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REAL-TIME EMISSIONS OF GASEOUS POLLUTANTS FROM VEHICLES UNDER HETEROGENEOUS TRAFFIC CONDITIONS

Summary. Air quality problems in cities are often a cause for worry. The air quality index is increasing daily, leading to an increase in cancer and many respiratory problems. Road transport in an urban area is a significant cause of air pollution. The vehicles must meet Indian emission regulations for which the emissions are measured using legally mandated standard driving cycles that did not accurately reflect real-world driving emissions because of varying traffic conditions, meteorological conditions, driving behaviour, vehicle power, performance, etc. This study focuses on real-time emissions of gaseous pollutants hydrocarbon (HC), carbon dioxide (CO2), carbon monoxide (CO), and nitric oxide (NO) from vehicle exhaust pipes under heterogeneous traffic conditions. The emissions were measured using a Portable Emission Measurement System (PEMS). The PEMS used was an AVL MDS 450 analyser mounted on the vehicle, and on-road emissions were captured. The test sample consists of four passenger vehicles with varying engine sizes, manufacturers, and fuel. The test route comprises city

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and highway areas, and it was discovered that the emissions were reduced by 40 to 70% on highways compared to the city. In petrol BSIV and BSVI engines, the emission was reduced to 41.73% for CO, 46.90% for HC, and 64% for NO in the city area. Speed and emissions scatter graphs were plotted for the vehicles, and it was found that in the city area, the optimum speed for less emission is between 30-40 km/h, and on highways, the optimum speed is 80-90 km/h. The emissions were also sensitive to the rate and frequency of acceleration and decelerations. This type of study is very limited in India, and more such studies are required for the assessment of air quality in metropolitan areas and successful traffic management strategies, as well as for determining instantaneous projections of pollutant emissions.

Keywords: real-world driving emissions, portable emission measurement system, heterogeneous traffic condition

1. INTRODUCTION

The air quality index and respiratory problems faced throughout the world are increasing and with grave health implications. Air quality issues in India have reached an alarming proportion. According to the World Air Quality report, Bhiwadi in Rajasthan is the most polluted city in the world, followed by Ghaziabad in Uttar Pradesh [1]. In 2021, New Delhi was named the world's most polluted capital city for the fourth year in a row. The decline in air quality is attributable to many reasons, among which pollution due to vehicular emissions is becoming a serious concern. In India, the Compound Annual Growth Rate (CAGR) of road length is 4.2%, as the total road length has increased from 3.99 lakh km to 63.86 lakh km from the year 1951 to 2019, respectively [2]. As the connectivity in the country and the quality of roads, the accident rates have declined, and the growth in the number of vehicles has also increased significantly. The Compound Annual Growth Rate (CAGR) for growth in the total number of registered vehicles was 9.91% as 67,007 were registered in the year 2003, and it increased to 2,95,772 vehicles in the year 2019 [2]. The compound annual growth in this period for registered two-wheelers was 10.38%, for cars jeeps and taxis 9.64%, for buses 3.26%, for goods vehicles 8.59%, and for others 7.63% [2]. As the number of vehicles on the road increase, the emissions increase. This increase in emissions has become a global concern and needs a solution, as there has been an increase in average temperatures, melting glaciers, climate change, global warming, etc. As per the International Energy Agency database in India itself, it was found that CO_2 emissions from coal, oil, and natural gas burning were reported as 1628.0 Mt, 595 Mt, and 83 Mt, respectively, in the year 2018. In the year 2018, a total of 33,514 Mt emission was reported from different sectors in India, of which 8258 Mt, that is, 25% of total emissions was from the transport sector [3].

The emissions released from fuel combustion contain major pollutants such as carbon monoxide (CO), oxides of Sulphur (SO_2), particulate matter (PM), nitrogen oxides (NO_x) and hydrocarbon (HC). The principal pollutants in diesel-powered vehicles are nitrogen oxides and particulates, whereas the main pollutants in petrol/gasoline-powered vehicles are hydrocarbons and carbon monoxide. These emissions have severe direct and indirect impacts on human health and ecology [4, 5, 6]. The effects of these pollutants on human health are summarized in Table 1.

Tab. 1

Effects of pollutants on human health

Pollutants	Effect on Health
CO	It affects the cardiovascular and nervous systems, decreasing physical coordination, eyesight, and judgement, as well as causing nausea and headaches, lowering productivity, and increasing discomfort.
NO_x	Causes infection susceptibility, pulmonary disease, lung function impairment, and irritations of the eyes, nose, and throat.
SO_2	It has a serious effect on lung function.
SPM and RPM (Suspended particulate matter and respirable particulate matter)	Fine particle pollution can be harmful or carry toxic trace chemicals, causing immune system impairment. Fine particles irritate lung tissue and cause long-term disorders by entering deep into the respiratory system.
HC	Cancer-causing potential.

2. LITERATURE REVIEW

Worldwide, the techniques used for emission measurement include Remote Sensing, Portable Emission Measurement Systems, Chasis and Engine Dyanometer measurements, and Road Tunnel studies.

The remote sensing technique is commonly used as it can monitor emissions from a large number of vehicles, up to 1000 vehicles per day [8]. In this technique, the detectors are calibrated and placed at the sampling location. The sensor detects changes in the concentration of pollutants in the air.

The tunnel measurement technique works on the principle of change in the concentration of pollutants at entry and exit points of tunnels, which also depends on tunnel characteristics and traffic flow conditions. The emissions are reported by estimating the airflow in the tunnel and multiplying it by the difference in the concentrations of pollutants obtained [8, 9].

Portal emission measurement systems are widely used, as they measure with good accuracy instantaneous emissions from vehicles, in addition, they also provide various parameters of vehicles such as revolution per minute, engine speed and temperature, speed, etc. They directly measure emissions such as HC, NOx, and CO from the tailpipes of vehicles [7].

