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Research Article

Experimental and simulation study to evaluate effect of radial air injection on performance of motorcycle silencers

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ABSTRACT

The effectiveness of engine exhaust silencers in reducing noise is crucial for addressing environmental and regulatory concerns. In this study, the effects of radial air injection at pressures of 2, 2.5, and 3 bar on temperature, sound pressure levels, and emissions are assessed to optimize the silencer performance. To investigate this, the study employs ANSYS for detailed 3D modelling of the silencers. This model is then carefully constructed to enable simulation studies to examine the impacts of radial air injection and temperature distribution. Experimental validation is carried out to validate simulation results to verify robustness and reliability. The findings show that three radial air jets effectively reduce carbon monoxide (CO) emissions and temperature. The most promising results are observed at 3 bar of radial air injection, where a temperature reduction of 217 K, a 2.94% decrease in CO emissions, and a 7.84 dB reduction in sound pressure levels are achieved. The agreement between simulation and experimental data demonstrates the potential of radial air injection in improving silencer performance, providing insights for developing more efficient and environmentally friendly exhaust systems.

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INTRODUCTION

The evolution of mufflers, commonly known as silencers, has been instrumental in addressing the disruptive noise produced by early automobiles since their development in the late 19th and early 20th centuries. Pioneers like Milton Reeves and Hiram Percy Maxim laid the foundation for modern muffler designs, which range from simple chamber configurations to advanced electronic noise-dampening systems. These advancements have enabled mufflers to effectively reduce engine noise while keeping pace with evolving vehicle architecture.

The Challenges encountered in reducing vehicle noise are clearly stated in literatures [1, 2]. When the exhaust fumes out, they generate two main types of noise: low-frequency noise (below 800–1000 Hz) and high-frequency noise (above 800–1000 Hz) [3]. Efforts have also been made

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to reduce noise from electric vehicles using structural modifications [4, 5], and government agencies of several other countries are taking initiative to control it [6]. Some of the earlier investigations shows that the relative loudness of sound (dBA) was reduced by 10.5 dBA by utilizing muffler perforated tube and absorbing chamber [7]. However, In addition to generating noise, exhaust system contribute to the risk of thermal stress and emission of hazardous pollutants. To address these issues, various modifications have been implemented to mitigate heat, noise, and toxic emissions [8-11]. Different types of mufflers have been developed as a result of the advancement of muffler technology, such as Combination mufflers/Silencers, Reflective/Reactive, and Dissipative/Absorptive [12]. Recently, hybrid mufflers, which integrate features of both reactive and dissipative mufflers, have been tested [13, 14] . While the reactive muffler shows a 33.2% increase in pressure drop compared to existing models, the hybrid muffler exhibits a 38% rise, proving to be the most effective in noise reduction. Nonetheless, optimizing muffler designs remains a challenge due to the trade-off between noise reduction and increased back pressure.

Researchers have explored various strategies to enhance muffler performance over time. Studies by Anthony et al. [15], Selvaraj and Deshmukh [16], and Zarei and Shokouhmand [17] have investigated jet injection, thermoacoustic vibration mitigation, and active noise control(ANC) systems. These studies offers promising solutions for vibration, temperature, and noise issues, as well as valuable insights into muffler design and operation. Recently, computational fluid dynamics (CFD), numerical models, and artificial intelligence (AI) tools have been increasingly used to predict experimental outcomes[18-23]. These advanced tools enable the optimization of designs and identification of potential issues before physical examination, thus saving time and resources. Research by Chen and Shi [24] and Ganesha and Bharath [25] has examined workflow evaluations, hotspot mitigation strategies, and CFD simulations. A CFD study on a CI engine equipped with a perforated reactive-type muffler showed a 25% increase in transmission loss [26]. Additionally, the effect of turbulent jets in cross flow and steady and air injection showed improvement in terms of noise [27-29]. Notably, recent investigations into radial air injection within engine silencer have revealed a 6dB reduction in sound pressure level and a 42 K decrease in temperature. [30].

Despite these advancements, there is a notable gap in research concerning the efficacy of radial air injection within motorcycle silencers, particularly concerning its performance across varying injection pressures of 2, 2.5 and 3 bar. This study aims to bridge this gap by integrating experimental and simulation approaches to assess the impact of radial air injection on muffler performance. The focus is on reducing emissions, controlling temperature, and minimizing acoustic noise to develop more efficient and environmentally friendly muffler designs for future automotive applications. The research involves simulations and experimental studies on the Pulser DTH 150cc silencer, evaluating the effects of Radial Jets in Cross Flow (JICF), and assessing temperature, sound pressure levels, and exhaust gas emissions. Through these comprehensive investigations, the study aims to advance the development of innovative muffler designs that are both effective and environmentally sustainable. The study encompasses conducting simulation and experimental studies on the silencer (Pulser DTH 150cc), performing simulation studies of radial jets in cross flow (JICF), and conducting experimental studies to assess the effects of jets on temperature, sound pressure level, and exhaust gas emissions.

Through these comprehensive investigations, current study on radial air injection in motorcycle silencers has practical implications for the automotive industry, offering potential improvements in noise reduction, temperature regulation, and emission control. These findings are valuable for manufacturers seeking enhanced muffler technologies and can guide future research into advanced exhaust system designs. Additionally, the study supports environmental goals by providing solutions that align with regulatory standards for cleaner and quieter vehicles, making it relevant to policy makers and environmental advocates as well.

EXPERIMENTAL METHODOLOGY

The experimental methodology involved a detailed setup (Fig. 1) designed to analyze the impact of compressed air injection on the performance of a 150 cc engine silencer. The setup included essential components such as the engine, silencer, compressor, FFT analyzer, transducer microphone, thermocouple, tachometer, pressure gauge, and a data visualization system. These components, described in Table 1, were meticulously integrated to enable comprehensive data collection and analysis during the experiment..

