milling and flotation section had strong efficacy that managed to reduce noise to below the OEL as in Figure 1. The summary of efficacy and residual noise in the concentrator is shown in Table 5. The crushing section had noise efficacy ranging from the lowest of 1.4 to the highest of 19.3. The two sources of noise in the milling section had the efficacy of 18.5 and 22.3 and were both strong enough to reduce residual noise to below the OEL. The three sources in the flotation section had the efficacy of 1.5, 17.2, and 17.9 with one failing to reduce noise to below the OEL. The three noise controls in the filtration section had an efficacy of 6.3, 17.2, and 17.9, all had residual noise below OEL. The efficacy of noise control measures at the four sections of the concentrator ranged from 1.4 to 22.3 dB.

Conclusion

Noise control measures at Konkola concentrator fall into two categories on of hierarchy of controls, and these are engineering and personal protective equipment (PPE). Enclosure, HPDs and silencers are the noise control measure being implemented and enclosure is the most available of the three noise controls. The majority of controls (76.5%) in the Concentrator had strong efficacy enough to successfully reduce noise levels to below the OEL, except a few (23.5%) controls in the crushing and flotation sections were unable to do that. Milling and filtration sections achieved strong efficacy in all their controls. Going by the above, the concentrator facility should focus on implementing further noise control measures in the crushing and filtration sections, as some of the current controls were not able to reduce noise levels to below the OEL. Furthermore, since a large portion of the identified noise sources are not housed, with a significant percentage being mobile, it is crucial to develop strategies to address noise from these sources, which may involve the use of advanced noise reduction technologies such as the use of metal alloys with enhanced dissipative properties.

What is known about this topic

- *Occupational noise-induced hearing loss (ONIHL) has a global prevalence and is ranked as the number one cause of work-related disability; although noise-related health effects are non-fatal, they contribute to reduced quality of life and may lead to early exclusion in the occupational environment which may indirectly contribute to premature deaths due to unaffordability of health care services;*

- *Africa has a paucity of studies on noise and the few studies done have focused on the four pillars of hearing conservation program (HCP) while neglecting record-keeping, periodic noise exposure monitoring, and audiometrics. The same pattern is prevailing in Zambia where a few studies were done directly related to noise health outcomes prevention rather than exposure assessment and evaluation of efficacy of control measures.*

What this study adds

- *The study helped to identify sources of high noise in different sections of the concentrator and highlights the efficacy of noise controls that are in use at Konkola concentrator;*
- *Further, the study suggests additional controls in areas where controls were missing and where they were found not to reduce noise exposures to acceptable levels;*
- *This study adds value in putting up occupational health programs to reduce the risks of noise-induced hearing loss.*

Competing interests

The authors declare no competing interests.

Authors' contributions

Nchimunya Bbautu and Masilu Daniel Masekameni drafted and conceptualized the experimental setup. Nchimunya Bbautu and Patrick Hayumbu collected, presented, analysed the data and arguments and prepared the manuscript. Masilu Daniel Masekameni, and Patrick Hayumbu supervised, developed, and validated the methodology, data analysis and interpretation. All authors read and approved the manuscript.

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Tables and figure

Table 1: noise-generating areas with various numbers of equipment

Table 2: description of noise release mechanisms

Table 3: noise release mechanism for the different equipment

Table 4: distribution of noise control measures

Table 5: control efficacies in the concentrator

Figure 1: noise levels emitted by various machines (before and after controls) compared with OEL (85 dB) and noise action level (82 dB)

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Table 1: noise-generating areas with various numbers of equipment

Area	Number of equipment	Demarcation
Crushing	9	None
Milling	2	None
Flotation	3	None
Filtration	3	None

Table 2: description of noise release mechanisms

Area	Release mechanism	Personal/area
Crushing	Pulsation & turbulence	No
Milling	Pulsation	No
Flotation	Jet & pulsation	No
Filtration	Jet & pulsation	No

Table 3: noise release mechanism for the different equipment		
Area	Name of equipment	Release mechanism
Crushing	Crushers	Pulsation
	Conveyor rollers-C4	Pulsation
	Conveyor rollers-C5	Pulsation
	Vent fan	Turbulence
	Pumps	Pulsation
	Loader-L03	Pulsation
	Loader-L04	Pulsation
	Loader-L12	Pulsation
	Vibration feeders	Pulsation
Milling	SAG mills	Pulsation
	Ball mills	Pulsation
Flotation	Agitators	Jet
	Pumps	Pulsation
	Compressors	Pulsation
Filtration	Press filter	Jet
	Thickeners	Pulsation
	Loader L09	Pulsation
SAG: semi-autogenous grinding		

Table 4: distribution of noise control measures			
Area	**Type of control**	**Number of times used per area**	**Control category**
Crushing	Enclosure	5	Engineering
	HPDs	3	PPE
	Silencer	1	Engineering
Milling	Enclosure	2	Engineering
Flotation	HPDs	2	PPE
	Enclosure	1	Engineering
Filtration	HPDs	2	PPE
	Enclosure	1	Engineering
HPDs: hearing protection devices, PPE: personal protective equipment			