The emissions are also predicted by several models like COPERT and Motor Vehicle Emission Simulator (MOVES), which are modelled using past emissions data. The use of artificial neural networks is becoming popular as the nonlinear relationships can be modelled, whereas Gaussian models are unable to explain vehicle emission's non-linearity nature [14]. Artificial Neural Network (ANN) models can parallel process, self-learn, and self-correct, making them more suitable for the prediction of vehicle emissions [17].

In the study conducted by Wyatt et al. [12], a PHEM model was used for CO_2 emissions for the 5 road grades (coefficients 0,0.5,1,2,3), and there were 48 test runs for each lap and section. It was observed that for 0 grade coefficient (which implies considering the area as flat), the average lap CO_2 emissions reported was between 400 to 513 gCO_2/km, which were increased by 1.4, 4.0, and 7.6% when the road grade coefficient was changed to 1, 2 and 3, respectively. It was also pointed out that for a route that has several changes in elevation over the length, the average flat road grade cannot be taken as the assumption of balancing the emissions from uphill sections and downhill sections would give wrong results. This is because the model indicates an increase in emissions with the increase in steepness of the grade.

Wang [13] conducted a study to understand the effect of altitude on emissions. It was conducted in China (it has 65% of its territory at an altitude higher than 1000 m, among which 33% have an altitude above 2000 m) on diesel vehicles and emissions were noted at different altitudes of 30, 1330, 1910, 2240, 2400, and 2990 m. The CO, NO_x, and PN emissions increased with altitude. The CO emissions increased by 209% at 2990 m altitude compared to an altitude of 30 m, and PN emissions were 3 times at 2990 m altitudes compared to 30 m altitude but NOx emissions show an increasing trend from an altitude of 30 m to altitude 2400 m, and after that, at altitude 2990 m, a decline in emission was observed. The decline was believed to be because of less oxygen concentration and an extremely long delay in the ignition of an engine at a high altitude.

Jaikumar et al. [14] reported that emissions quantified with the help of models or inventories are much lower than the actual emissions from vehicle exhaust to local air. The study was conducted on 10 different vehicle passenger cars using an AVL Digas analyser, and the observed data was used to prepare a prediction model. The best model was observed in the nonlinear autoregressive exogenous input (NARX) model, which has 4 inputs (speed, RPM, engine speed, VSP, and acceleration). The results of the model were compared to those of the COPERT model and the emission factors of the Automotive Research Association of India (ARAI), and it was reported that these models predict the emissions while the developed model results were accurate with 0.9 as an index of agreement.

Furthermore, the study conducted by Jaikumar et al. [15] on 10 vehicles included buses, three-wheelers, passenger cars, and two-wheelers and the route consisted of roads of different categories such as 2 lanes, 4 lanes, and 6 lanes with separated and mixed flow traffic characteristics. It was reported that due to larger engines and higher exhaust flow rates, buses emitted higher NO emissions than other vehicles. For two-wheeler vehicles, the CO emissions were the lowest; however, compared to other vehicles, two-wheelers had the highest HC emissions. The results obtained were compared with the COPERT model and the Comprehensive Modal Emission Model (CMEM), which under-predicted emissions.

Mahesh et al. [16] studied the real-world emissions of motorcycles of engine size varying from 70 cm^3 to 124 cm^3 by AVL Ditset gas 1000 on the four urban arterial roads near the IIT Madras campus. The emission factors for CO for vehicles were found to be greater than Bharat Stage (BS) emission standard values. The lowest value reported was 3.81 times, and the highest value was reported as 12.3 times greater than BS Standard emissions.

An ANN (Artificial Neural Network) based model was developed representing CO and NO_2 concentrations at traffic intersections and arterial roads in Delhi. The model for NO_2 concentrations used a 2-year data from 1 January 1997 to 31 December 1998 to train and develop a model, and then it predicted emissions for a 1-year period (1 January to 31 December 1999) and predicted 76% error-free at the intersection and 59% at arterial roads [17]. The model for CO concentrations under-predicted the concentrations values and concluded that univariate time-series models do not consider inversion conditions; thus, time-based models fail to forecast CO concentrations in poor meteorological conditions [18].

3. STUDY AREA AND METHODOLOGY

3.1. Study area

This study was conducted in Jodhpur, a city in Rajasthan, India, as shown in Figure 1. The route selected consisted of a city area and a highway. The route consists of varying traffic conditions, traffic lights, pedestrian crossings, and road conditions. The change in road type and traffic conditions throughout the route was marked by waypoints ranging from M1 to M3. This divides the test route into two segments. The total length of the route is 14.7 km, which consists of a city area of 4.4 km and a 10.3 km highway area. The route considered for the emission test is shown below in Figure 2, and the grade of the roads measured by the GPS device is reported in Table 2.

Fig. 1. Study area

Fig. 2. Test route for data collection

Tab. 2

Description of segments in the route

Road Identification	**Segment Length (km)**	**Grade (%)**
M1-M2 (City)	4.4	-0.20%
M2-M3 (Highway)	10.3	0.10%

3.2. Instrument set-up

This study used the following equipment: (a) AVL MDS 450, (b) Garmin Etrex 10, (c) 2 kW inverter, and (d) portable battery as shown in Figure 3.

(a) (b) (c)

Fig. 3. (a) AVL MDS 450 (b) Garmin Etrex 10 GPS Device,
(c) 2 kW inverter and portable battery

The AVL MDS 450 was used to measure RPM, CO, HC, CO_2, O_2 and NO. The range and accuracy of measuring these parameters are presented in Table 3.