The experiment began with a 15-minute engine run to stabilize its operating conditions. Initial measurements were taken to evaluate the sound pressure level, temperature, and emission levels with the unmodified silencer. Afterward, compressed air was injected at various points and pressures using an air jet system, and measurements were recorded for each configuration to assess the changes in performance. Compressed air was then supplied sequentially at the first and second injection points at pressures of 2 bar, 2.5 bar, and 3 bar. This process was repeated, with air introduced at both the first and second points, and then simultaneously at all three injection points, maintaining the same reservoir pressures. In each scenario, temperature, sound pressure, and emission levels were measured and documented. This methodology systematically explored the effects of compressed air injection on the engine›s silencer, offering valuable insights into its acoustic and thermal behavior under varying conditions.

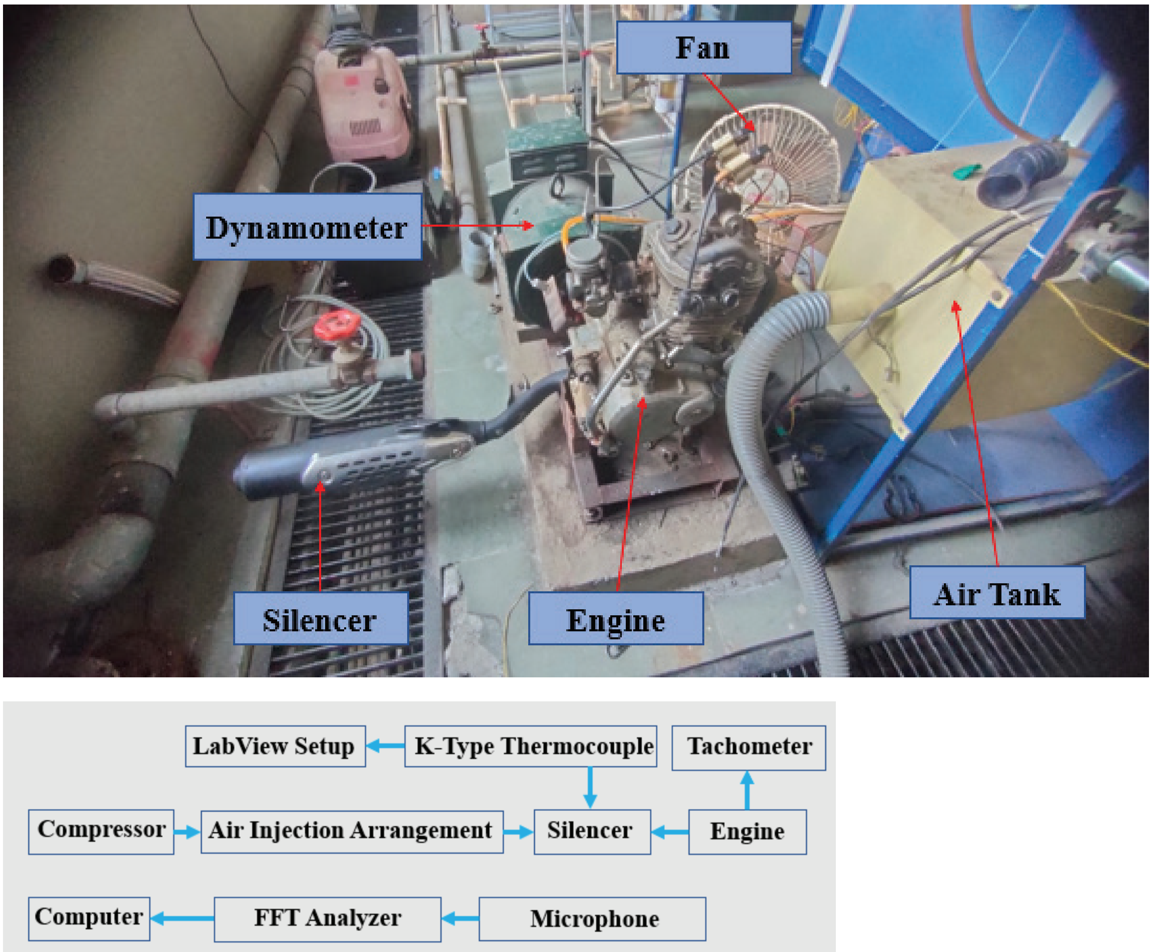


Figure 1. Experimental setup and its line diagram.

Table 1. List of key components used in experimental setup

Sr. No.	Component	Description
1	Engine	A 150 cc four-stroke engine from a Pulser DTH 150cc bike, featuring a carburettor fuel injection system, 5-speed gearbox, and air cooling.
2	Silencer	A reflective type silencer designed for the Pulser DTH 150 cc bike, equipped with four reflective chambers.
3	FFT Analyzer	Fast Fourier Transform (FFT) spectrum analyzer utilizing a NI 9234 4-channel module for sound and vibration input, offering 51.2 KS/s/channel and compatibility with IEPE sensors.
4	Microphone	MI-1433 pressure field microphone with a frequency range of 20 Hz to 8 kHz, along with an MI-3111 preamplifier.
5	Thermocouple	K type thermocouple for temperature measurement.
6	Pressure Gauge	Bourdon tube pressure gauge with a range of 0 to 5 bars, for air pressure measurement.
7	Pneumatic Connectors	HDPE plastic 3-way connectors for air pipe connections, offering flexibility and abrasion resistance.
8	Flexible Hose	Transparent PVC tube with high flexibility and resistance to atmospheric agents.
9	Capillary Tube	Copper tube offering high strength, flexibility, and resistance to high temperatures and pressures.
10	Electric Meter	Meter displaying energy usage and other parameters such as voltage, power factor, and reactive power.
11	Dynamometer	Device used to measure torque, force, speed, and power required to operate a machine or motor.
12	Manometer	Pressure measuring device using a U-shaped glass tube filled with liquid.
13	NI 9234	4-channel module for sound and vibration input, compatible with IEPE sensors.
14	NI cDAQ-9172	USB Compact DAQ Chassis providing connectivity for sensor measurement systems.
15	Netel NPM-MGA-1	Auto Exhaust Multigas Analyzer

Air Jet and Copper Tube Arrangements

The setup consists of a circular ring with a single inlet and eight outlets directed toward the center, designed to inject eight air jets radially along specific points of the silencer›s length. Compressed air is introduced radially into the silencer through a specialized system, illustrated in the accompanying figure. This system includes essential components such as a plastic tube, T-type pipe connector, Teflon tube, and copper tube, all working together to ensure precise control of air injection. The arrangement enables the injection of compressed air at three distinct locations within the silencer, optimizing the analysis of its performance under varying conditions (Fig. 2).

