Indian Journal of Engineering & Materials Sciences
Vol. 33, June 2026, pp. 344-357
DOI: 10.56042/ijems.v33i03.25215

Effect of position of radial air injection for reduction of temperature and emission levels in a conventional silencer

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Received: 03 November 2025; accepted: 28 March 2026

The silencer has been a device mainly used for attenuating engine exhaust noise. Several modifications have been attempted to make silencers more efficient. The performance of a silencer has been measured by the amount of reduction in sound pressure level. The aim of this study has been to determine the effect of radial injection of air in the silencer on temperature, sound pressure level, and emission levels. To carry out this study, the design of the available silencer has been examined, and a 3D model has been prepared in ANSYS. A simulation study has been conducted to determine the temperature distribution inside the silencer, the effect of radial air injection along the length of the silencer, and the reduction of emission gases. The simulation study has also been carried out to evaluate the temperature distribution inside the silencer. The input parameters to the silencer have been determined through the simulation study of an I.C. engine. It has been observed from the simulation results that a temperature reduction of 312 K has been achieved with three radial air jets. Furthermore, a reduction in CO emissions has also been observed due to radial air injection.

Keywords: CO emissions, Emission level, Radial air injection, Silencer, Sound pressure level, Temperature distribution

1 Introduction

Noise, popularly referred to as unwanted sound, is one of the serious and pressing environment problems in the world today. The World Health Organization (WHO) specifies 55 dB as a hygienic guide value for the average level of noise in residential areas. However sound levels of around 70 dB are very common in our towns and cities. Since people tend to judge a mechanical product's quality by its ability to operate quietly, noise has become an increasingly serious problem in product design. Traffic noise is the most important environmental noise source in the world today. Twenty-five percent of the populations in urban areas are exposed to transportation noise with an equivalent sound level of over 65 dB. At this sound level sleep is seriously affected resulting in several health problems. Statistics today shows that an increase in noise effects awareness. Hence several measures to abate the noise effects are on the increase.

The unnecessary sound from the automobiles can be reduced to a considerable extent by the use of mufflers, also known as silencer. It helps to reduce noise as well as temperature of exhaust. In all muffler designs the tailpipe length can have an important effect. The tailpipe itself acts as a resonant cavity that couples with the muffler cavity. But designing mufflers have been a challenging task for the designer for many years as it not only reduces the noise but it also creates backpressure, which reduces the overall efficiency of the engine[1] noise creates annoyance, sleep disturbance and if it is too loud then it can damage our hearing capability. Hence it is necessary to install muffler in every automotive so that noise emission can be controlled and remain within the noise norms[2]. Different types of mufflers have been used over the years, some of which are reflective/reactive mufflers, dissipative/absorptive mufflers and combination mufflers. Jets in cross flow, also called transverse jets, have been used in the modified versions of mufflers in order to reduce the exit temperature as well as noise emissions[3].

Numerous work has been done in which the design of the muffler was changed, and several research articles are available in which multiple types of mufflers have been used in series or parallel or both in series and parallel to reduce the muffler noise, temperature and emission level. Kuo *et al.*[4] have investigated an active noise control (ANC) system for muffler. In their research, ANC system was implemented for muffler to cancel engine exhaust

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noise. The characteristics of engine exhaust noise for fixed and changing engine speed were analyzed. Both ANC and ANE system performance were done by real time experiments using synthesized engine noise for fixed and changing engine speed. Experiment results showed that the electronic muffler can reduce the noise levels more effectively. Deshmukh *et al.*[5] have carried out simulation and experimental study to observe the effect of jets on temperature of flue gases and noise. The effect of jet is clearly seen in the performance of muffler. As the jet pressure increases, temperature reduces due to mixing process taking place inside the muffler at very high velocity of jets. The jets at high pressure are very effective to reduce engine flue gas temperature with slight increase in pressure. Zarei & Shokouhmand[6] have discussed vibration and its influence on the behavior of flowmeters in a station. Such vibrations are mainly caused by the thermos-acoustic process in the area adjacent to the junction of two trains of pressure regulator and the heat exchangers. Bawaskar *et al.*[7] have performed the work flow analysis on the two-wheeler exhaust system. It was found out that approximately 70 % pressure drop can be reduced if length of exhaust pipe at starting reduced by 50 mm and restriction to the flow was removed. It can be seen that first 3 iterations show slight increase in the pressure drop across the exhaust system which will result in to increased work for the two-wheeler engine to overcome the resistance by exhaust system. In the fourth iteration, design pressure across the exhaust system drop down by 12.3 KPa and it was observed to be 5 KPa which reduces the required work by the engine to force exhaust gases out of the system drastically. This will result in increased engine efficiency and low fuel consumption for similar work production by engine. Bharath *et al.*[8] have observed that hot spots on the silencer surface due to non-uniform distribution of heat over the surface can significantly reduce by changing the profile of the silencer tube either by providing different perforations or by providing dimples on the surface. Hot spots on the silencer body create high temperature oxidation that could lead to corrosion and mechanical breakage of silencer. By providing dimple patterns on the outer surface of the silencer the temperature distribution was observed to be uniform and there was decrease in the temperature in the outer surface of the silencer. It was also proved that providing dimples will not have such influence on building back pressure that could affect silencer performance. Shi *et al.*[9] have used large commercial CFD (Computational Fluid Dynamics) software Fluent, to simulate the distribution of the internal flow field of a special engine muffler. The influence of the flow field on the erasure effect was analyzed, which may be a credible guidance of the muffler structural design. Based on the physical numerical modeling of the flow field of the muffler, the author simulated the field by numerical method with Fluent and analyzed the effect which the internal flow field has on the performance of the muffler. Vijayaraghavan *et al.*[2] have modified exhaust system such that it consists of a outer shell, inner shell with perforation and asbestos fibers as a filling and noise absorbing material. Here, asbestos fibers are used as a noise absorbing and pollution control material. Its effects on noise and emissions reduction level are analyzed. The model was tested with 100cc Suzuki, four stroke, petrol engine. Better results were observed than a conventional silencer. Modification was done in silencer structure without much change. From the exhaust gas analyzing results, it was observed that 11.3% reduction in exhaust frequency and 20% in noise level, compared with the conventional silencer which confirms the commercial usage of this modified silencer. Sreenivasan *et al.*[10] have designed the component of normal exhaust system such as muffler or silencer shell, perforated tube, spiral resonator and have carried out a Finite Element Approach for analysis of muffler noise developed at different locations as well as temperature distribution over silencer. In order to minimize two-wheeler noise, testing was carried out in a Bajaj pulsar two-wheeler by redesigning a spiral resonator and perforator tube which is capable of attenuating noise level by about 7 dB (decibels). The results obtained from simulation that as the distance increases from inlet of silencer the sound pressure level decreases gradually. Obtained results shows a significance decrease of sound pressure level about 7 dB from existing silencer to new designed silencer.

2 Materials and Methods

2.1 Modeling of silencer

he available silencer is reflective type and has four compartments. The compartments are separated by the riveted plates. The flue gases from engine run in to first compartment through a pipe. This pipe after entering first compartment has perforations on it along length. The flue gases pass through different compartments through the hole in the plates separating the compartments. The silencer is

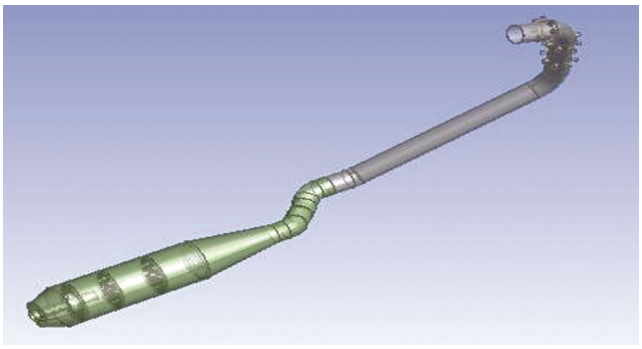


Fig. 1 — 3D Model of silencer.

