RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 5 No. 2 (2024) 217-226
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

Analysis of Three Different Silencer Nozzles in Reducing Airgun Noise for Occupational Safety and Health by Using IMMI Software

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DOI: https://doi.org/10.30880/rpmme.2024.05.02.025

Article Info

Received: 15 June 2024
Accepted: 10 October 2024
Available online: 31 December 2024

Keywords

Normal airguns, Silencer nozzles, IMMI simulation software, Noise maps, CEJN, Silvent, Chicago Pneumatic, ICOP equation

Abstract

Noise exposure is a serious problem in industrial environments which poses significant risks to workers' health and safety. This study aimed to address this issue by evaluating the use of normal airguns and the effectiveness of silencer nozzles in reducing noise levels. Objectives included mapping noise exposure in a production area, simulating and selecting the best silencer nozzle based on noise reduction performance and comparing the simulated noise exposure levels with Malaysian occupational safety and health standards. Using IMMI simulation software, noise maps showed that normal airguns contributed to hazardous noise exposure. To mitigate this, three silencer nozzles: CEJN, Silvent and Chicago Pneumatic were tested as replacements. The Chicago Pneumatic model proved most effective in reducing noise by up to 41 dB(A). Further analysis using the ICOP equation calculated daily noise exposure levels for workers showed that silencer nozzles significantly reduced noise exposure to below permissible limits. Results showed that while normal airguns exceeded safe noise levels, silencer nozzles maintained levels well within safety thresholds which enhances workplace safety. The study concluded that silencer nozzles were effective in lowering noise exposure levels in industrial settings and enhancing workplace safety which highlights the importance of implementing noise control measures and utilizing simulation software for accurate noise reduction predictions.

1. Introduction

Noise can be considered as an unpleasant sound that might affect physiological variables and it is frequently encountered in hazardous situations because of industrialization and urbanization [1]. Over 5% of the world's population or 430 million people require hearing loss rehabilitation (432 million adults and 34 million children) and over 700 million people or one out of every ten people are expected to suffer disabling hearing loss by 2050 [2]. Occupational noise-induced hearing loss (ONIHL) is the most common occupational disease in the world and noise-induced hearing Loss (NIHL) is the most often reported occupational disease in Malaysia in 2021 [3][4]. The Department of Occupational Safety and Health (DOSH) confirmed an occupational noise-related hearing disorder (ONRHD) report on 7941 patients in 2020. This statistic shows that ONRHD represents 87% of all confirmed occupational diseases in Malaysia and remains the most often reported occupational disease [5].

According to the Guidelines on Management of Occupational Noise-Related Hearing Disorders, the manufacturing, mining and quarrying, utilities, transport, storage and communication sectors have the most confirmed ONRHD cases [6]. High noise levels can be produced by machinery and job tasks in metal manufacturing operations which can be harmful to hearing [7]. The effects of industrial and traffic noise include a variety of auditory and nonauditory effects such as hearing loss, psychological problems, high blood pressure, irregular heart rhythms, difficulty sleeping, irritation and stress, decreased work efficiency and difficulty understanding what is said in conversation [8]. It has been proposed that the wear debris produced by a friction system in a friction interface can easily cause unstable vibration and noise [9]. The metal cutting industry now uses a variety of cutting coolants which aid in reducing friction, wear and cutting temperature while also assisting with chip removal in the cutting area. The use of cutting coolants improves surface roughness and increases the working lives of tools [10]. Cold air gun (CAG) nozzles supply low-temperature compressed air which was specially designed to cool and lubricate the machining zone and provide effective coolant cleaning and dirt separation [11]. However, this air-blowing process frequently generates excessive noise levels which poses a significant occupational health and safety hazard for workers within the manufacturing facility.

As a result, there is an urgent need to develop and implement an integrated approach that utilizes advanced predictive analysis such as the IMMI software to effectively simulate, analyse and reduce indoor factory acoustic noise in terms of engineering controls, thereby improving occupational safety and health standards within industrial workspaces.