The copper tube utilized in this setup measures 2.45 mm in outer diameter and 1mm in inner diameter. It serves as a conduit, linking the Teflon tube at one end to the silencer at the other end. The copper tubes are radially connected to the silencer at each of the eight designated points along the circumference. This configuration is replicated at three distinct locations spanning the length of the silencer, as illustrated in the accompanying figure.

(a) (b)

Figure 2. (a) Air jet arrangements (b) Copper tubes connected to the silencer.

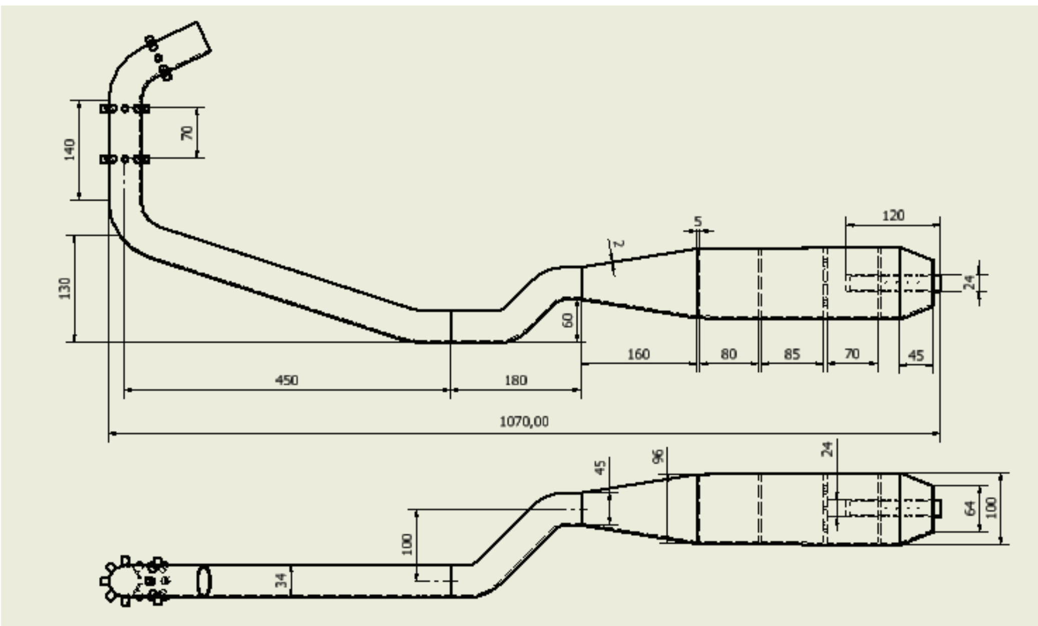


Figure 3. Cross section views of silencer.

Simulation Study

Modeling of silencer

The first step in the simulation study involved creating a CAD model of the silencer. This began with an examination of an existing silencer, during which precise measurements were taken. Using these measurements, a 3D model of the silencer was developed in Autodesk Inventor. The silencer being studied is a reflective type, consisting of four compartments separated by riveted plates. Flue gases from the engine enter the first compartment through a pipe, which is perforated along its length as it enters the compartment. The gases then pass through the various compartments via openings in the separating plates. A detailed depiction of the silencer is provided in Figure 3.

Additionally, three modified silencers were modelled. These modifications introduce a radial airflow arrangement. In the first model, air is injected radially through eight holes located 70mm from the end of the silencer pipe. The second model extends this arrangement by adding eight more holes at distances of 140 mm and 210 mm from the end while retaining the initial airflow arrangement. In the simulation study, boundary conditions were derived from manual tests and applied throughout the analysis. The conditions were as follows: the fuel used was methane (CH_4), with an inlet fuel flow rate for combustion set at 0.000188 kg/s, an inlet air flow rate for combustion at 0.0036 kg/s, and an inlet air flow rate for the radial jets at 0.001894 kg/s. Methane was selected as the fuel because Ansys provides complete combustion for fuels like Gasoline (C8H18) by default, and to simulate incomplete combustion, methane is the appropriate option.

Simulation study on temperature

Ansys Fluent was used for simulation to determine the temperature distribution of flue gases inside the silencer (Pulser DTsi 150 cc). The tetrahedral mesh was used for