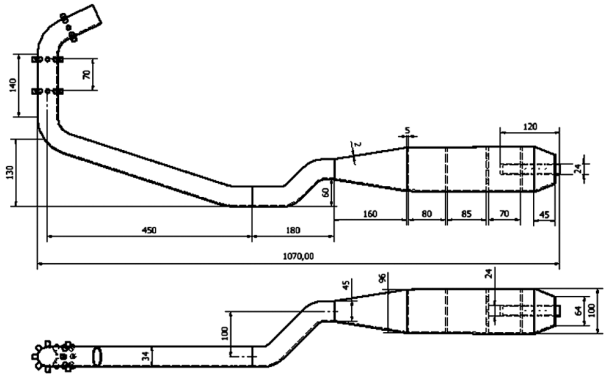


Fig. 2 — Cross section views of silencer.

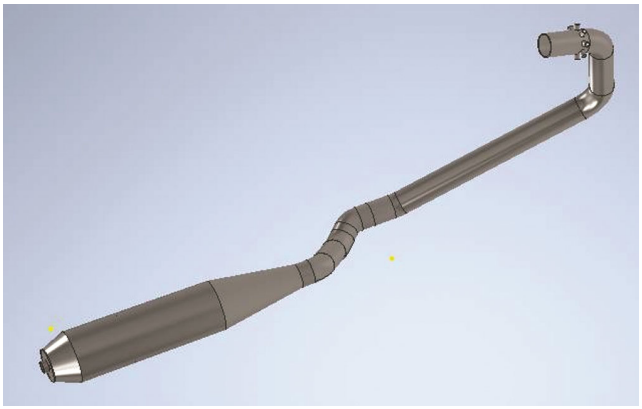


Fig. 3 — Model of modified silencer.

approximately 1121 mm long. The detailed view of the silencer can be seen in the Fig. 1. The sectional view along with the dimensions of the silencer is shown in Fig. 2.

The modified models have arrangement for radial air injection. First model has arrangement for radial air injection through 8 holes at a distance of 70 mm from the end of the silencer pipe as seen in Fig. 3 and Fig. 4. Second model adds same arrangement at a distance of 140 mm from the end while retaining the earlier arrangement as seen in Fig. 5. Third model adds further this arrangement for radial air injection



Fig. 4 — Closer View of arrangement for radial air inlet.

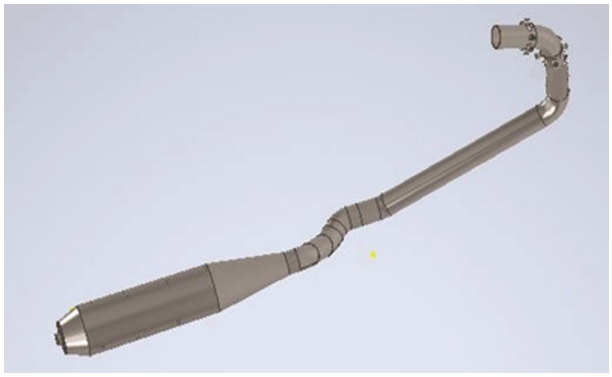


Fig. 5 — Modified silencer for radial air injection at two locations.

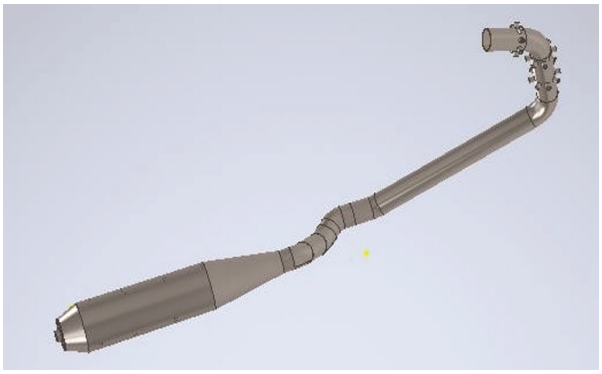


Fig. 6 — Modified silencer for radial air injection at three locations.

through 8 holes at a distance of 210 mm from the end while retaining the earlier arrangements as seen in Fig. 6.

2.2 Simulation study on temperature

The simulation is done in ANSYS Fluent for temperature distribution of flue gases in silencer. Tetrahedral mesh has been used for meshing. The skewness for tetrahedral mesh is kept below 0.9 for obtaining good results in simulation. Reservoir pressure of inlet air is taken as 2 bar and temperature

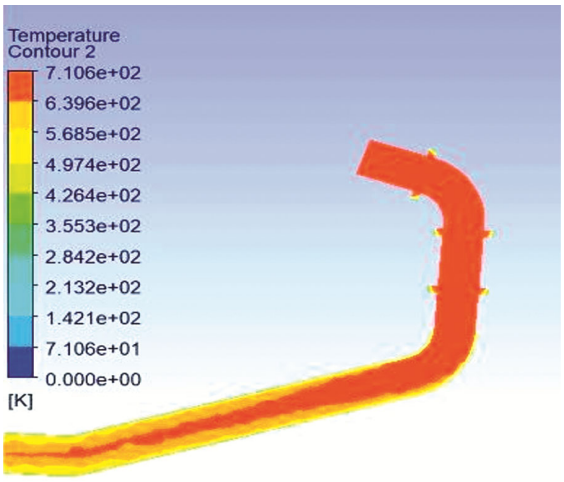


Fig. 7 — Simulation on unmodified silencer.

input given is that of the measured value. Simulation study has been done for the following four cases:

i. Simulation of available silencer which is simulation of silencer without any modification.
ii. Simulation of silencer with air injection radially at first location on silencer.
iii. Simulation of silencer with air injection radially at first and second location on silencer.
iv. Simulation of silencer with air injection radially at first, second and third locations on silencer.

2.2.1 Simulation of unmodified silencer

The CAD model of available silencer is imported in ANSYS Fluent. Meshing is done using tetrahedral meshing element. The inlet temperature to silencer is the temperature of the available engine exhaust i.e. 710 K. The reference points selected are the end points and the midpoints of the silencer chamber. The temperature contour is taken along the plane cutting the silencer symmetrically along the length. The temperature contour of the silencer is shown in Fig. 7. Figure 8 shows temperature distribution along the silencer.

2.2.2 Simulation of silencer with air injection radially at first location

In this case air is injected radially through 8 holes in the silencer at a location which is measured along the length of silencer at 70 mm from the flue gas inlet of silencer. The air is injected at temperature of 300 K and pressure of 2 bar. The effect on temperature of flue gases due to interaction of flue gases can be seen in simulation in the form of the reduction in temperature. The temperature distribution is seen in the cross-sectional temperature contour taken 10 mm before and after first air injection point as seen in

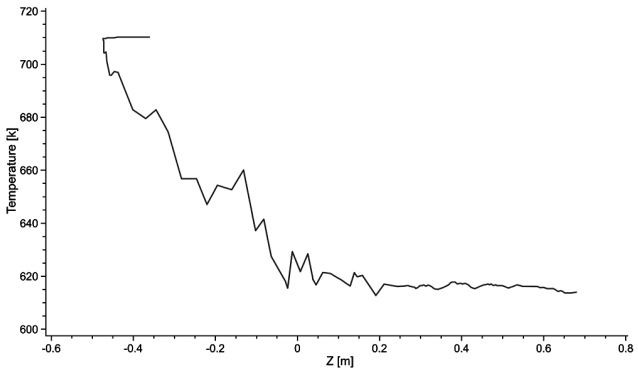


Fig. 8 — Temperature distribution along the length of silencer.