Tab. 3

Range and accuracy of AVL MDS 450 (Source: AVL handbook [27])

Measured	**Measuring**	**Resolution**	**Accuracy**	
CO	0-15 % vol.	0.01 % vol.	< 0.6 % vol.: ≥ 0.6 % vol.:	± 0.03 % vol. ± 5 % o. M.
CO_2	0-20 % vol.	0.01 % vol.	< 10 % vol.: ≥ 10 % vol.:	± 0.5 % vol. ± 5 % o. M.
HC	0-30 ppm vol.	≤ 2.000: 1 ppm vol.	< 200 ppm vol.: ≥ 200 ppm vol.: ≥ 10000 ppm vol.:	± 10 ppm vol. ± 5 % o. M. ± 10 % o. M.
O_2	0-25 % vol.	0.01 % vol.	< 2 % vol.: ≥ 2 % vol.:	± 0.1 % vol. ± 5 % o. M.
NO	0-5 ppm vol.	1 ppm vol.	< 500 ppm vol.: ≥ 500 ppm vol.:	± 50 ppm vol. ± 10 % o. M.

Before starting the sampling, the machine was calibrated by an AVL representative, with known concentrations of gases as specified by the manufacturer, as shown in Figure 4.

Fig. 4. Calibration of the AVL MDS 450 machine

3.3. Sampling procedure

The sampling was not done in cold start conditions as vehicles were picked from the source and taken to MBM University, marked as waypoint M1 in the test route, as shown in Figure 5, where the machine was installed in the vehicles. For every run, the HC test and leak test were done before sampling. The speed and location of the vehicle were recorded by hand using the GPS device Garmin Etrex 10. The AVL MDS 450 used the inverter and the portable battery as power sources. The tailpipe of the vehicle was connected to the sampling hose. The RPM sensor was then connected to the engine. Thereafter, the vehicle was run on the test route. The laptop was connected to the AVL MDS 450, and the data for emission was recorded. For all the vehicles, the driver was the same. The data was collected from 13:30 to 15:30 hours.

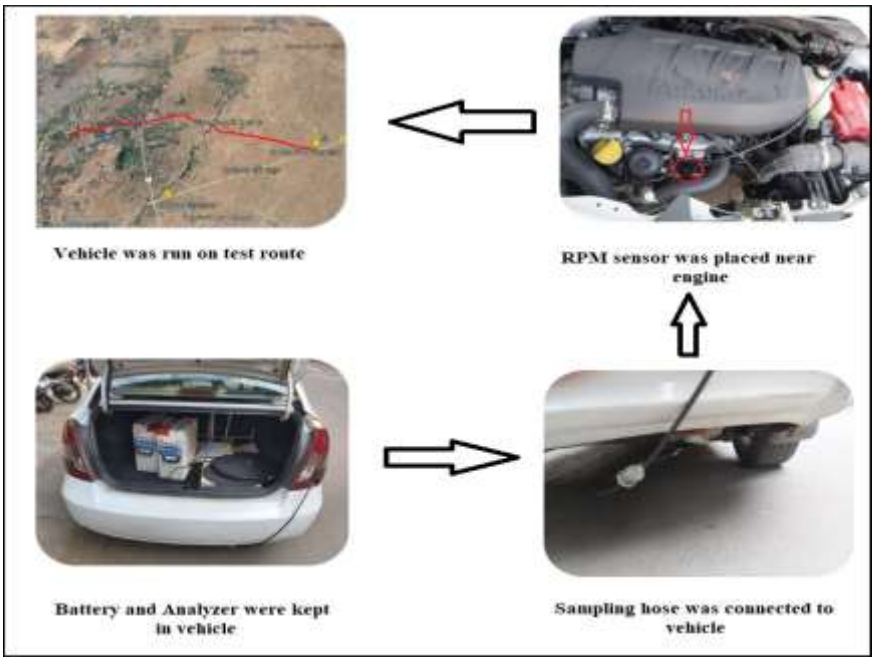


Fig. 5. Flow chart of preparation of the vehicle for testing

3.4. Test vehicles

The vehicles were selected with varying engine sizes, manufacturers, and fuel used. The details of the test vehicles are highlighted in Table 4.

Tab. 4

Details of vehicles used for data collection

Specifications	V1	V2	V3	V4
Displacement(cc)	10866	1197	1248	1497
Curb Weight (kg)	952	950	975	1173
No. of Cylinders	4	4	4	4
Emission Standard	BSIV	BSVI	BSIV	BSIII
Transmission	Manual	Automatic	Manual	Manual
Model	2015	2021	2018	2010
Fuel	Petrol	Petrol	Diesel	Diesel
Odometer Reading	23,581	7,217	61,938	1,61,399

3.5. Data collection

The vehicle was parked at waypoint M1, and the analyser, GPS device, and vehicle were started simultaneously. The AVL MDS 450 analyser measured RPM, CO, CO_2, HC, NO, and O_2, as shown in the figure, and the GPS device measured the coordinates, elevation profile, and speed-time profile of the test route, as shown in the figure. The data obtained from the gas analyser and GPS device were correlated based on the time stamp, then the unrelated data was removed, and an excel sheet was formed, which was then used for the analysis.

The data recorded by AVL MDS 450 for the pollutants CO, CO_2, and O_2 were recorded in % vol unit, while the data recorded for HC and NO was in ppm. The unit of the pollutants was converted into a standard unit of g/s using an empirical equation, which is been also studied by [16, 19].

$$E = P \times EFR \times \rho \qquad (1)$$

Where,

E = emission rate of pollutants in g/s

P = pollutant concentration measured in % vol or ppm

EFR = exhaust flow rate measured in L/s

ρ = density of pollutant in g/L

The EFR is measured from an exhaust flow metre device, but without this device, the study by Mahesh et al. [16] suggested that “For a four-stroke engine, the exhaust flow rate (in L/s) equals half the engine size (in litres) times the number of revolutions per second; for a two-stroke engine, the exhaust flow rate (in L/s) equals the engine size (in litres) times the number of revolutions per second.” This assumption is used in this study because of the absence of an exhaust flow metre device.