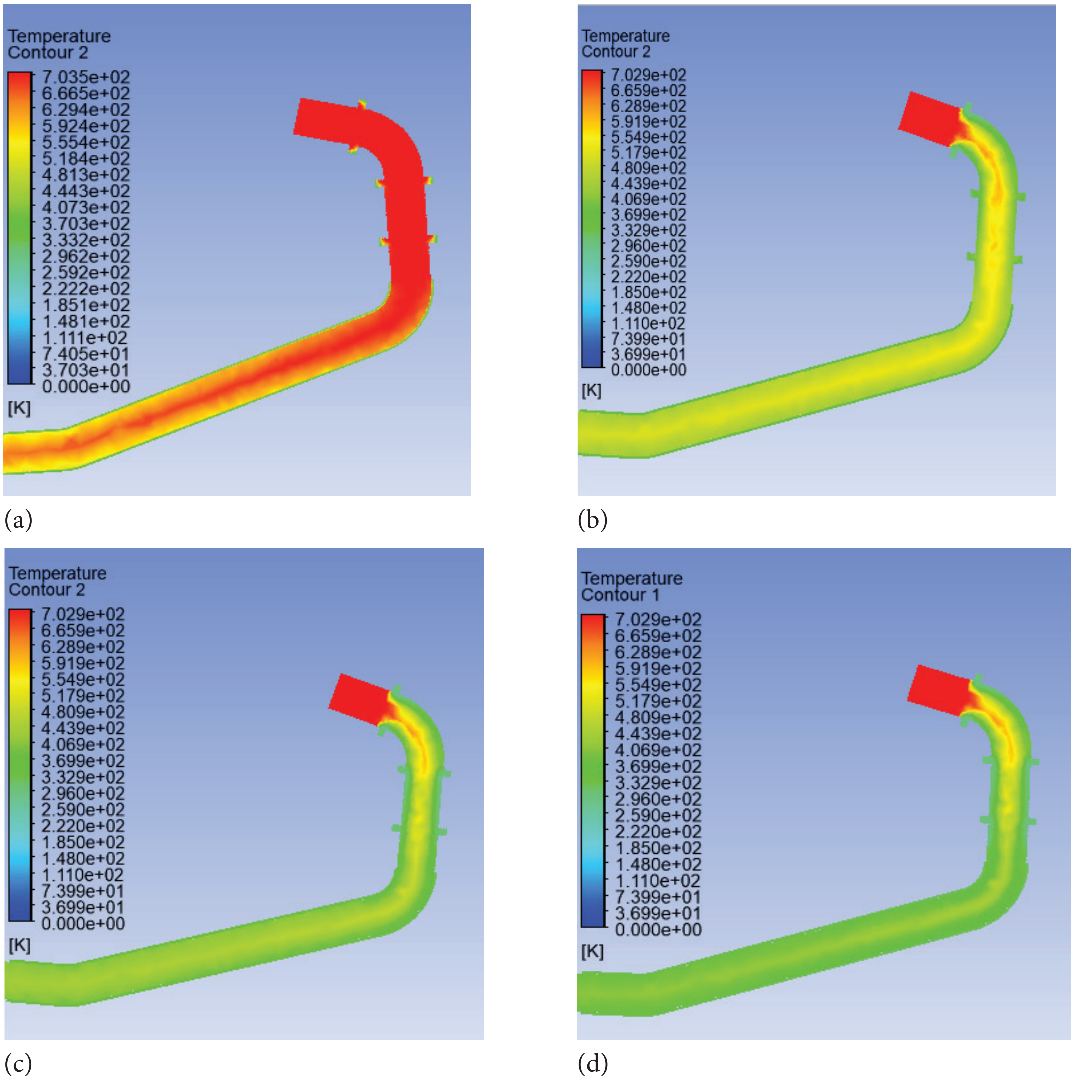


Figure 4. Simulation of silencer with air injection at various locations (a) Silencer without modification (b) Air injection at first location (c) Air injections at two locations (d) Air injection at three locations.

meshing. The skewness was kept below 0.9 for the tetrahedral mesh to produce decent simulation results. The observed temperature of 300 K was used as the input, and the reservoir pressure of the incoming air is assumed to be 3 bar. Four cases have been analysed through simulation**: 1.** A simulation of an existing silencer that has not been modified; **2.** Radial air injection at the silencer's first location, measured along the silencer's length at 100 mm from the flue gas inlet end of the silencer; **3.** Radial air injection at two locations along the silencer's length, measured along the silencer's length at 100 mm and 200 mm from the flue gas inlet end of the silencer; and **4.** Radial air injection at three locations on the silencer, measured along the length of the silencer at 100, 200, and 300 mm from the flue gas inlet end of the silencer. In each of the four scenarios, the temperature contour is measured along the plane, cutting the silencer symmetrically along the length, as show in Figure 4. The figure illustrates the resulting temperature contour, showing the distribution of temperatures across the silencer's length. The colour gradient in the contour plot indicates that the highest temperatures are concentrated near the flue gas inlet, with a significant reduction as the flue gases move along the silencer due to the cooling effect of the radial air injection. Temperature significantly drops as it progresses through the silencer, highlighting the effectiveness of air injection at multiple points. This temperature reduction aligns with the overall objective of lowering exhaust gas temperatures to enhance silencer performance and reduce thermal stress on the system.

Simulation study on emission level

The emission level in the silencer is simulated using Fluent. The study's goals were aimed to analyse of the amount of gases released during methane (CH_4) combustion and the degree of reduction achieved. Boundary conditions for the full simulation were computed from manual experiments. The following boundary conditions were used: Methane (CH_4) was the fuel used. The inlet fuel flow and air flow for combustion were 0.000188 kg/s and 0.0036 kg/s, respectively, and the inlet air flow for radial jets was 0.001894 kg/s. Since Ansys consistently provides complete combustion for gasoline (C_8H_{18}) and other fuels, methane was the fuel used. Ansys can only use methane as fuel to achieve incomplete combustion. Simulation results are observed and recorded for emissions such as CO_2, CO, NO_x, and soot in parts per million. One such emission contour obtained for a silencer with three radial jets is depicted in Figure 5 and is measured along the line that cuts the silencer symmetrically along its length.

The colour scale in the figure shows a marked decrease in CO_2 levels as the gases move towards the silencer's outlet. This reduction can be attributed to the dilution effect of the radial air injection, which enhances the mixing of the exhaust gases and reduces CO_2 concentration effectively. The simulation results suggest that radial air injection at multiple points can play a significant role in lowering CO_2 emissions, thereby improving the environmental performance of the silencer.