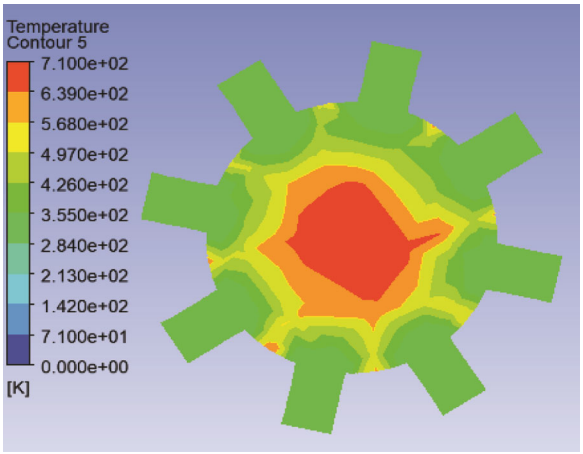


Fig. 9 — Cross Sectional view of radial air injection at first point.

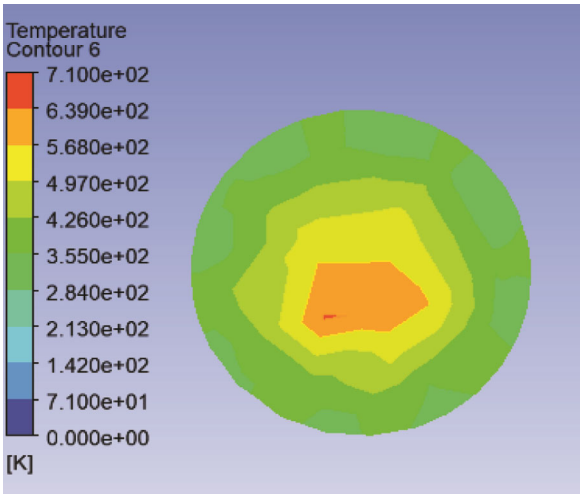


Fig. 10 — Cross sectional view at 10 mm after first radial air injection.

Fig. 9 and Fig. 10 respectively. Also, temperature contour at the point of injection can be seen in Fig. 11. Lateral cross section in Fig. 12 shows mixing of hot flue gases and injected air.

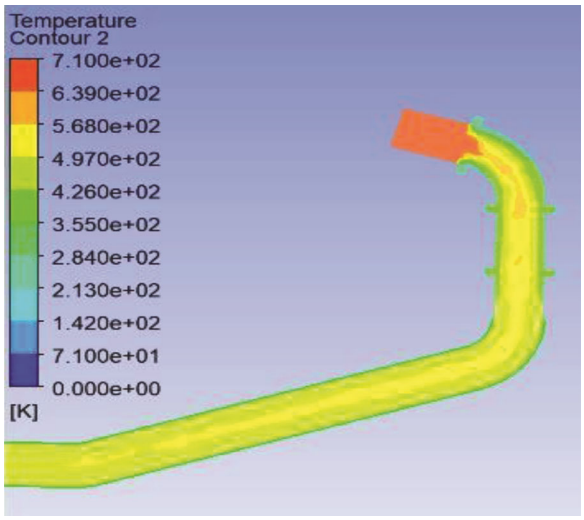


Fig. 11 — Simulation on modified silencer with one radial injection.

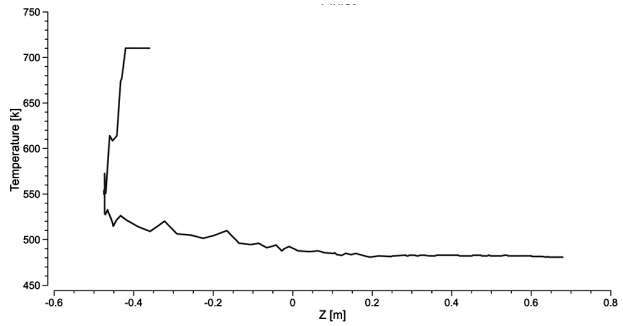


Fig. 12 — Temperature distribution along the length of silencer.

2.2.3 Simulation of silencer with air injection radially at first and second locations

In this case air is injected radially through 8 holes in the silencer at two locations which is measured along the length of silencer at 70 mm and 140 mm from the flue gas inlet end of silencer. The high pressure air at 2 bar is injected at room temperature i.e. 300 K. The effect on temperature of flue gases due to interaction of flue gases can be seen in simulation by the reduction of the temperature. Figure 13 and 14 show the temperature distribution contours at the first and second radial points respectively. Figure 15 shows the temperature distribution 10 mm after first air injection point. Lateral cross section in Fig. 16 shows mixing of hot flue gases and injected air. The temperature distribution along the length of the cylinder is shown in Fig. 17.

2.2.4 Simulation of silencer with air injection radially at first second and third locations

In this case air is injected radially through 8 holes in the silencer at a location which is measured along

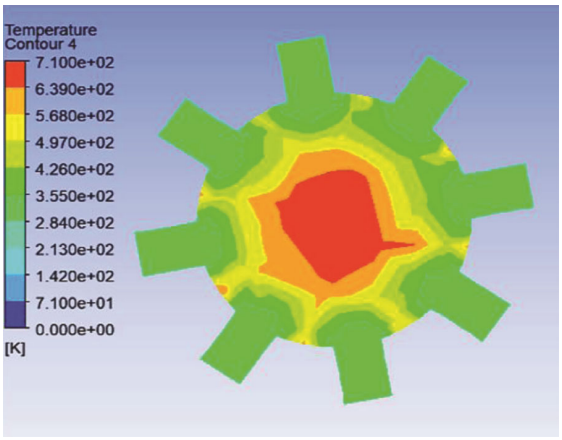


Fig. 13 — Cross Sectional view of radial air injection at first point.

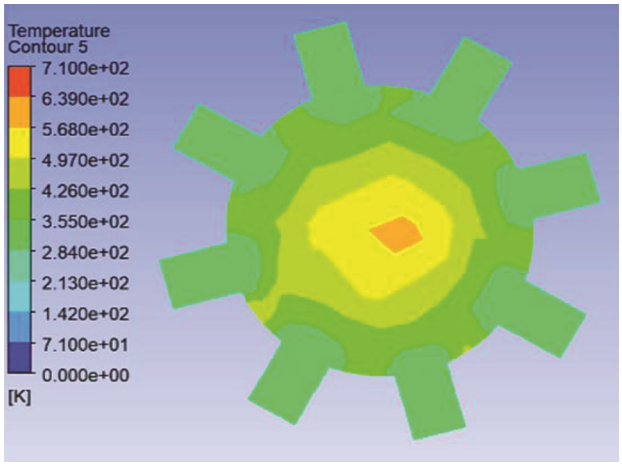


Fig. 14 — Cross Sectional view of radial air injection at second point.

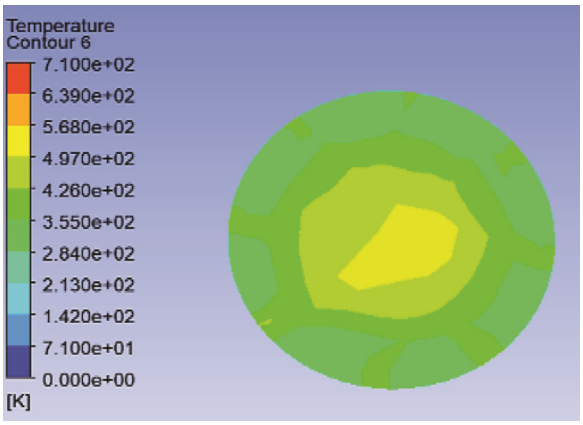


Fig. 15 — Cross sectional view at 10 mm after second radial air injection.

the length of silencer at 70 mm, 140 mm and 210 mm from the flue gas inlet end of silencer. The air is inlet at room temperature that is 300 K and pressure of 2 bar. The effect on temperature of flue gases due to

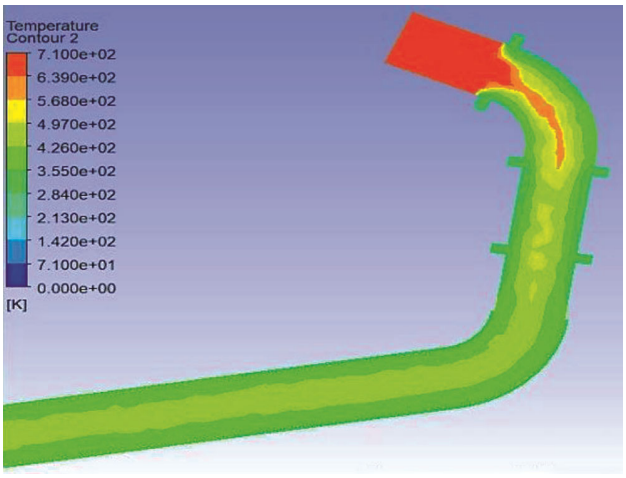


Fig. 16 — Simulation on modified silencer with two radial injections.