Table 5: control efficacies in the concentrator

Area	Noise source	Noise control	Noise before control	Noise after control	Efficacy	Decibel reduced
			(dB)	(dB)	(%)	dB
Crushing	Crushers.	Enclosure	92.3	85.6	7.3	25
	C4-conveyor	HPDs	85.4	72.9	14.6	73
	C5-conveyor	HPDs	77.4	64.9	16.2	65
	Vent fan.	Silencer	88.0	79.6	9.5	4
	Pumps.	Enclosure	91.6	80.4	12.2	80
	Loader-L03	Enclosure	86.8	85.6	1.3	75
	Loader-L04	Enclosure	89.4	82.7	7.5	22
	Loader-L12	Enclosure	88.2	85.3	3.3	59
	Vibration Feeders	HPDs	80.7	68.2	15.5	68
Milling	SAG mills.	Enclosure	85.7	70.1	18.2	70
	Ball mills	Enclosure	88.9	75	15.6	75
Flotation	Agitators	HPDs	78.9	66.4	15.8	66
	Pumps	HPDs	78.5	66	15.9	66
	Compressors	Enclosure	89.2	87.6	1.5	76
Filtration	Press filter	HPDs	85.1	72.6	14.7	73
	Thickeners	HPDs	82.5	70	15.2	70
	Loader -L09	Enclosure	87.8	82.6	5.9	36

HPDs: hearing protection devices, SAG: semi-autogenous grinding

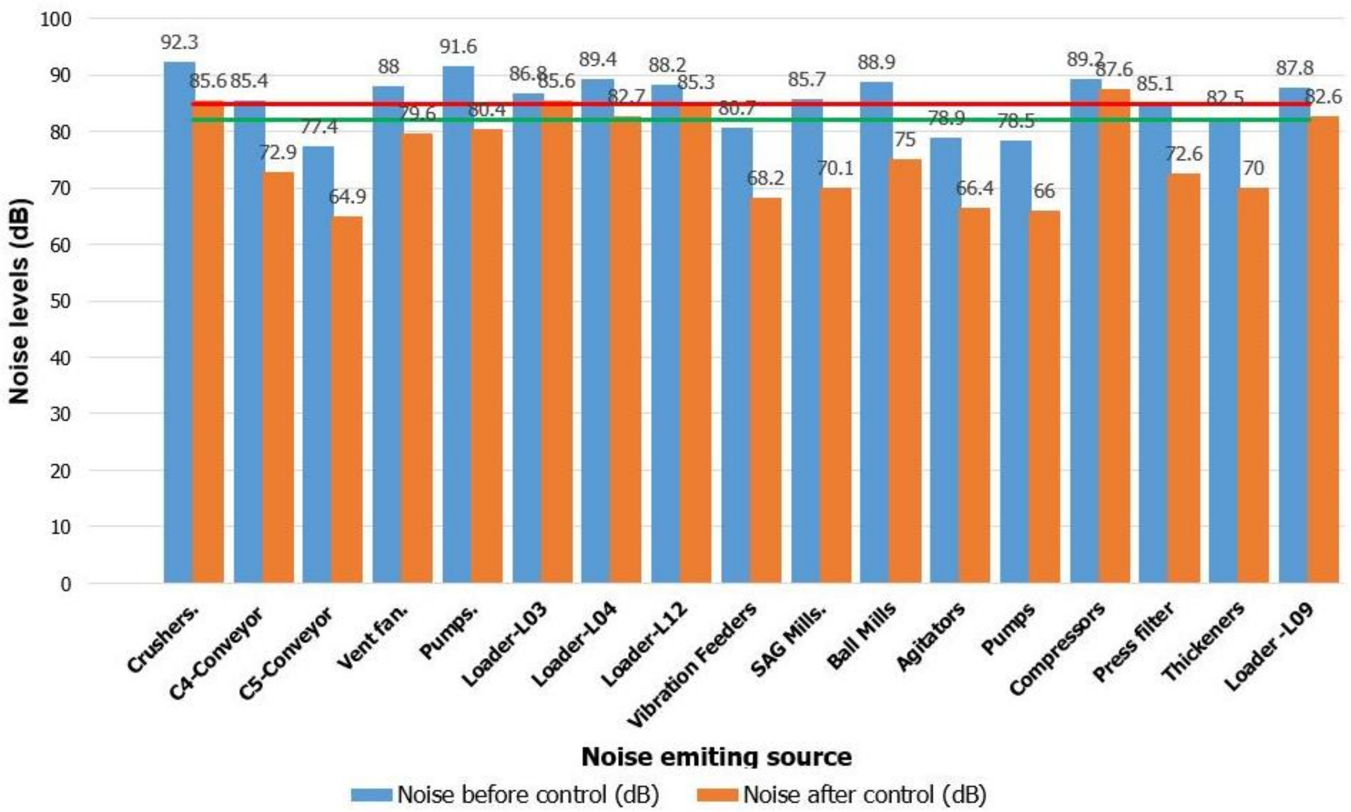

Figure 1: noise levels emitted by various machines (before and after controls) compared with OEL (85 dB) and noise action level (82 dB)