2. Methodology

The three main phases of this study are depicted in the flowchart shown in Figure 1. Phase 1 was the informative review section, Phase 2 was the result collection phase and Phase 3 was the result analysis phase. The study commenced from Phase 1 with a comprehensive literature review of online journals and theses to gather foundational knowledge for the study. Subsequently, Phase 2 involved simulating different noise maps to assess the acoustic environment within an indoor factory's production area as well as the noise exposure experienced by workers at various locations and parameters. Phase 3 entailed a detailed analysis of these noise maps and discussed the results and calculated daily noise exposure levels for workers using various airgun brands through an established formula. Finally, the simulated noise exposure levels obtained from the acoustic software were compared with the established occupational safety and health standards in Malaysia.

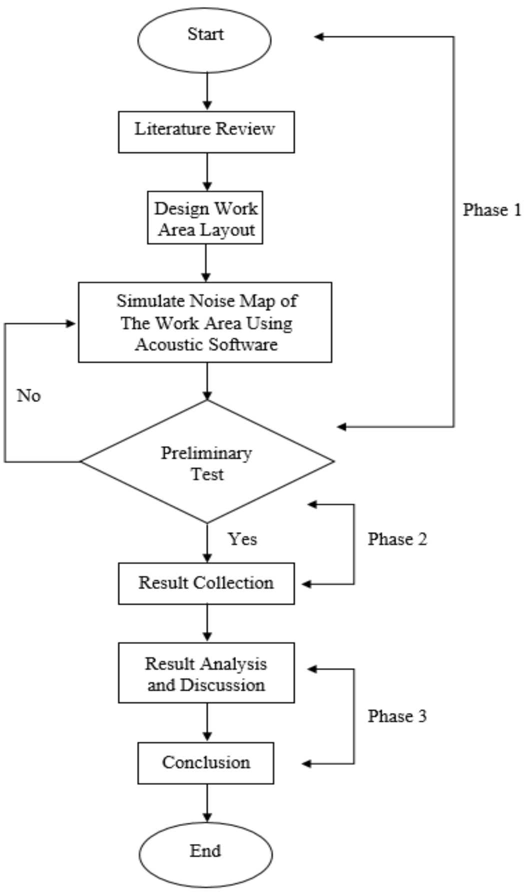


Fig. 1 *Overall flowchart of the study*

2.1 Phase 1

Phase 1 represented the cornerstone of this project which lays the groundwork for a structured and systematic exploration into the acoustic design of work areas. The integration of a scholarly literature review with the application of acoustic simulation tools formed the essence of this phase.

2.1.1 Literature Review

This section describes the methodology used to investigate the noise levels produced by airguns and the details of silencer nozzle specifications. In addition to consulting academic journals and theses, the methodology drew upon authoritative sources such as the Occupational Safety and Health Administration (OSHA) website to understand the standard noise levels associated with airgun operation. Furthermore, information on silencer nozzle specifications was obtained by carefully browsing the websites of several manufacturers.

In this study, the noise level produced by normal airguns as shown in Fig. 2 was using data from the website of the OSHA. According to OSHA's guidelines, the noise levels produced by airguns typically fall within a range of 90-115 dB(A) [12]. However, 115 dB(A) was selected as the baseline to capture and analyse the highest noise levels that might occur during airgun operations. By selecting 115 dB(A) as the baseline, the study aimed to create a simulation that emphasized the most critical noise scenarios, ensuring that the noise map provided valuable insights into potential noise impacts and associated mitigation strategies.

Fig. 2 *Normal airgun* [13]

To ensure accuracy and dependability, the websites of three silencer nozzle manufacturers were visited to gather comprehensive specifications for the silencer nozzles used in this study. Table 1 shows the specifications of different silencer nozzles obtained from three manufacturers.

Table 1 *Specifications of different silencer nozzles obtained from three different manufacturers* [14-16]

Specification	Silencer Nozzle 1	Silencer Nozzle 2	Silencer Nozzle 3
Photo of product			
Brand name	CEJN	Silvent	Chicago Pneumatic
Model	112089962	501-L	6158112720
Sound level	82.0 dB(A)	78.0 dB(A)	73.4 dB(A)
Blowing force	NA	2.78 N	2.3 N

2.1.2 Design Work Area Layout

In this study which focused on noise level simulation and analysis within a specific work environment, an approximately 50 m^2 work area layout as shown in Fig. 3 was meticulously created using AutoCAD 2021. Architectural elements like windows and doors were purposefully included as part of the AutoCAD design process to replicate an actual industrial environment. These elements' sizes and locations were carefully planned to emulate the physical attributes of a typical industrial workspace.