4. RESULTS AND DISCUSSIONS

4.1 Comparison of Modified Indian Driving Cycle with speed-time profile

The driving cycle (DC) is a speed-time profile representing the normal driving behaviour of a given vehicle type in a given city or region, specifically the speed and acceleration characteristics. Due to factors such as topography, infrastructure, and vehicle type, it has been observed that the driving cycle differs by region. In India, the Modified Indian Driving Cycle (MIDC) is used as the standard driving cycle for passenger vehicles, as shown in Figure 6. The driving cycle covers a distance of approximately 10.647 km in 1180 seconds with a maximum speed of 90 km/h. The driving cycle is designed in a way to represent normal driving conditions, but due to the increase in the road network, traffic, and vehicles categories, it has failed to represent the driving conditions, which can be seen by the speed-time profile of the four vehicles recorded by the GPS device. When compared with the MIDC cycle, it can be seen that according to the MIDC cycle, the vehicle accelerates and deaccelerates 4 times in a span of 195 seconds, and this pattern repeats itself four times in the driving cycle until approximately 780 seconds, whereas in the speed-time profile of vehicles V1, V2, V3 recorded by the GPS device. The speed-time profile of vehicles V1, V2 and V3 are shown in Figures 7, 8 and 9.

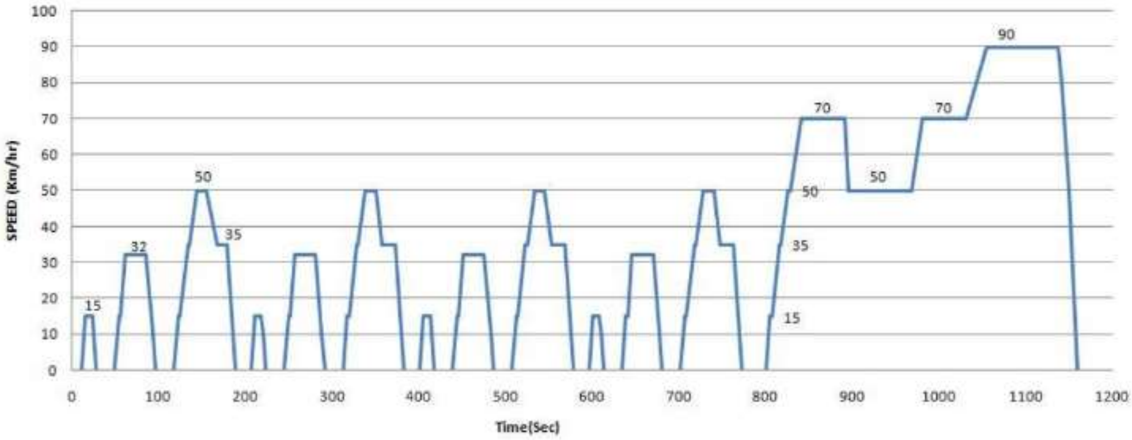


Fig. 6. Modified Indian Driving Cycle

It was observed that for vehicle V1, there were 6 phases of acceleration and deceleration in 195 seconds and stopped for 43 seconds, for vehicle V2, there were 5 phases of acceleration and deceleration, for vehicle V3, there were 4 phases of acceleration and deceleration, but unlike other vehicles, the initial accelerations were very low compared to other vehicles. The MIDC cycle consists of two phases, an Elementary Cycle of Emission (ECE) and an Extra-Urban Driving Cycle (EUDC), which represents driving conditions in the city and highway, respectively. Similarly, the test route also consists of the city area and highway area. In the ECE phase, the distance covered is approximately 4.053 km in 780 seconds. The average speed for the cycle is 19 km/h, while in the city area, vehicles V1, V2, V3, and V4 are 26.5, 22.2, 38.9 and 25.5 km/h, respectively. In the EUDC phase, the distance covered is 6.594 km in 400 seconds. The average speed for the cycle is 59.3 km/h, while in highway areas, vehicles V1, V2, V3, and V4 are 42.4, 45.1, 43.7 and 47.8 km/h, respectively. Hence, it can be clearly observed that there is a huge variation in the MIDC driving cycle because real-world driving involves varied horsepower, average speeds, traffic congestion, road grades, and maximum acceleration rates compared to the authorized driving cycle. There is a strong need for updating this cycle or introducing new cycles, as it is used to test the emissions in the Chasis Dyanometer test.