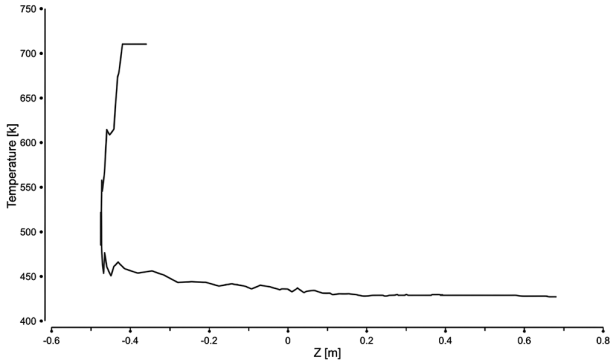


Fig. 17 — Temperature distribution along the length of silencer.

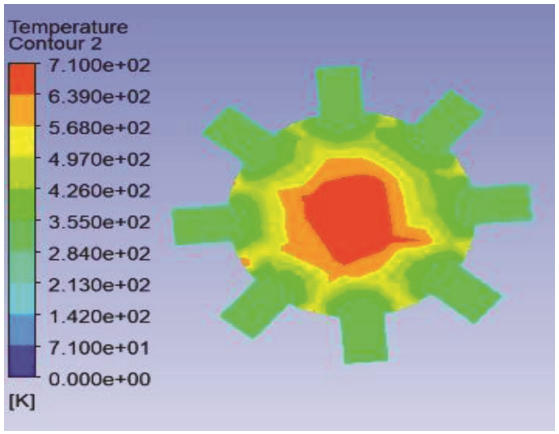


Fig. 18 — Cross sectional view of radial air injection at first point.

interaction of flue gases can be seen in simulation by the reduction of the temperature. The temperature distribution is seen in the cross-sectional temperature contour after the last air injection point as seen in Fig. 21. Also, temperature contour at the point of injection can be seen in Fig. 18, 19 and 20. Lateral

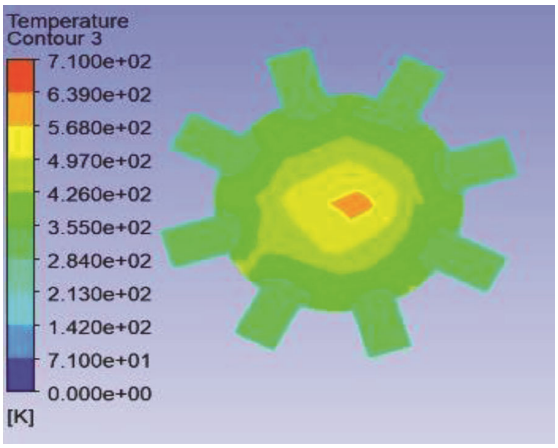


Fig. 19 — Cross sectional view of radial air injection at second point.

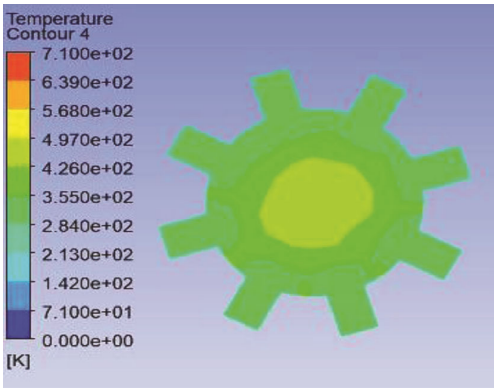


Fig. 20 — Cross sectional view of radial air injection at third point.

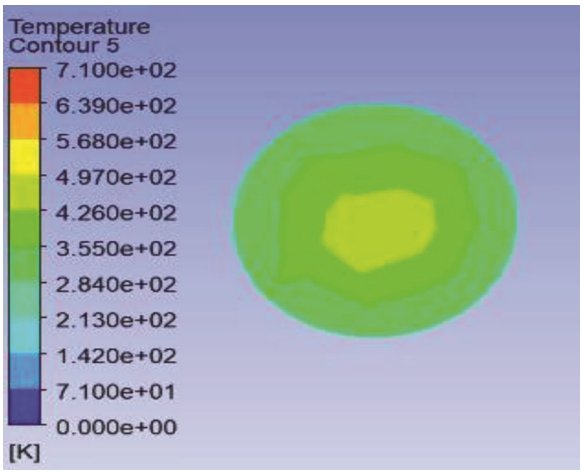


Fig. 21 — Cross sectional view at 10 mm after third radial air injection.

cross section in Fig. 22 shows mixing of hot flue gases and injected air. The temperature distribution along the length of the silencer is shown in Fig. 23.

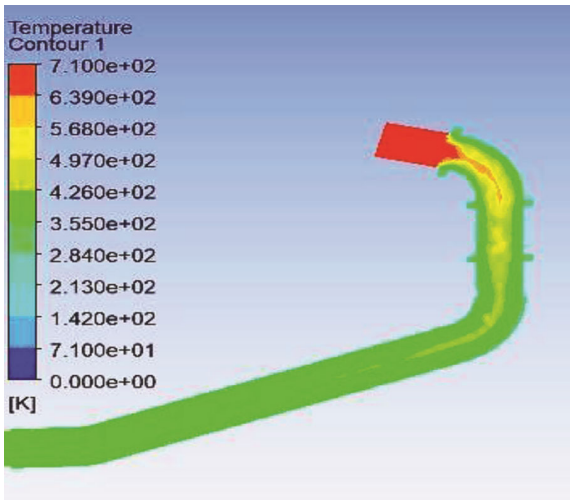


Fig. 22 — Simulation on modified silencer with three radial injections.

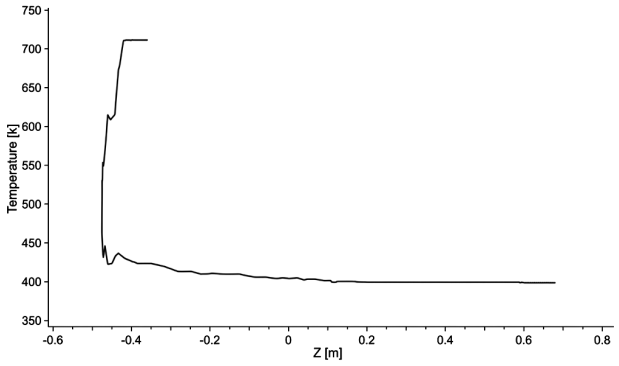


Fig. 23 — Temperature distribution along the length of silencer.

2.3 Experimental Setup

In the experimental study, a comprehensive setup was employed to investigate the performance and characteristics of various mechanical components. A 150cc Pulsar DTH four-stroke petrol engine, capable of delivering a maximum power of 14 bhp at 8500 rpm and a torque of 13.25 Nm at 6500 rpm, served as the core apparatus. The engine was connected to a reflective type silencer with four chambers, modified to include three injection planes with 8, 6, and 6 jets per plane, respectively. Sound and vibration data were collected using the NI 9234, a 4-channel, 51.2 KS/s/channel module, and processed through a FFT analyzer. Temperature measurements were taken using K-type thermocouples, while a tachometer monitored engine speed. A bourdon tube pressure gauge, with a range of 0 to 5 bars, measured air pressure in the manifold. Additional components included a microphone (MI-1433), capable of capturing sound frequencies from 20 Hz to 8 kHz, and a flexible PVC hose for efficient air flow management. Data acquisition and timing control were facilitated by the NI cDAQ-9172, an 8-slot USB Compact DAQ chassis. The experiments aimed to provide insights into the interplay of these components under varying conditions, thereby contributing to the enhancement of mechanical system designs. The actual experimental setup is shown in Fig. 24 and line diagram shown in Fig. 25.