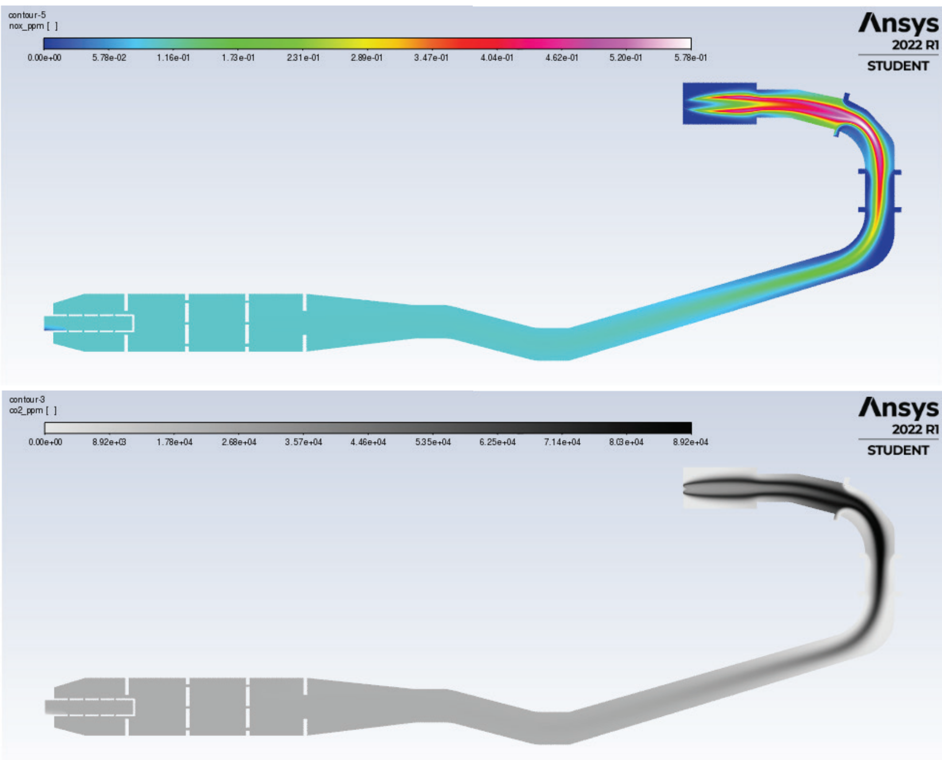


Figure 5. Simulation on modified silencer with three radial jets for CO_2 and NO_x emission in ppm.

RESULTS AND DISCUSSION

Experimental Results

SPL results

The sound pressure level is measured using an FFT analyser. Figure 6. illustrates how frequency spectra are obtained for an engine running at 1400 rpm. Wideband spectra were obtained from the experiment, indicating that no single frequency dominated the results. To evaluate the usefulness of the results and draw inferences from the experiment, it was essential to determine the total sound pressure level. Therefore, the first step in deciding to acquire good outcome is figuring out the overall sound pressure level (OASPL).

The OASPL is found for all the cases, i.e., for no air injection, single point air injection, two point air injection, and three point air injection. The results for each case are discussed below.

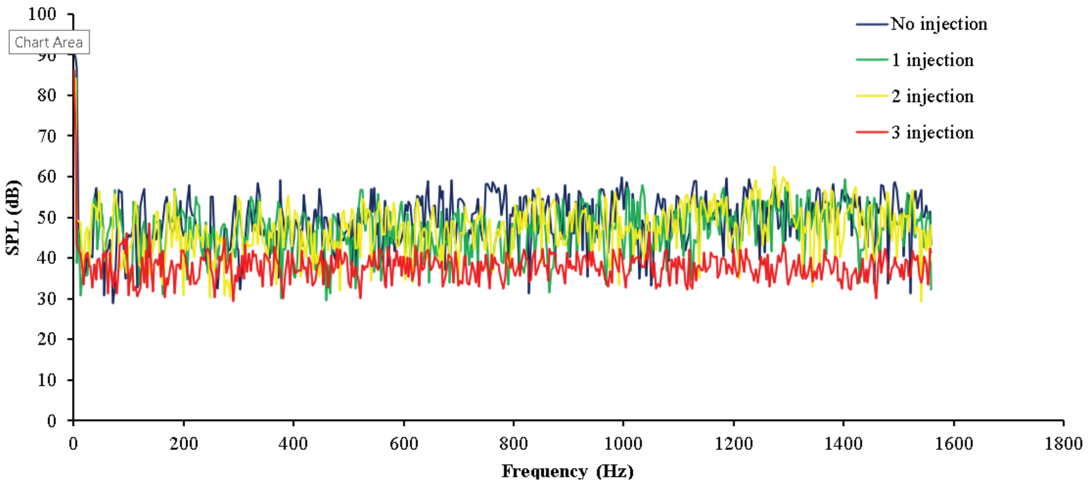
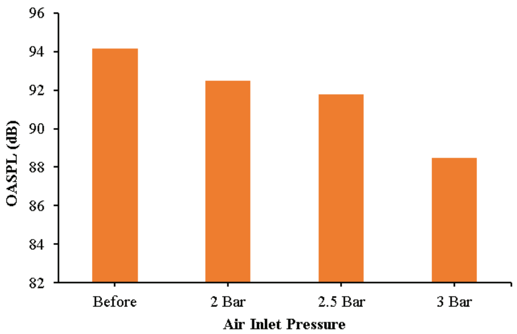
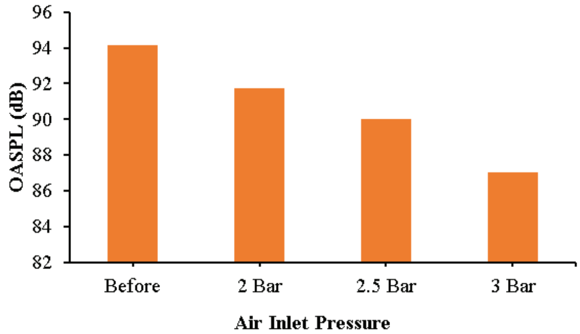


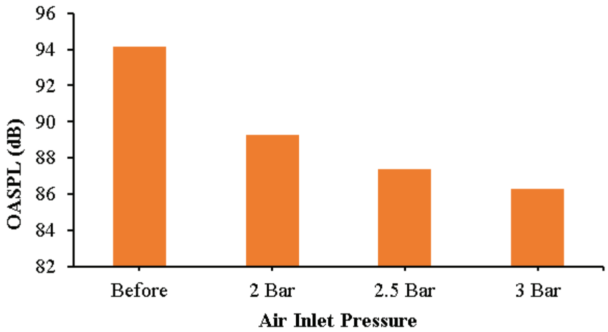
Figure 6. Frequency spectra for engine running at 1400 rpm with different injection.



(a)



(b)



(c)

Figure 7. OASPL results for air injection (a) Case1 (b) Case 2 (c) Case 3.

Case 1: At the first point, or 100 mm from the silencer to the flue gas input, air injection is applied. The sound pressure level tends to drop by 1.65 dB with the addition of air radially at initial point at 2 bar. Additionally, for air injection at 2.5 bar, the sound decreases by 2.36 dB. A 5.65 dB reduction in sound is typically achieved by air injection at a reservoir pressure of 3 bar. The results are displayed in the Figure 7-a.