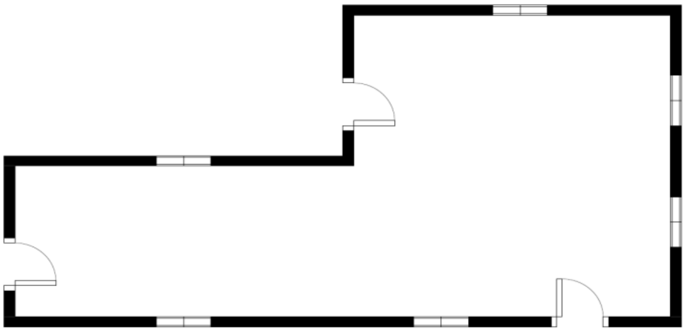


Fig. 3 *Designed work area layout created using AutoCAD 2021 software*

2.1.3 Simulate Noise Map of the Work Area Using Acoustic Software

The creation of a noise map using acoustic software represented a pivotal step in the assessment and management of acoustic environments within a work area or any specified location. The specialized acoustic software called IMMI version 2023 was selected in this study to create a noise map of the production area inside the indoor factory environment. The IMMI acoustic software was recognized for its capability to simulate and model complex acoustic phenomena which enables users to gain valuable insights into how sound interacted with different structural elements, materials and environmental conditions.

2.2 Phase 2- Result Collection

Phase 2 was dedicated entirely to the meticulous collection of noise data within the designed production area in the indoor factory setting. The objective during this phase was to generate comprehensive noise maps for evaluation with a particular focus on the performance of three distinct silencer nozzles, each sourced from different manufacturers. The process of entering data into IMMI was meticulously executed with a focus on gathering accurate and relevant information. This involved supplying the software with comprehensive data on noise sources, the physical layout of the factory and the specifications of the three selected silencer nozzles.

To create a realistic representation of the work environment, the simulation setup within IMMI software was customized to mirror real-world conditions. Specific parameters such as air gun operation and workers' placement at different factory positions were precisely defined. After that, the software conducted simulations that generated noise maps detailing the sound propagation throughout the workspace.

The assessment of noise exposure levels for workers at different positions was very important. This was made possible by the software's integration of the simulated noise maps, allowing for the determination of the decibels (dB) of noise exposure for each person positioned at a different workstation. These calculations considered both the time and spatial aspects of noise exposure and provided a comprehensive knowledge of the risks faced by workers.

2.3 Phase 3- Result Analysis and Discussion

This phase focused on analysing and interpreting the noise exposure data obtained from IMMI software simulations which offers a solid foundation for a detailed examination of silencer nozzle efficacy within the production area.

The three silencer nozzles which were sourced distinctly were evaluated for their noise reduction performance. By plotting their performance against the baseline noise levels within the factory, the rank order of effectiveness was established which identified the most efficient design for noise attenuation.

Besides that, the simulated noise levels were juxtaposed with Malaysian occupational safety and health noise standards. Using the simple equation provided in the Industry Code of Practice (ICOP) for Management of Occupational Noise Exposure and Hearing Conservation 2019 and shown in equation 1, the daily noise exposure level of workers for the effective duration of the working day, $L_{EX,8h}$ was calculated for each case [17].

$$L_{EX,8h} = L_{eqTe} + 10\log\left(\frac{T_e}{T_0}\right) \quad (1)$$

Where,

L_{eqTe} = A-weighted equivalent continuous sound pressure level for the effective duration of the working day

T_e = Effective duration of the working day

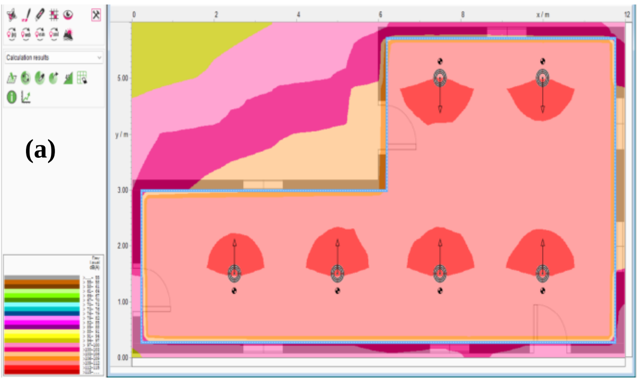
T_0 = Reference duration, (8 hours)

3. Results and Discussion

This chapter described the complex dynamics surrounding noise production when airguns were used to air blow metal products, especially while coolant and debris were removed.