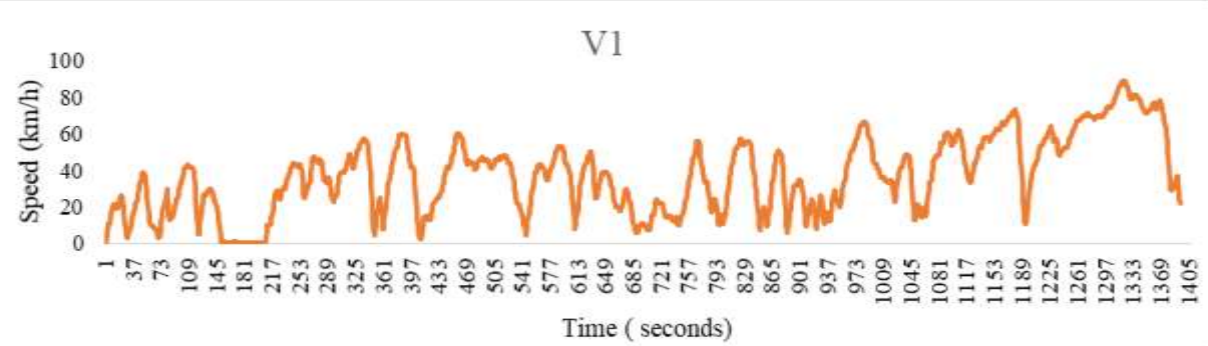


Fig. 7. Speed-Time profile of vehicle V1

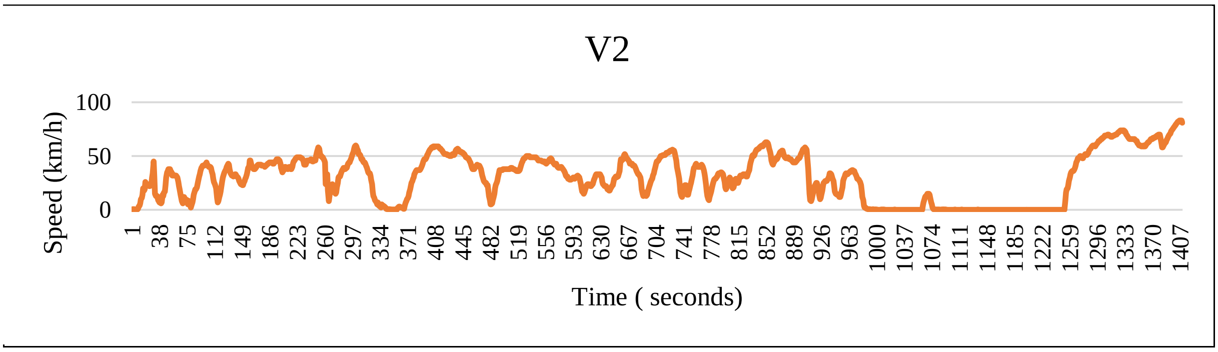


Fig. 8. Speed-Time profile of vehicle V2

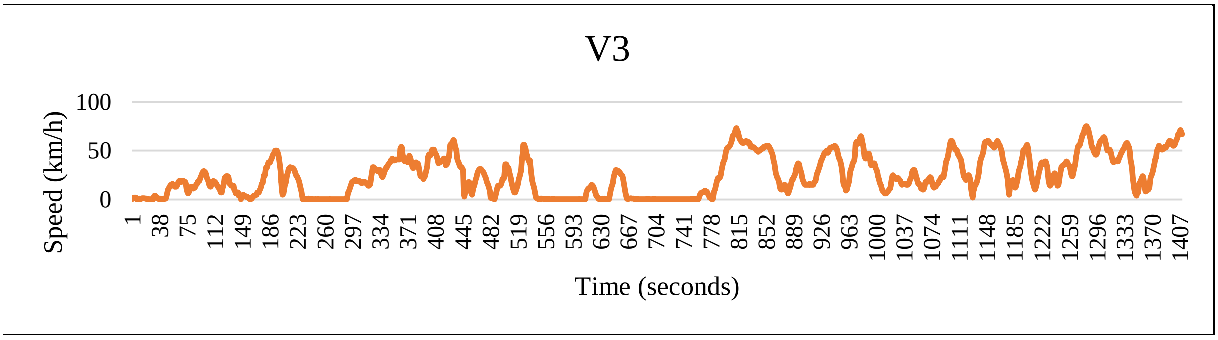


Fig. 9. Speed-Time profile of vehicle V3

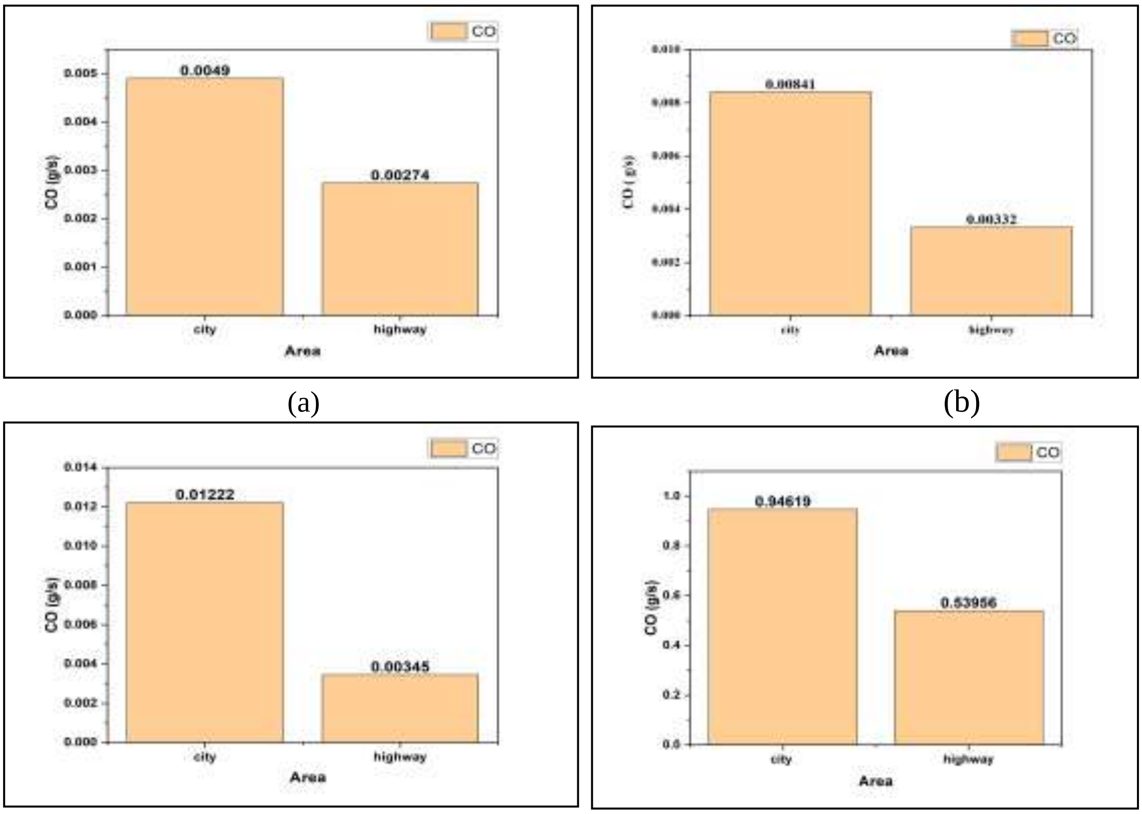
Many researchers have suggested and developed a local driving cycle, which would help for a better understanding and designing of local traffic conditions, field conditions, and evaluation of vehicle performance that would help policymakers in making decisions [20-23]. The new driving cycle should be more representative of real-world driving characteristics, such as higher speed and acceleration, than the current one. Instead of aggregating to a single driving cycle, it should discriminate between different types of roads and locales. Apart from regulatory driving cycles, which involve extreme driving circumstances, countries like Australia, the United Kingdom, Germany, and France have devised driving cycles to estimate emissions and fuel usage [24]. India has heterogeneous traffic conditions and should consider taking a similar approach.