Case 2: Air injection occurs at both the first and second points or 100 and 200 millimetres, from the silencer's flue gas inlet to the silencer. As depicted in Figure 7-b the sound pressure level tends to drop by 2.414 dB with the addition of air radially at initial point at 2 bar. At 2.5 bar of air injection, the sound is further attenuated by 4.10 dB. A 7.11 dB reduction in sound is typically achieved by air injection at reservoir pressure of 3 bar.

Case 3: Three spots—a spacing of 100, 200, and 300 millimetres—between the silencer and the flue gas input are used for radial air injection. The sound pressure level tends to drop by 4.84 dB with the addition of air radially at initial point at 2 bar. At 2.5bar of air injection, the sound is further attenuated by 6.75 dB. Sound is generally reduced by 7.84 dB by air injection at a reservoir pressure of 3 bar (Fig. 7-c).

Temperature results

During experimentation, for measuring temperature of the mixture of flue gases and injected air, the temperature is measured at a location which is 100 mm after the inlet of silencer, 200 mm before the reflective chambers, and at outlet of silencer.

Case 1: First-point air injection, or 100 mm between the silencer and the flue gas inlet. A temperature decrease of 7.643 K is observed for air injected at 2 bar in comparison to no air injection, according to temperature measurements for the first location (Fig. 8-a). A 20.543 K temperature drop occurs when air is supplied at 2.5 bar pressure. Moreover, the temperature reduces by 24.595 K when air is supplied at 3 bar. **Case 2:** Air injection occurs at the first and second points, or 100 and 200 mm, respectively, from the silencer›s flue gas entrance. The temperature reduction for air injected at 2 bar compared to no air injection is 44.955 K, according to the temperature data for the first and second sites (Fig. 8-b). A 2.5 bar air injection causes a 51.356 K temperature drop. Furthermore, the temperature decreases by 72.265 K when air is supplied at 2 bar pressure. **Case 3:** Air injection radially at three locations, i.e., at a distance of 100 mm, 200 mm and, 300mm from flue gas inlet to the silencer. Temperature results for air injection at the first and second location shows (Fig. 8-c) temperature reduction of 59.508 K for air injected at 2 bar compared to no air injection. For air injected at 2.5 bar, the temperature reduces by 69.444 K. Further for air injected at 3 bar, the temperature further drops by 85.53 K.

Emission level results

The Emission level is found for all the cases, i.e., for no air injection, single point air injection, two-point air injection and three point air injection. The results for each case are discussed below and displayed in Table 2.

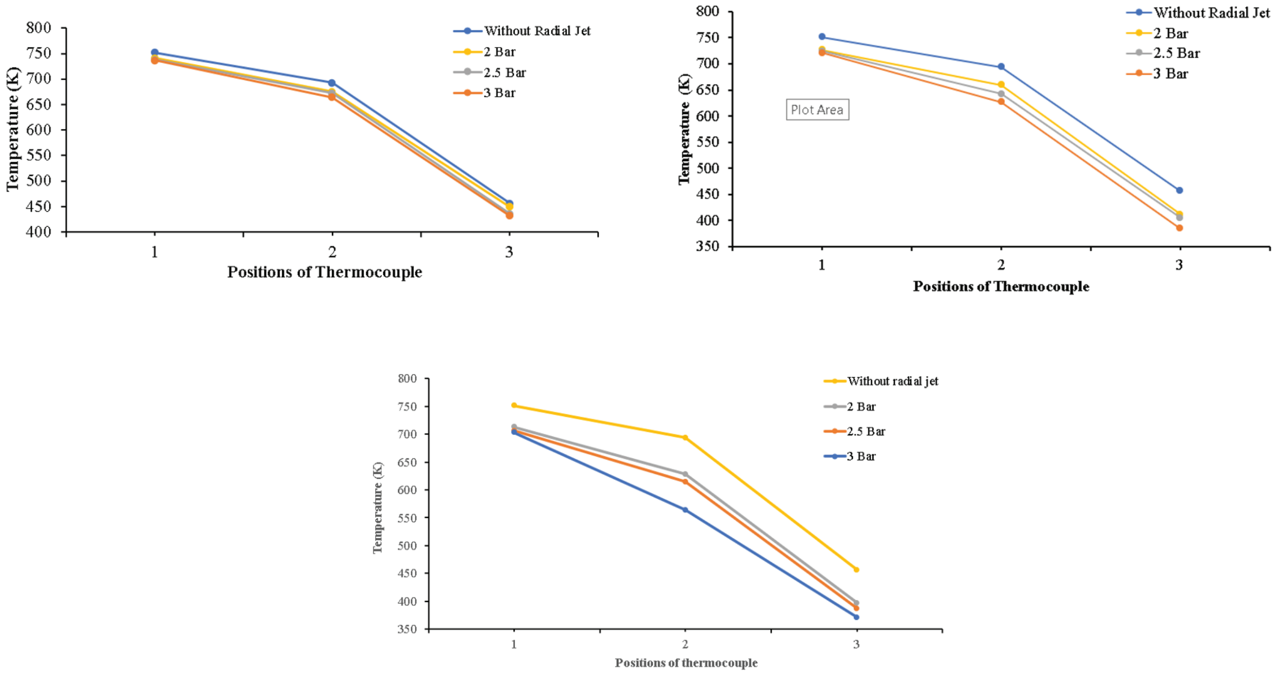


Figure 8. Temperature distribution for air injection (a) Case1 (b) Case 2 (c) Case 3.