3.1 Assessment of Noise Exposure Before Installing Silencer Nozzles (Normal Airguns)

The initial section of this study concentrated on simulating a noise map before installing silencer nozzles. The noise map illustrated the distribution of noise levels produced by 6 normal airguns across the work area layout and the noise exposure levels for each worker using normal airguns in the designed work area were shown in Fig. 4.



(b)

Short list		RP_0001 | 2023-12-26 14:19 (in working	
Noise prediction			
Variant 0		Setting: Copy from "Reference Setting"	
		Day	
		LV	L r,A
		/dB	/dB
IPkt001	worker 1	85.000	110.509
IPkt002	worker 2	85.000	110.454
IPkt003	worker 3	85.000	110.815
IPkt004	worker 4	85.000	110.711
IPkt005	worker 5	85.000	110.874
IPkt006	worker 6	85.000	110.709

Fig. 4 *(a) Noise map of using normal airguns; (b) Noise exposure levels for each worker using normal airguns*

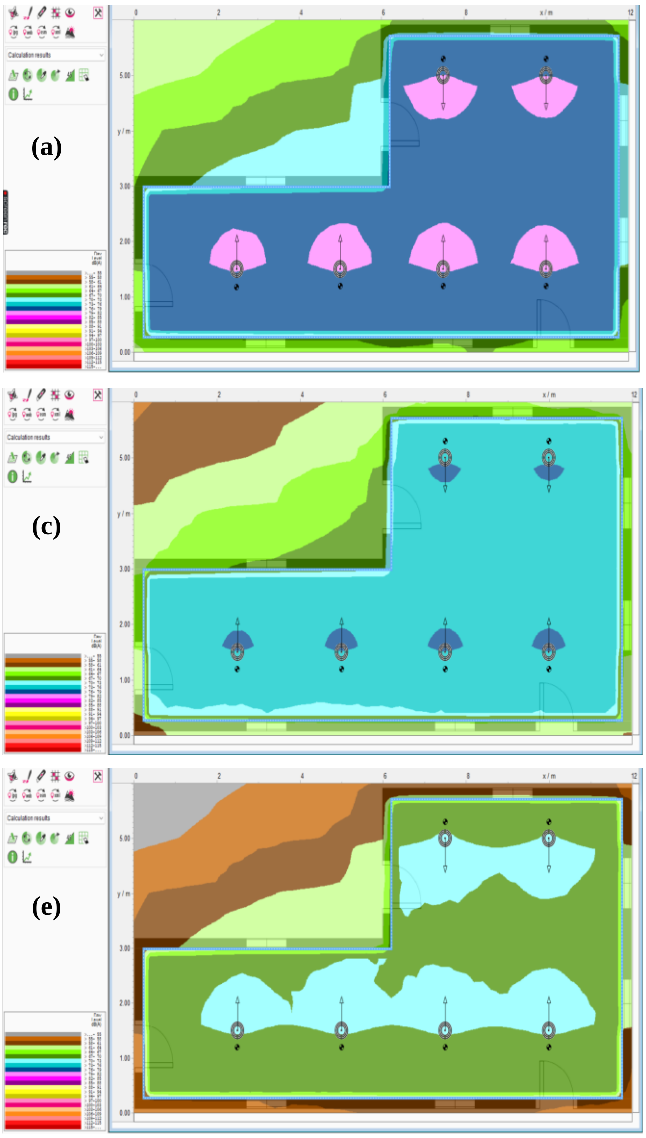
Notably, a significant portion of the work area exhibited noise levels ranging between 109 to 112 dB(A), with the immediate surroundings of the airguns experiencing even higher levels of 112 to 115 dB(A). These results showed certain locations in the workplace with excessive noise exposure, especially close to the normal airguns which could pose health and safety risks to workers working in these zones.