4.2 Comparison of emissions in the city and highway areas

In this study, it was observed that the emissions in highway areas were reduced to 40-70% compared to the emissions in the city areas. This is because of the traffic and road condition variations in the city and highway areas. The traffic in the highway area is more homogeneous than the traffic in the city areas. Also, the roads in the city area are in much better condition than the highway area consisting of few or zero potholes and rough patches. The steady condition is obtainable in the highway area as there are less frequent acceleration and deceleration compared to the city area, which plays a vital role in the release of emissions. The variation in power requirement in vehicles in highway areas is mostly constant compared to city areas because of congestion in city areas.

4.2.1 CO emission

It was observed that CO emission was reduced to 44.08, 60.23, 71.76 and 42.97% for vehicles V1, V2, V3 and V4, respectively, as shown in Figure 10. This gas is the consequence of an incomplete combustion reaction, which occurs when the amount of oxygen available is inadequate to burn the raw material injected into the combustion system.



(a) (b)

(c) (d)

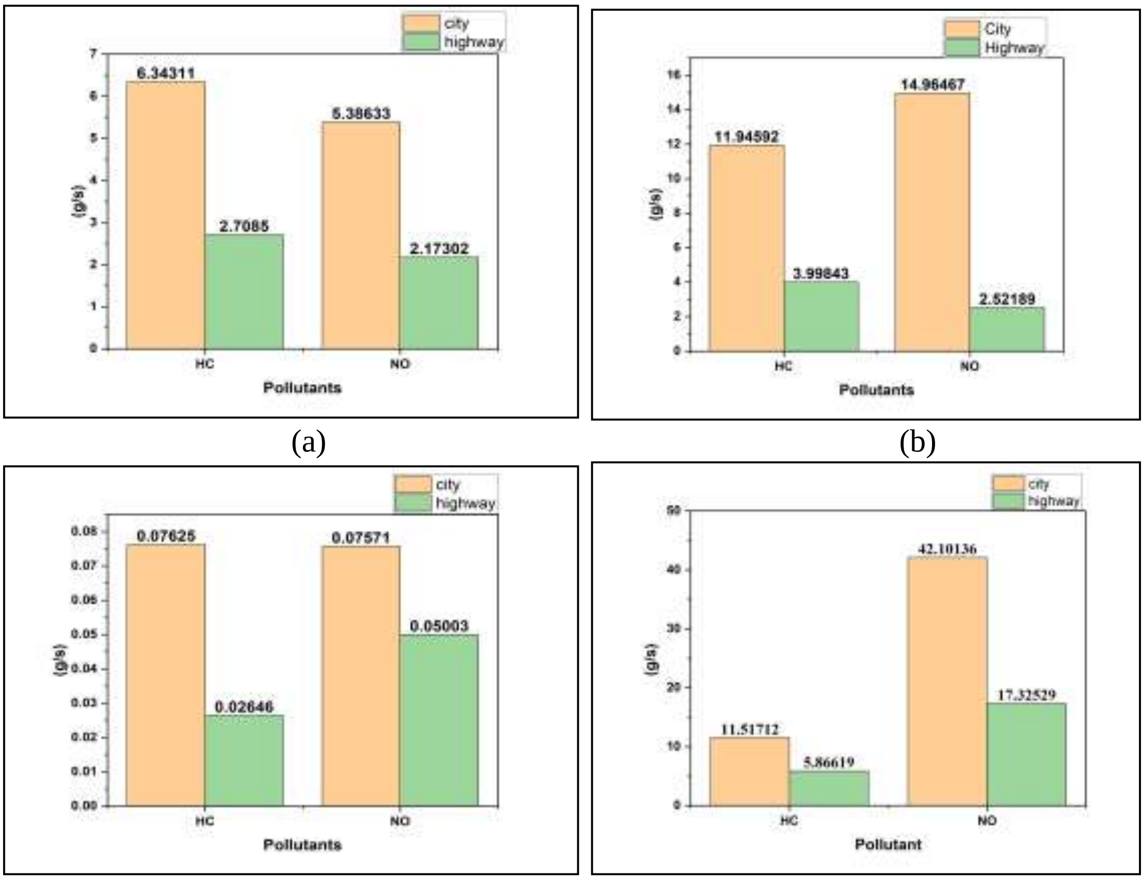
Fig. 10. (a) CO emissions from vehicle V1, (b) CO emission from vehicle V2, (c) CO emission from vehicle V3, (d) CO emission from vehicle V4

This gas also constitutes major exhaust gases that are released from vehicle tailpipes. Apart from the vehicle tailpipe, another important component in the generation of CO in gasoline engines is the chamber. In some regions of the chamber, there is a lack of oxygen, which encourages partial oxidation of the fuel, which is why designing chambers has always been a challenge and a constant area of research.