Table 2. Comparison with BS VI and BS III norms at different air injections

Emissions	BS-IV Norms	BS-III Norms	Results			
			No Injection	1 Injection	2 Injection	3 Injection
CO (%)	0.5	3	2.99	2.58	1.1	0.05
HC (PPM)	500	3000	187	124	49	6

Case 1: With no injection on the available silencer, CO emission found 2.99%, and HC emission found 187 ppm. **Case 2:** Air injection at first point, i.e., at a distance of 100 mm from flue gas inlet to the silencer. The addition of air radially at first point at 3 bar tends to decrease the CO emission level by 0.41% and HC emission by 63 ppm. **Case 3:** Air injection at the first point and second point, i.e., at a distance of 100 mm and 200 mm from flue gas inlet to the silencer. The addition of air radially at first point at 3 bar tends to decrease the CO emission level by 1.89% and HC emission by 138 ppm. **Case 4:** Air injection at three locations i.e., at a distance of 100 mm, 200 mm and, 300 mm from flue gas inlet to the silencer. The addition of air radially at the first point at 3 bar tends to decrease the CO emission level by 2.94% and HC emission by 181 ppm.

Simulation Results

The reference points on the silencer for getting the values of temperature as shown in Figure 9. The point L1, L6 and L11 on silencer in simulation is the point where the experimental temperatures are recorded.

Temperature results

The simulation study showed (Fig. 10) that the maximum temperature at the silencer outlets without an air jet was 614 K. The maximum temperature at location 1 with an air jet was 481 K. When the air jet at location 2 was activated, the temperature decreased to 423 K, and when the air jet at location 3 was activated, the temperature dropped to 397 K.

Emission level results

The findings showed that the reaction of CO with O_2 to create CO_2 was the reason for the decrease in CO percent. However, it was also observed that the CO_2 percentage decreased. It happened as a result of heated CO_2 reacting with cold O_2, producing carbon tetroxide (CO_4) and carbon trioxide (CO_3), which Ansys cannot detect in the data. Extremely unstable CO_3 and CO_4 also disintegrated into CO_2 and O_2. The percentage of CO_2 is really raised by the amount of CO that is transformed into CO_2. The results above confirm that NO_x gases are produced at high temperatures and that adding cold air can significantly lower their quantity. Unburned gasoline collects in exhaust and is known as soot. The results above confirm that NO_x gases are produced at high temperatures and that adding cold air can significantly lower their quantity. Unburned gasoline collects in the exhaust and is known as soot.

Given that soot is a long-term process, the Ansys model cannot produce correct results. However, because it gives soot less time to adhere to the exhaust wall, It can be reduced by continuously introducing air at a high speed. Table 3 below displays detailed emission simulation data.

The table provides a clear comparison of the emission by-products for various configurations of radial air

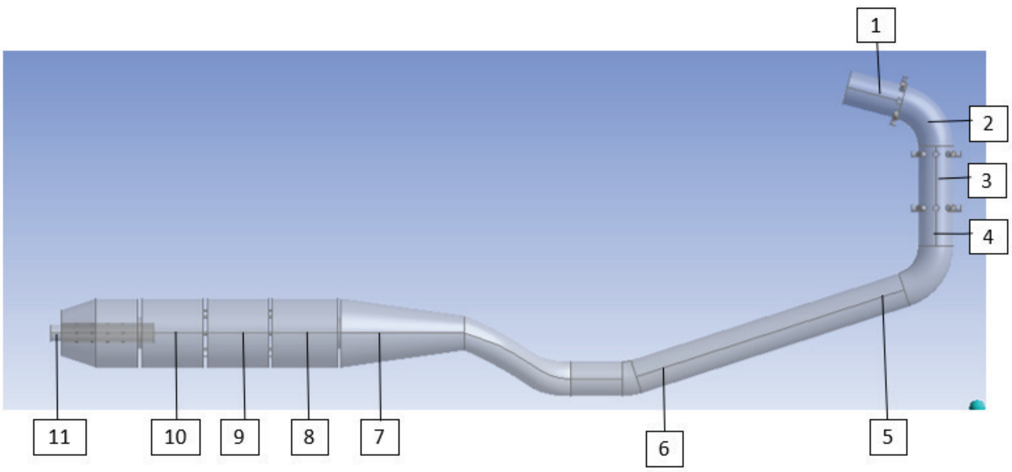


Figure 9. Location of reference points along the length of silencer.

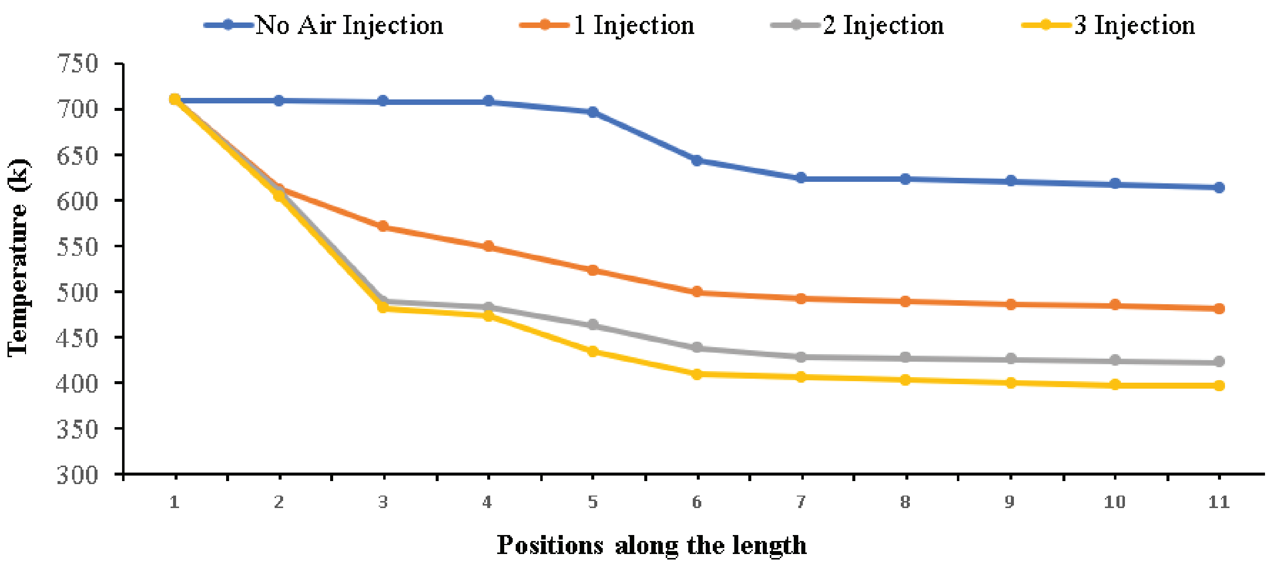


Figure 10. Temperature distributions along the length of silencer.