Moreover, the widespread distribution of noise levels in the work area between 109 to 112 dB(A) indicated a serious problem with noise pollution that required attention. The noise map showed that although certain corners of the work area layout had lower noise levels, ranging from 100 to 103 dB(A), these places were still within harmful noise limits and constituted only a tiny percentage of the overall workspace. Additionally, the increased noise levels near the normal airguns emphasized the need for noise control measures to minimize exposure and associated health hazards for workers.

All workers' documented noise exposure levels positioned at various locations within the workspace were around 110 dB(A). These values were highlighted in red which indicates that the workers exceeded the noise exposure limit (NEL) of 85 dB(A) stipulated by the Occupational Safety and Health (Noise Exposure) Regulations 2019.

3.2 Assessment of Noise Exposure After Installing Silencer Nozzles

The work area layout was then equipped with the respective silencer nozzles which are CEJN, Silvent and Chicago Pneumatic to replace the original use of normal airguns. Fig. 5 illustrates the noise maps post-installation of silencer nozzles from CEJN, Silvent and Chicago Pneumatic and the noise exposure levels for workers using CEJN, Silvent and Chicago Pneumatic silencer nozzles in the workplace.



(b)

Short list		RP_0001 | 2024-03-04 15:57 (in working	
Noise prediction			
Variant 0		Setting: Copy from "Reference Setting"	
		Day	
		LV	L r,A
		/dB	/dB
IPkt001	worker 1	85.000	77.408
IPkt002	worker 2	85.000	77.561
IPkt003	worker 3	85.000	77.716
IPkt004	worker 4	85.000	77.709
IPkt005	worker 5	85.000	77.903
IPkt006	worker 6	85.000	77.734

(d)

Short list		RP_0001 | 2024-03-08 16:22 (in working	
Noise prediction			
Variant 0		Setting: Copy from "Reference Setting"	
		Day	
		LV	L r,A
		/dB	/dB
IPkt001	worker 1	85.000	73.570
IPkt002	worker 2	85.000	73.480
IPkt003	worker 3	85.000	73.809
IPkt004	worker 4	85.000	73.709
IPkt005	worker 5	85.000	73.883
IPkt006	worker 6	85.000	73.726

(f)

Short list		RP_0001 | 2024-03-10 14:45 (in working	
Noise prediction			
Variant 0		Setting: Copy from "Reference Setting"	
		Day	
		LV	L r,A
		/dB	/dB
IPkt001	worker 1	85.000	68.915
IPkt002	worker 2	85.000	68.904
IPkt003	worker 3	85.000	69.206
IPkt004	worker 4	85.000	69.076
IPkt005	worker 5	85.000	69.271
IPkt006	worker 6	85.000	69.124

Fig. 5 *(a) Noise map post-installation of CEJN silencer nozzles; (b) Noise exposure levels for each worker using CEJN silencer nozzles; (c) Noise map post-installation of Silvent silencer nozzles; (d) Noise exposure levels for each worker using Silvent silencer nozzles; (e) Noise map post-installation of Chicago Pneumatic silencer nozzles; (f) Noise exposure levels for each worker using Chicago Pneumatic silencer nozzles*

The overall noise levels across the work area showed considerable improvement with the use of silencer nozzles. The CEJN silencer nozzles brought most of the workspace noise levels down to between 76 to 79 dB(A). The Silvent silencer nozzles achieved slightly lower levels with most of the workspace recording between 73 to 76 dB(A). The Chicago Pneumatic silencer nozzles were the most effective which reducing most of the workspace noise levels to between 67 to 70 dB(A). These reductions showed a notable improvement in noise pollution within the workspace which significantly lowered the risk of noise-induced health issues for workers.

Notably, the installation of all three silencer nozzles resulted in significant reductions in noise levels around the airguns. For the CEJN silencer nozzles, areas that previously experienced noise levels between 112 to 115 dB(A) were reduced to 79 to 82 dB(A). Similarly, the Silvent silencer nozzles reduced noise levels from 112 to 115 dB(A) to 76 to 79 dB(A). The Chicago Pneumatic silencer nozzles were particularly effective which brought noise levels down from 112 to 115 dB(A) to 70 to 73 dB(A). These results demonstrated that each type of silencer nozzle could significantly reduce noise exposure near the airguns which lowers health and safety risks for workers in these zones.