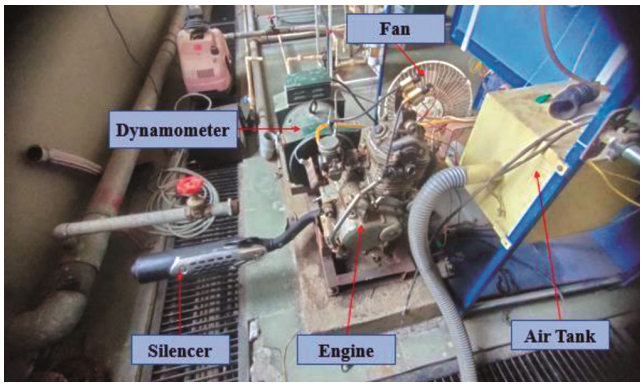


Fig. 24 — Experimental set-up.

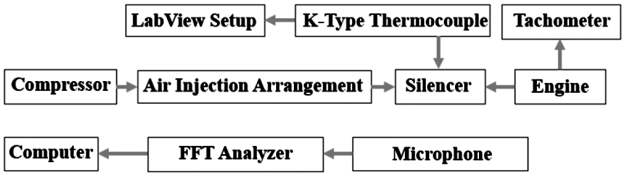


Fig. 25 — Line diagram for the experimental set-up.

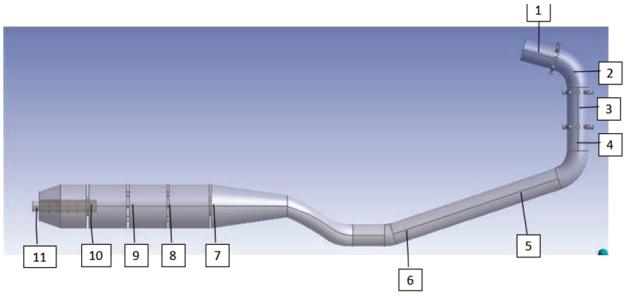


Fig. 26 — Location of reference points along the length of silencer.

3 Results and Discussion

3.1 Simulation result comparison of three cases

For comparing the results, several locations along the length of the muffler have been taken as shown in Fig. 26 and Fig. 27 shows the temperature distribution along the length of silencer at points shown in Fig. 26. From the simulation study it was observed that the max temperature at the outlets of silencer without air jet is 614 K and with air jet at location 1

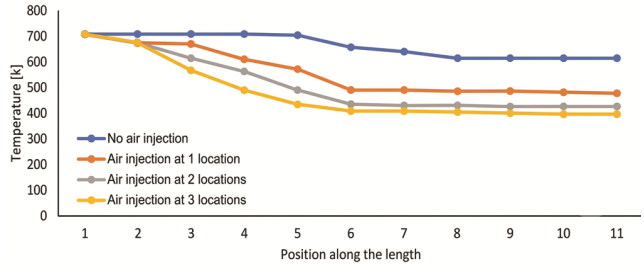


Fig. 27 — Temperature distribution along the length of silencer at points shown in Fig. 24.

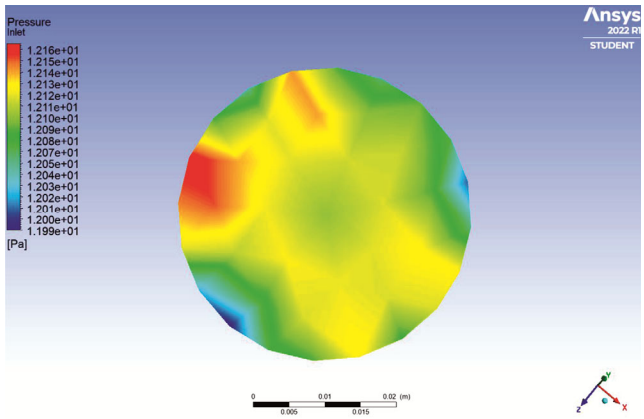


Fig. 28 — Simulation study of modified silencer inlet condition.

is 481 K. Further when the air jet at location 2 was activated the temperature dropped to 427 K and when the air jet at location 3 was activated the temperature dropped to 398 K.

3.1.1 Simulation study on Pressure Level

Simulation is done in ANSYS Fluent for pressure distribution of flue gases in silencer. The first step of simulation is to import the CAD model in ANSYS Fluent. After importing the model meshing is done. For meshing tetrahedral mesh is used. The skewness for tetrahedral mesh is kept below 0.9 for obtaining good results in simulation.

For all the simulation the boundary conditions considered are according to standard values. Reservoir pressure of inlet air is taken as 2 bar and pressure input given is that of the measured value of 1 bar.

3.1.2 Simulation of modified Silencer

The simulation has been performed as per the boundary conditions mentioned above. The reference points selected are the end points of the silencer chamber. The pressure contours are taken on the lateral planes along the length of the silencer. Figure 28 and Fig. 29 show pressure contours at the inlet and outlet respectively of the silencer. Figure 30

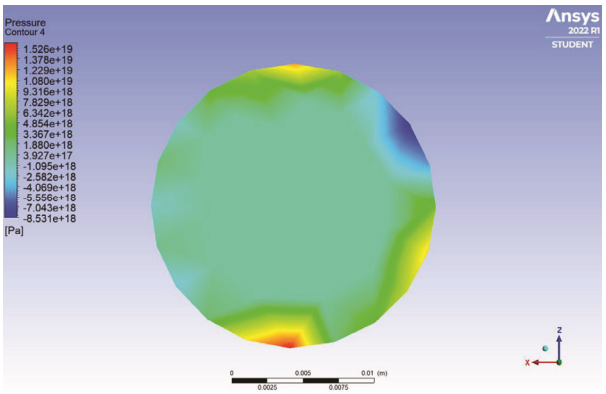


Fig. 29 — Simulation study of modified silencer outlet condition.

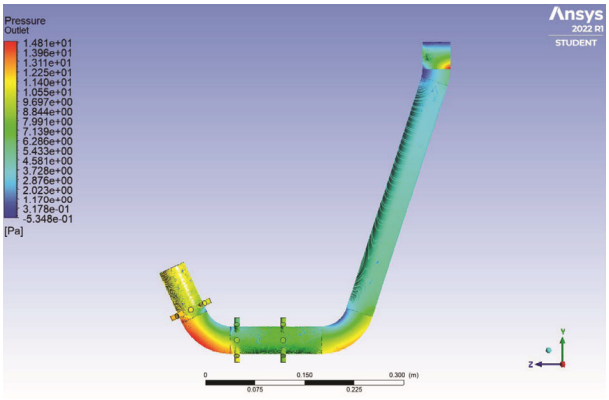


Fig. 30 — Simulation study of modified silencer on the walls of the silencer (1).

shows the pressure contour on the walls of the silencer.

3.1.3 Simulation study on Emission Level

Simulation is done in ANSYS Fluent for emission level in the silencer. It was performed to study the effect of radial air injection on the reduction of flue gases during combustion of methane (CH_4). The boundary conditions imposed were same as the parameters achieved from the experimental testing of the engine.

i. Fuel Used: Methane (CH_4)
ii. Inlet Fuel Flow (for combustion): 0.000188 kg/s
iii. Inlet Air Flow (for combustion): 0.0036 kg/s
iv. Inlet Air Flow for Radial Jets: 0.001894 kg/s

The fuel used was methane as ANSYS always provide complete combustion for Gasoline (C_8H_{18}) and other fuels. To achieve incomplete combustion ANSYS only has option to use ethane as fuel.