Table 3. Emission data for all four cases of silencer

Condition for Radial Jets	**By-Products**		
	Carbon Monoxide (CO)		
	PPM	**Actual (%)**	**Reduced %**
Without Radial Jet	4.75 x 10^4	4.75	-
Radial Jets at First Location	0		100
Radial Jets at Second Location	0		100
Radial Jets at Third Location	0		100
	Carbon Dioxide (CO_2)		
	PPM	**Actual (%)**	**Reduced %**
Without Radial Jet	1.03 x 10^5	10.3	
Radial Jets at First Location	2.82 x 10^5	2.82	72.62
Radial Jets at Second Location	1.88 x 10^5	1.88	81.74
Radial Jets at Third Location	1.78 x 10^4	1.78	82.71
	Soot		
	PPM	**Actual (%)**	
Without Radial Jet	1.48 x 10^4	-	
Radial Jets at First Location	0	100	
Radial Jets at Second Location	0	100	
Radial Jets at Third Location	0	100	
	Nitrogen Oxides (NO_x)		
	PPM	**Actual (%)**	
Without Radial Jet	0.793	-	
Radial Jets at First Location	0.314	60.41	
Radial Jets at Second Location	0.157	80.21	
Radial Jets at Third Location	0.0869	89.59	

injection. Without radial jets, significant levels of carbon monoxide (CO), carbon dioxide (CO_2), soot, and nitrogen oxides (NOx) are observed. However, the introduction of radial jets dramatically improves emission characteristics. CO and soot are completely eliminated with air injection at any of the three specified locations. For CO_2, the most significant reduction (82.71%) occurs when air is injected at the third location. Similarly, NOx levels see a substantial decline, with an 89.59% reduction noted at the third injection point. These findings highlight the effectiveness of radial jet implementation in significantly lowering harmful emissions and improving the overall environmental performance of engine exhaust systems.

Comparison of Simulation and Experimental Results

The temperature results from simulation and experimentation at four different locations on the silencer are presented in Figure 11. The temperature difference between the results of the simulation and the experiment ranges between 1.98 K to 157.42 K.

The results outperform those of a similar study by Deshmukh and Waghmode [30], in which the jet pressure was restricted to 2 bar. In this instance, the jet pressure was raised from 2 bar to 3 bar, which also assisted in lowering the development of back pressure. In a comparative analysis with previous study, significant advancements are observed in understanding the effects of radial air injection within engine silencers, particularly regarding CO_2 emission reduction. While the previous work focused on the effectiveness of radial air injection in controlling noise and temperature, this study extends the scope by quantifying CO_2 emission reductions. The current simulation results show that injecting air at three distinct locations within the silencer significantly decreases CO_2 concentrations, highlighting the environmental benefits of this approach. The earlier study confirmed the positive impact on noise and thermal management but did not explore the specific effects on CO_2 emissions. Therefore, this study not only corroborates previous findings on noise and temperature control but also provides new insights into emission reduction, underscoring the broader environmental implications of optimizing radial air injection in silencer designs.

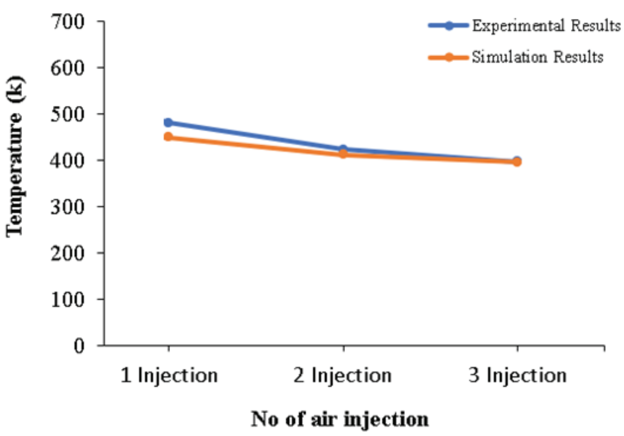


Figure 11. Comparison between simulated and experimental results.

CONCLUSION

The simulation and experimental study have been carried out to study the effect of injection of air at three locations on the temperature, sound of engine and, emission level. The injection of air radially at three locations clearly shows the reduction in temperature of flue gases in silencer. As the air inlet pressure increase, there is a decrease in the temperature of flue gasses with a slight increase in pressure inside the silencer. Also, as the number of air injection locations along the length increase the temperature of flue gases reduces further. This method of lowering temperature, noise of engine and, emission level is effective. Following conclusions can be drawn from the current study:

1. Temperature Reduction: Radial air injection significantly improves temperature management in silencers. At the highest pressure of 3 bar, the temperature reduction reaches 85.53 K, demonstrating a substantial cooling effect that enhances the performance and safety of the exhaust system.
2. Noise Reduction: Radial air injection at 3 bar pressure achieves the most effective noise reduction, with a decrease of 7.84 dB in sound pressure levels. This indicates that the method is highly effective in minimizing noise pollution, making it a valuable solution for quieter engine operation.
3. Emission Reduction: Radial air injection also significantly lowers emissions, with a 2.94% reduction in carbon monoxide (CO) levels at 3 bar. This reduction, along with a decrease in hydrocarbon (HC) emissions, underscores the potential of radial air injection to improve the environmental performance of exhaust systems.

The study focuses on radial air injection at multiple locations; thus, finding optimum number of injection locations and locating these injection locations to give optimum results is a matter of future investigations.

NOMENCLATURE

CFD	Computational Fluid Dynamics
JICF	Jet in Cross Flow
ANC	Active Noise Control
OASPL	Overall Sound Pressure Level
dBA	A Weighted decibels
PPM	Parts Per Million
dB	*Decibel*
K	*Kelvin*
CO	*Carbon Monoxide*
NO	*Nitric Oxide*
NO_2	*Nitrogen Dioxide*
kPa	*Kilo Pascals*

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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