Due to the action of temperature, secondary oxidation might occur. CO generated by partial fuel oxidation can react with oxygen molecules in the cylinder's zones. In CO emissions, there are two primary pathways. The first is a rich mixture, and the second is inefficient combustion, which occurs when all of the hydrocarbon fuel is not entirely burned; for example, if the mixture does not reach equilibrium, partially burned fuel and incomplete oxidation would result in increased CO emissions. This is usually due to a variety of factors. The first reason is a lack of sufficient residence time, which prevents the equilibrium from being reached. The second cause is poor fuel/air mixing, which results in rich local patches with high equilibrium CO, which causes a lack of oxygen inside the mixing zone to be burned out.

4.2.2 NO and HC emission

It was observed that NO emission was reduced to 59.65, 83.14, 33.91 and 58.84% and HC emissions were reduced to 57.30, 66.52, 65.29 and 49.06% for vehicles V1, V2, V3 and V4, respectively, as shown in Figure 11.



(a) (b)

(c) (d)

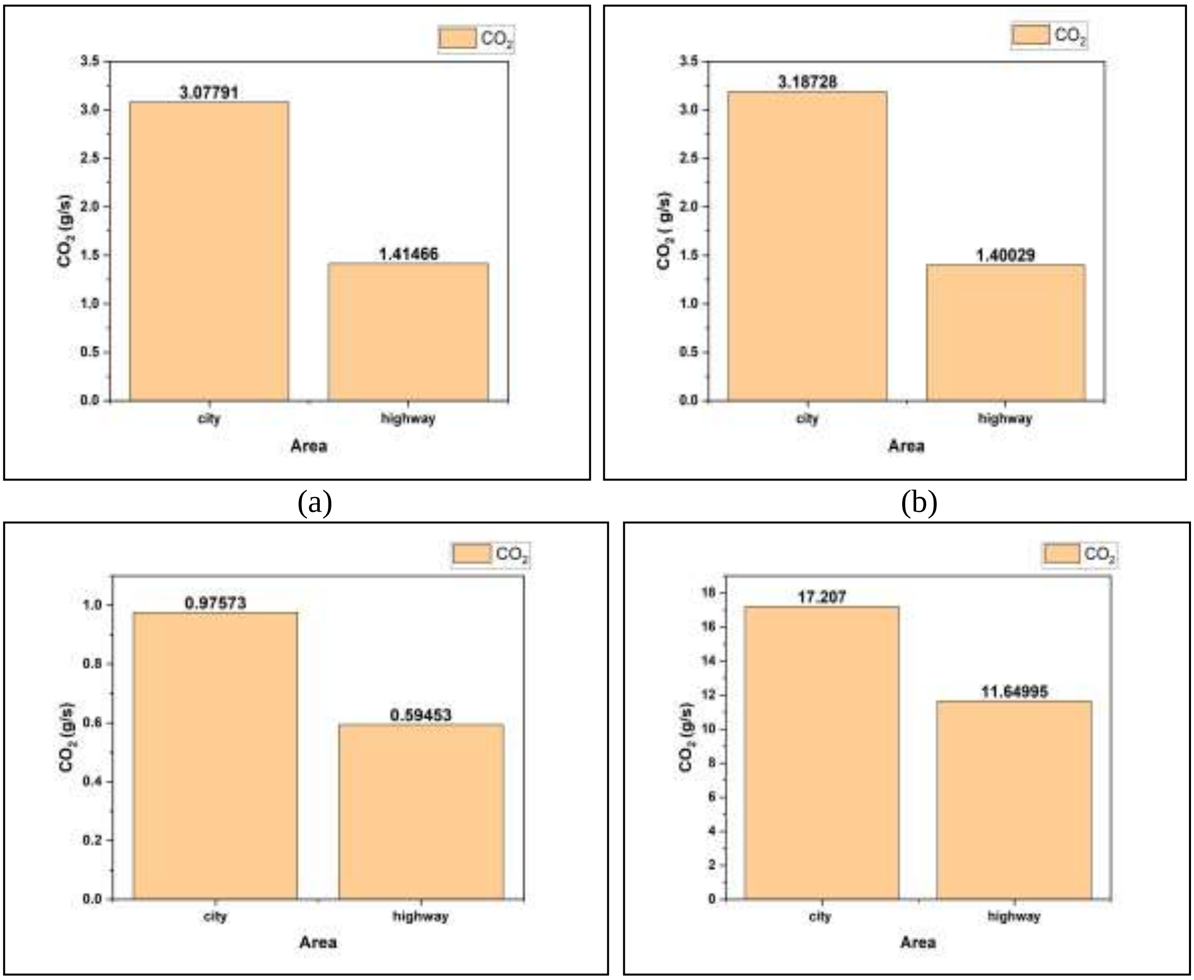
Fig. 11. (a) HC and NO emissions from vehicle V1, (b) HC and NO from vehicle V2, (c) HC and NO from vehicle V3, (d) HC and NO from vehicle V4

NO is created in the environment through a high-temperature (over 1600 degrees Celsius) chain reaction that starts with nitrogen and oxygen. An early burning mixture frequently creates more NO than a late burning mixture due to the higher temperatures at which it is compressed. NO is formed at the back of the flame, inside the area where the gas has been burned; it is also formed within the flame itself but to a lesser level.