3.1.4 Simulation for Unmodified Silencer

The inlet temperature to combustion chamber is calculated by performing tests. The inlet temperature

is 300 K and combustion is simulated. The reference points selected are both inlet and outlet end, radial jets, and wall of silencer.

3.1.5 Simulation of silencer with air injection radially at first location

In this case air is injected radially through 8 holes in the silencer at a location which is measured along the length of silencer at 70mm from the flue gas inlet end of silencer. The air is injected at temperature of 300 K and mass flow rate of 0.001894 kg/s. The effect of emission of gases can be seen in simulation. Figure 31, 32, 33 and 34 emission of CO, CO_2, soot and NOx in ppm after the radial air injection at the first location.

Table 1 shows the Simulation of emission results. Form the results, it was observed that CO percent was reduced due to reaction of CO with O_2 forming CO_2. But it was noted that CO_2 percent was reduced. It occurred due to reaction of hot CO_2 with cold O_2 forming Carbon Trioxide (CO_3) & Carbon Tetroxide (CO_4) and ANSYS cannot show these gases in results. Both CO_3 & CO_4 are highly unstable and again broke down into CO_2 & O_2. Thus CO_2% is increased by amount of CO being converted into CO_2 which was not generated by ANSYS. NOx gases are reduced as they form at high temperature and its concentration can substantially reduce due to introduction of cold air.

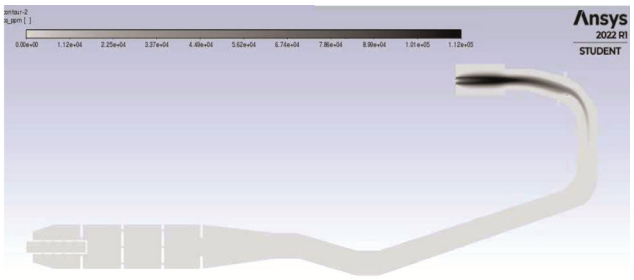


Fig. 31 — Simulation on modified silencer with one radial jet for CO emission in ppm.

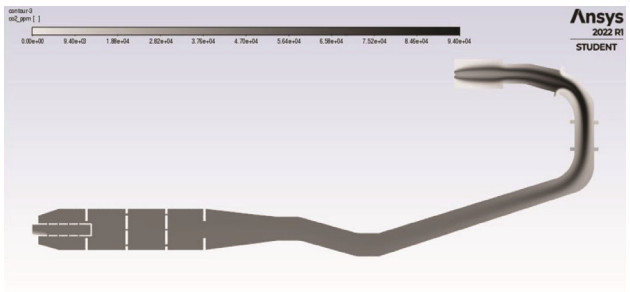


Fig. 32 — Simulation on modified silencer with one radial jet CO_2 emission in ppm.

3.2 Experimental Result

3.2.1 Experiments performed on Unmodified Silence

Experimental Study has been performed on the available silencer. The mass flow of fuel and air were calculated initial. All calculations were performed with respect to time. Table 2 shows experimental results on the available silencer.

3.2.2 Temperature Readings

Table 3 shows the experimental results on the unmodified silencer of temperature readings. Given

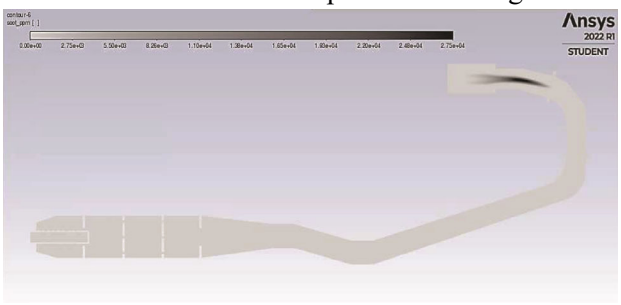


Fig. 33 — Simulation on modified silencer with one radial jet Soot emitted in ppm.

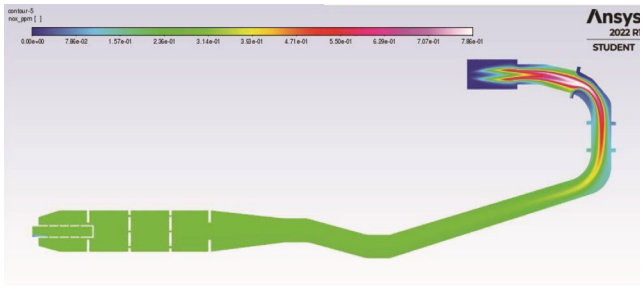


Fig. 34 — Simulation on modified silencer with one radial jet NOx emission in ppm.

Table 1 — Simulation of emission results.

Condition of Radial Jets	By-products							
	Carbon Dioxide (CO_2)			Carbon Monoxide (CO)			NO_X	
	ppm	Actual %	Reduced %	ppm	Actual %	Reduced %	ppm	Actual %
Without Radial Jet	1.03×10^5	10.3	--	4.75×10^4	4.75	--	0.793	--
Radial Jet at First Location	2.82×10^4	2.82	72.62	0		100	0.3.14	60.41

Table 2 — Experimental results on the available silencer.

Load	M_f	M_a	A/F	IP	BP	$\eta_{Thermal}$	η_{Volume}	BSFC	BMEP	Torque
0	0.000149	0.00331	22.244	6.324	0	0	161.6	0.4464	0	0
200	0.000161	0.00331	20.53	6.851	0.2	2.91	161.67	2.9016	119.114	1.364
400	0.000163	0.00346	21.22	6.927	0.4	5.77	161.5	1.467	238.22	2.728
600	0.000177	0.00346	19.46	7.556	0.6	7.94	169.5	1.066	357.34	4.09
800	0.000178	0.00346	19.438	7.565	0.8	10.57	169.5	0.801	476.45	5.45
1000	0.000182	0.00346	18.938	7.761	1	12.87	169.5	0.6577	595.5	6.82
1200	0.000188	0.0036	19.06	8.024	1.2	14.95	173	0.566	714.68	8.18

N = 1400 RPM

Table 3 — Experimental results on the unmodified silencer of temperature readings.

T_1	T_2	T_3
478.16	458.61	183.58

Table 4 — Experimental results *on* the available silencer of noise readings.

Without Jets

T_1	T_2	T_3	OASPL
478.168	458.617	183.58	95

below are the experimental results acquired for temperature on the available silencer. Where T_1, T_2 and T_3 are the Thermocouple position. Through these position with the help of NI-9129 Module for Temperature Measurement the reading for Temperature were taken. The readings at T_1 is 478.168°C, at T_2 it is 458.617°C and at T_3 the temperature acquired is 183.58°C.

3.2.3 Noise readings

Table 4 shows the experimental results on the available silencer of noise readings. Given below are the Experimental Results acquired for Noise on the Available Silencer. Where, T_1, T_2 and T_3 are the thermocouple position. Through these position with the help of Microphone the reading for Noise were taken. The OASPL of the acquired Silencer is 95 dB.

3.2.4 Experiment performed on modified silencer

During experimentation, for measuring temperature of 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: Air injection at first point i.e., at 100 mm from flue gas inlet to the silencer. Temperature results for air injection at first location shown in Fig. 35. The temperature reduction of 7.643 °C for air injected at 2 bar compared to no air injection. For air injected at 2.5 bar the temperature reduces by 20.543°C. Further

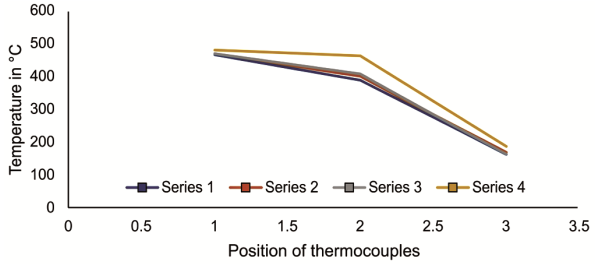


Fig. 35 — Only 1st inlet open condition for temperature on modified silencer.