The noise exposure levels for workers using each type of silencer nozzle were also significantly reduced. Workers using CEJN silencer nozzles reported noise exposure levels around 77 dB(A) which showed a reduction of up to 33 dB(A). With Silvent silencer nozzles, workers experienced noise exposure levels of about 73 dB(A) which indicated a reduction of up to 37 dB(A). The Chicago Pneumatic silencer nozzles provided the greatest reduction with workers' noise exposure levels around 69 dB(A) which shows a reduction of up to 41 dB(A). Crucially, none of these values were highlighted in red which indicating that all workers' noise exposure levels were within the 85 dB(A) noise exposure limit mandated by the Occupational Safety and Health (Noise Exposure) Regulations 2019.

3.3 Assessment of Daily Noise Exposure Using ICOP Equation

In the previous part of this study, continuous noise exposure levels of workers were determined using simulated noise maps and data from the IMMI software. However, it was noted that workers did not continuously use airguns throughout their entire 8-hour working time. The airguns were typically used intermittently for tasks such as cleaning metal products by removing coolant and debris.

It was found that airgun operators used the airgun to perform the cleaning process for up to 10 minutes each time during changes between different manufacturing and research processes [18]. Therefore, it was assumed that workers spent approximately 10 minutes out of every hour performing the air blow process in this study.

To calculate the daily noise exposure level of workers for the effective duration of the working day for each case, a simple equation as outlined in the ICOP for Management of Occupational Noise Exposure and Hearing Conservation 2019 and shown in equation 1 of the previous chapter was employed. Table 2 summarises the daily noise exposure level of workers for the effective duration of the working day for each case.

Table 2 *Daily noise exposure level of workers for the effective duration of the working day*

Airgun/ Silencer Nozzle	$L_{EX,8h}$ (dB(A))
Normal Airgun	107.2
CEJN	74.2
Silvent	70.2
Chicago Pneumatic	65.6

3.4 Analysis and Discussion of Noise Reduction Results

Table 3 summarises the noise exposure levels for each worker simulated from IMMI software that measured in dB(A) while Table 4 summarises the daily noise exposure of workers using ICOP equation that measured in dB(A). Notably, the range of noise reduction using different silencer nozzles obtained from three different manufacturers varied from 33 to 41 dB(A).

Table 3 *Summarisation of noise exposure levels for each worker simulated from IMMI software that measured in dB(A)*

Silencer Nozzle	Pre-installation (Normal Airgun)	Post-installation of Silencer Nozzle	dB(A) Reduction Findings
CEJN	110.0	77.0	33.0
Silvent	110.0	73.0	37.0
Chicago Pneumatic	110.0	69.0	41.0

Table 4 *Summarisation of daily noise exposure of workers using ICOP equation that measured in dB(A)*

Silencer Nozzle	Pre-installation (Normal Airgun)	Post-installation of Silencer Nozzle	dB(A) Reduction Findings
CEJN	107.2	74.2	33.0
Silvent	107.2	70.2	37.0
Chicago Pneumatic	107.2	65.6	41.0

From the results, it was clear that the noise exposure levels for each worker simulated from IMMI software were 110.0 dB(A) and the daily noise exposure of workers using the ICOP equation for normal airguns was 107.2 dB(A) respectively which exceeded the NEL established by DOSH. Employers had to make sure that their employees were not exposed to daily noise levels higher than 85 dB(A) or a daily personal dose of 100%. Additionally, the maximum sound pressure level should not exceed 115 dB(A) at any time with a peak sound pressure level of 140 dB(C) as stated in the Occupational Safety and Health (Noise Exposure) Regulations 2019 [19].