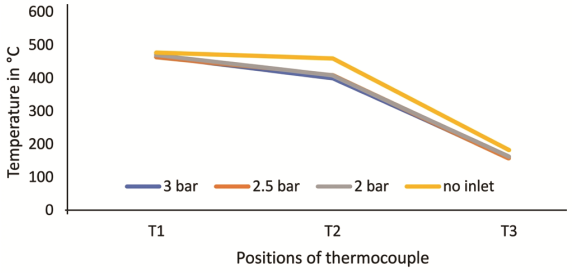


Fig. 36 — Only 2nd inlet open condition for temperature of modified silencer.

for air injected at 3 bar the temperature drops by 24.595°C.

Case 2: Air injection at first point and second point i.e., at 200 mm from flue gas inlet to the silencer. Temperature results for air injection at second location shown in Fig 36. The temperature reduction of 30.182°C for air injected at 2 bar compared to no air injection. For air injected at 2.5 bar the temperature reduces by 30.388 °C. Further for air injected at 3 bar the temperature further drops by 35.929 °C.

Case 3: Air injection radially at three locations i.e., at 300 mm from flue gas inlet to the silencer. Temperature results for air injection at first and second location shown in Fig 37. The temperature reduction of 26.755°C for air injected at 2 bar compared to no air injection. For air injected at 2.5 bar the temperature reduces by 29.552°C. Further for air injected at 3 bar the temperature further drops by 30.342°C.

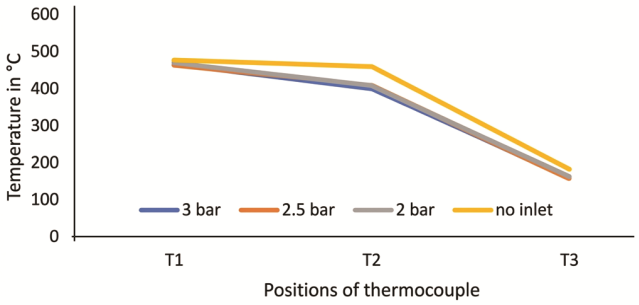


Fig. 37 — Only 3rd inlet open condition for temperature on modified silencer noise readings (SPL Results).

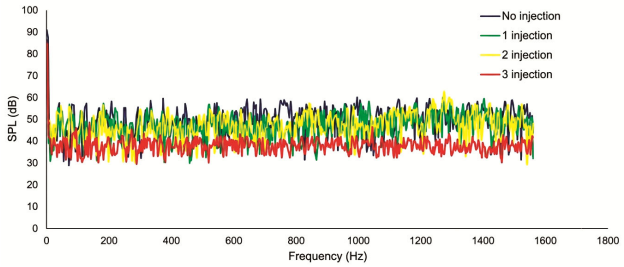


Fig. 38 — Frequency spectra for engine running at 1400 rpm with different injections on modified silencer.

The sound pressure level is measured using microphone and FFT. The frequency spectra for engine running at speed of 1400 rpm as seen in Fig. 38. In this experiment the spectra obtained is of broadband nature and no single frequency dominates the results. To get the efficiency of the result and draw conclusion of experimentation we need to obtain overall sound pressure level. Hence the decision making step to obtain sound results is to calculate the overall sound pressure level. This is done in further section.

3.2.5 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.

Case 1: Air injection at first point i.e., at 100 mm from flue gas inlet to the silencer. The addition of air radially at first point at 2 bar tends to decrease the sound pressure level by 1.65 dB. Further the sound reduces by 2.36 dB for air injection at 2.5 bar. The air injection at 3 bar reservoir pressure tends to decrease sound by 5.65 dB. The results can be seen in Fig. 39.

Case 2: Air injection at 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 2 bar tends to decrease the sound pressure level by 2.414 dB. Further the sound reduces by 4.10 dB for air injection at 2.5 bar. The air injection at 3 bar reservoir pressure tends to decrease sound by 7.11 dB. The results can be seen in Fig. 40.

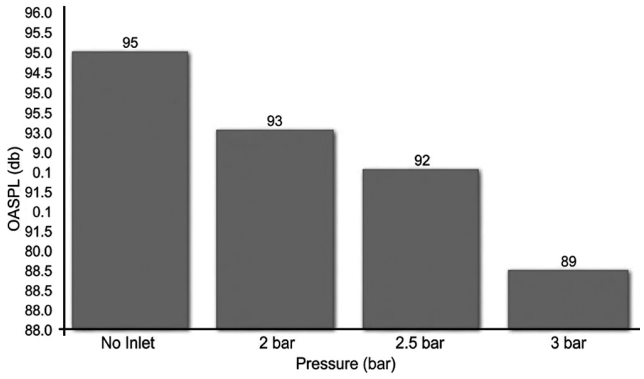


Fig. 39 — Only first inlet open condition for noise on modified silencer.

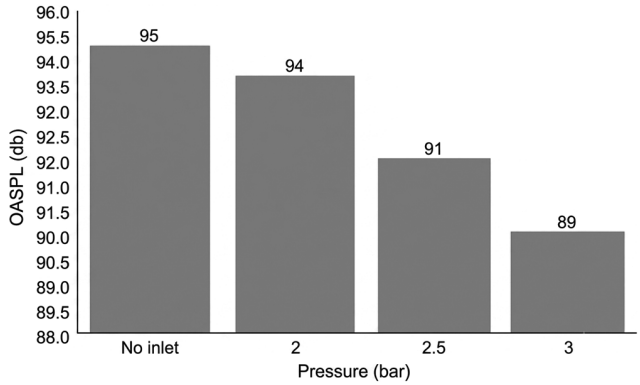


Fig. 40 — Only 2nd inlet open condition for noise on modified silencer.

Case 3: Air injection radially at three locations i.e., at a distance of 100mm, 200mm and 300mm from flue gas inlet to the silencer. The addition of air radially at first point at 2 bar tends to decrease the sound pressure level by 4.84 dB. Further the sound reduces by 6.75 dB for air injection at 2.5 bar. The air injection at 3 bar reservoir pressure tends to decrease sound by 7.84 dB. The results can be seen in Fig. 41.

3.2.6 Emission readings

Table 5, 6, and 7 shows simulation results of CO_2, Soot and NO_x emission. 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. With no injection on the available silencer, CO emission found 2.99% and HC emission found 187 ppm and shown in Fig 42 and 43. Injection 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. Air injection at second point i.e., at 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 1.80% and HC emission by 151 ppm. The addition of air radially at first point, point i.e., at 100 mm from flue gas inlet to the silencer at 3 bar tends to decrease the CO emission level by 1.84% and HC emission by 130 ppm.

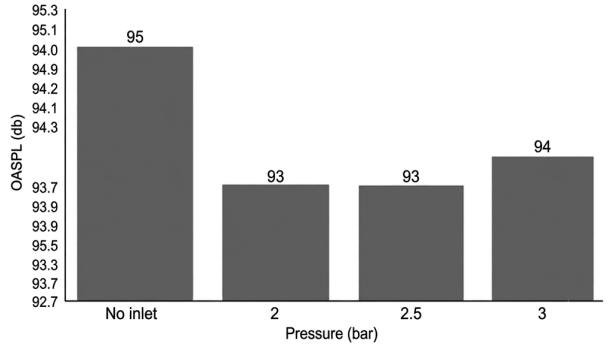


Fig. 41 — Only 3rd inlet open condition for noise on modified silencer.