Fig. 6 illustrates the daily exposure duration limit set by DOSH and stated in the ICOP for Management of Occupational Noise Exposure and Hearing Conservation 2019. From Fig. 6, it was clear that the allowable exposure duration limit for workers using normal airguns to remove coolant and debris from metal surfaces was between 1 minute and 3 seconds to around 3 minutes which is significantly lower than the requirement of approximately 10 minutes of air blow process per hour. With the usage of silencer nozzles, regardless of the manufacturers, the noise exposure levels for each worker simulated from IMMI software and the daily noise exposure of workers using the ICOP equation were all below 82 dB(A). This indicated that the allowable exposure duration limit for workers using any silencer nozzles could extend beyond 16 hours in a hearing-safe environment. With the use of silencer nozzles, the noise exposure levels remained well below the permissible limits which provides a significant safety margin for workers' hearing health.

Noise level dB(A)	Daily exposure duration limit
82	16 hrs
83	12 hrs 42 mins
84	10 hrs 5 mins
85	8 hrs
86	6 hrs 21 mins
87	5 hrs 2 mins
88	4 hrs
89	3 hrs 10 mins
90	2 hrs 31 mins
91	2 hrs
92	1 hrs 35 mins
93	1 hrs 16 mins
94	1 hrs
95	48 mins
96	38 mins
97	30 mins
98	24 mins
99	19 mins
100	15 mins
101	12 mins
102	9 mins
103	7 mins 30 sec
104	6 mins
105	5 mins
106	3 mins 45 sec
107	3 mins
108	2 mins 22 sec
109	1 mins 30 sec
110	1 mins 3 sec
111	1 mins 11 sec
112	56 sec
113	45 sec
114	35 sec
115	28 sec

Fig. 6 *Daily exposure duration limit* [17]

Furthermore, it was also important to note that the noise reduction simulated from the IMMI software was identical to the results obtained through manual calculation using the ICOP equation. This finding was supported by research that the noise reduction simulated from the IMMI prediction software program aligned with the results obtained through calculation [20]. Additionally, another study also found a strong correlation between measured and simulated values by the IMMI software which confirms the program's accuracy in predicting sound pressure levels and other acoustic features throughout the simulated area [21]. These studies collectively demonstrated that the IMMI acoustic software provided reliable and accurate predictions which enhances the credibility of the noise reduction results obtained in this study.

To determine the most effective silencer nozzle design for noise attenuation, Table 5 provided a recommendation ranking for different silencer nozzles obtained from three different manufacturers based on their noise reduction performance. This ranking facilitated better decision-making and resource allocation toward noise control efforts which allows for prioritization of choices and concentrating on the silencer nozzle that had the greatest impact on noise reduction in a designed work area layout.

Table 5 *Recommendation ranking for different silencer nozzles obtained from three different manufacturers based on noise reduction performance*

Silencer Nozzle	Noise Reduction (dB(A))	Ranking
Chicago Pneumatic	41.0	1
Silvent	37.0	2
CEJN	33.0	3

4. Conclusion

In conclusion, the objectives of this study were successfully met which provide valuable information about noise reduction strategies for industrial environments. Firstly, the mapping of noise exposure levels highlighted significant hazards associated with the use of normal airguns which emphasizes the need for effective noise control measures to protect workers' health and safety. Through simulation and evaluation, it was proved that silencer nozzles, especially the Chicago Pneumatic model could effectively lower noise levels by up to 41 dB(A), hence reducing risks to worker health and safety. Furthermore, it was shown that the simulated and calculated daily noise exposure levels for workers using silencer nozzles were significantly lower than regulatory limits which ensures compliance with occupational safety and health standards in Malaysia.

Future research could improve this study by examining a wider range of silencer nozzles from various brands or models to evaluate the effectiveness of silencer nozzles in reducing noise and by experimenting with different work area layouts to understand noise propagation in diverse environments. Conducting real-world experiments in the metal cutting industry can verify simulation results and refine noise reduction strategies. However, this is recommended for researchers with industrial sponsorship due to the high cost of silencer nozzles. Additionally, investigating the synergistic effects of combining silencer nozzles with other noise reduction strategies such as sound-absorbing materials or machinery enclosures could identify optimal combinations that maximize noise attenuation while minimizing cost and operational impact.

Acknowledgement

The authors wish to express their gratitude to the Faculty of Mechanical and Manufacturing Engineering at Universiti Tun Hussein Onn Malaysia for helping to make this study a success.

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