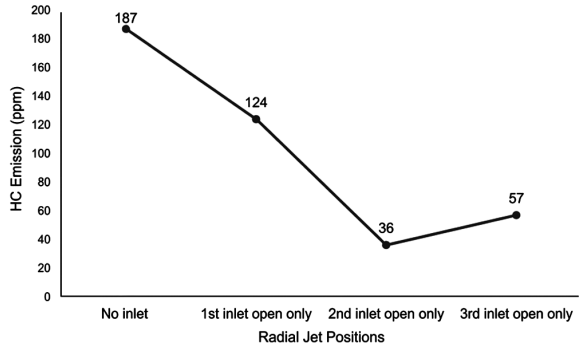


Fig. 42 — HC emission in ppm for different Radial jet conditions.

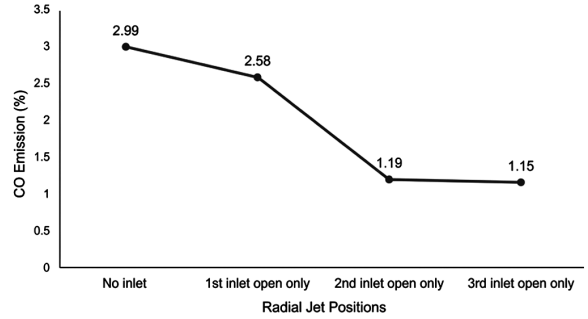


Fig. 43 — CO emission % for different Radial jet conditions.

From the results, it was observed that CO percent was reduced due to reaction of CO with O_2 forming CO_2. But it was noted that CO2 percent was also reduced. It occurred due to reaction of hot CO_2 with cold O_2 forming Carbon Trioxide (CO_3) & Carbon Tetroxide (CO_4) and ANSYS cannot show these gases in results. Both CO_3 & CO_4 are highly unstable and again broke down into CO_2 & O_2. Thus CO_2 % is actually increased by amount of CO being converted into CO_2. Which was not generated by ANSYS.

NOx gases are formed at high temperatures and its amount can be substantially reduced due to introduction of cold air and can be verified in above results.

Table 5 — Simulation results of CO_2 emission.

Condition of Radial Jets	By Products Carbon Dioxide (CO_2)		
	ppm	Actual %	Reduced %
Without Radial Jet	1.03×10^5	10.3	--
Radial Jet at First Location	2.82×10^4	2.82	72.62
Radial Jet at Second Location	1.88×10^4	1.88	81.74
Radial Jet at Third Location	1.78×10^4	1.88	82.71

Table 6 — Simulation results of soot emission.

Condition of Radial Jets	By Products Soot	
	ppm	Reduced %
Without Radial Jet	1.48×10^4	--
Radial Jet at First Location	0	100
Radial Jet at Second Location	0	100
Radial Jet at Third Location	0	100

Table 7 — Simulation results of NOx emission.

Condition of Radial Jets	By Products Nitrogen Oxides (NO_X)	
	ppm	Reduced %
Without Radial Jet	7.93×10^{-1}	--
Radial Jet at First Location	3.14×10^{-1}	60.41
Radial Jet at Second Location	1.57×10^{-1}	80.21
Radial Jet at Third Location	8.69×10^{-1}	89.59

Soot is unburned fuel which gets collected in exhaust. ANSYS model cannot accurately generate result for soot as it is long term process. But it can reduce due to constant introduction of air at high velocity as it allows less time for soot to stick on wall of exhaust.

3.3 Comparison of Experimental Readings between Simulated Results and Experimental Results

The temperature results of simulation and experimentation at location 4 on silencer is shown in Fig. 44. The difference in temperature between simulation and experimental results varies from 1.98 K to 157.42 K in value.

3.3.1 Comparison of Modified Silencer with BS6 Norms

Table 8 shows the difference between BS3 and BS4 in power rating. As the world became more aware of the need to reduce carbon footprints, many countries, including India, started taking serious steps to control vehicle pollution. In 2000, the Indian government introduced the Bharat Stage Emission Standards (BSES) to limit harmful emissions from vehicles.

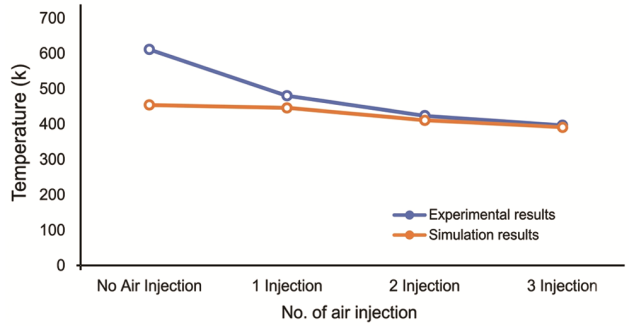


Fig. 44 — Comparison between simulated and experimental results.

Let's take a closer look at the difference between BS3 and BS4 engines, and understand how moving from older to newer engines affects their performance.

In general, BS4 engines are much better at managing and reducing evaporative emissions compared to BS3 engines. This means vehicles with BS4 engines are cleaner and pollute less.

Look at the change in emission levels from BS3 to BS4 for CE vehicles based on their engine power output.

Table 9 shows the difference between BS6 and BS3 in Fuel Type. The big change is about 90% reduction of PM (particulate matter) in BS4 engines higher than 50 HP. The highly toxic Nitrous Oxide (NOx) vapor emissions go down by a whopping 92% in BS4 engines higher than 75 HP. Bharat Stage III (BS3) standards regulate air pollutants from internal combustion engines in India, effective nationwide since October 2010. BS3 limits pollutants: carbon monoxide (2.30 g/km), hydrocarbons (0.20 g/km), and nitrogen oxides (NOX) (0.15 g/km). Initially favored for their cost-efficiency, BS3 engines now face scrutiny for their high emissions. Table 10 shows the comparison Table of BS6 and BS4 in given conditions. Consequently, the government mandated the shift to Bharat Stage IV (BS4) engines to reduce pollution. BS6 standards, effective from 1st April 2020, use Selective Catalytic Reduction (SCR) units to

Table 8 — Difference between BS3 and BS4 in power rating.

POWER RATING	BS3-CE VEHICLES		BS4-CE VEHICLES	
HP	NOx + HC g/km	PM g/KW	NOx + HC g/km	PM g/KW
<10.72 HP	7.5	0.6	No Change	
49.61 HP ≤ 75 HP	4.7	0.4	4.7	0.025
75 HP ≤ 174 HP	4	0.3	0.4 + 0.19	0.025

Table 9 — Difference between BS6 and BS3 in Fuel Type.

Fuel Type	Pollutant Gases	BS6 (BSVI)	BS3 (BSIII)
Petrol Passenger Vehicle	Nitrogen Oxide (NOx) Limit	<60mg>	<85mg>
Petrol Passenger Vehicle	Particulate Matter (PM) Limit	<0.05g/km>>	<0.05g/km>
Petrol Passenger Vehicle	HC + NOx	<0.16g/km>	<0.35g/km>
Petrol Passenger Vehicle	Carbon Monoxide (CO) Limit	<1.0g/km>	<2.3g/km>

Table 10 — Comparison Table of BS6 and BS4 in given conditions.

Emission Level	BS VI Norms	BS III Norms	Results			
			No Inlet	1 Inlet	2 Inlet	3 Inlet
CO %	0.5	3	2.99	2.58	1.19	1.15
HC ppm	500	3000	187	124	36	57

reduce emissions. SCR converts NOX into water and nitrogen using AdBlue, a urea and deionized water solution. BS6 vehicles emit no more than 60 mg/km of NOX and use low-sulfur fuel. BS6 fuel is compatible with older vehicles. Real Driving Emission (RDE) testing measures pollutants under real-world conditions.

4 Conclusion

The simulation and experimental study have been carried out to study the effect of injection of air at three locations on the temperature and sound of engine. The injection of air radially at three locations clearly show the reduction in temperature of flue gases in silencer. As the air inlet pressure increases there is decrease in temperature of flue gasses with slight increase in pressure inside silencer. Also, as the number of air injection's locations along the length increase the temperature of flue gases reduces further. This method of reducing temperature and noise of engine is effective. 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.

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