The production of HC emissions is caused by a lack of air or a rich mixture during combustion. In the engine, an incomplete reaction results in the emission of unburned hydrocarbon. It is worth mentioning another source of hydrocarbon emissions at this point because it is considerable. Evaporation allows more volatile and lighter fuels, typically gasoline, to escape through the seals of a vehicle's fuelling system [25]. Secondary impacts such as global warming result from the emission of exhaust gases into the environment. Furthermore, hydrocarbons can combine with nitrogen oxide species to produce ozone molecules, a reaction that is catalysed by sunshine.

4.2.3 CO_2 emission

It was observed that CO_2 emission was reduced to 54.03, 56.06, 39.06 and 32.29% for vehicles V1, V2, V3 and V4, respectively, as shown in Figure 12.



(a) (b)

(c) (d)

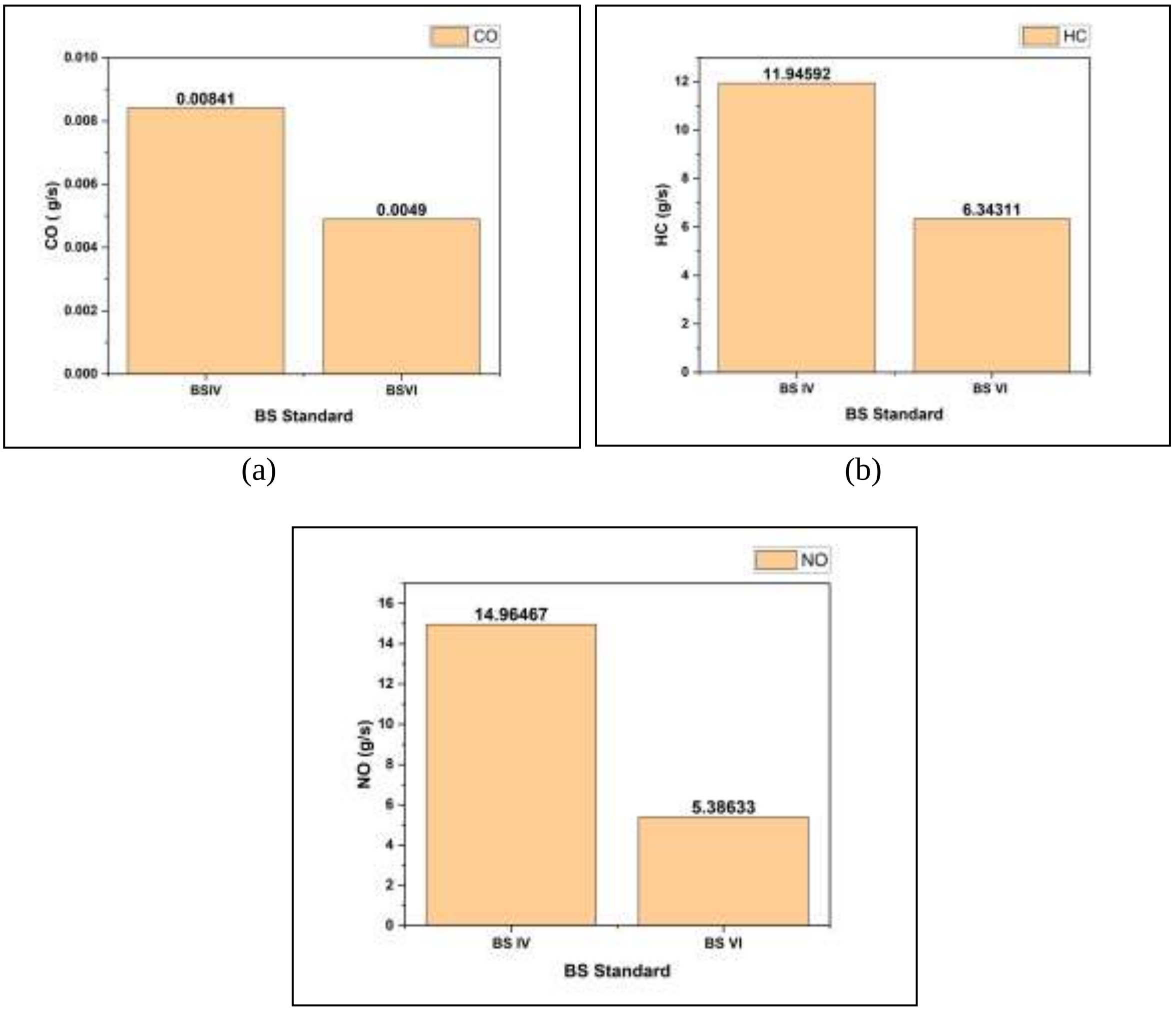
Fig. 12. (a) CO_2 emissions from vehicle V1, (b) CO_2 emission from vehicle V2, (c) CO_2 emission from vehicle V3, (d) CO_2 emission from vehicle V4

CO_2 is released as a result of the complete combustion of fuel. It is one of the greenhouse gases (GHG), and as fossil fuels are depleted, the amount of CO_2 produced rises, resulting in global warming. According to scientists, the global temperature will rise by 1 degree Celsius by 2030, affecting most agricultural patterns.

4.3. Comparison of emissions from BSIV and BSVI vehicles

The Indian Ministry of Road Transport and Highways (MoRTH) prepared a draft notification of Bharat Stage (BS) VI emission criteria for all major on-road vehicle categories in India on February 19, 2016. All light- and heavy-duty vehicles, as well as two- and three-wheeled vehicles, manufactured on or after April 1, 2020, were subject to the BS VI standards.

In this study, vehicles (V1 and V2) from the same company and of the same model but of different manufacturing years were used to find the reduction in emissions.

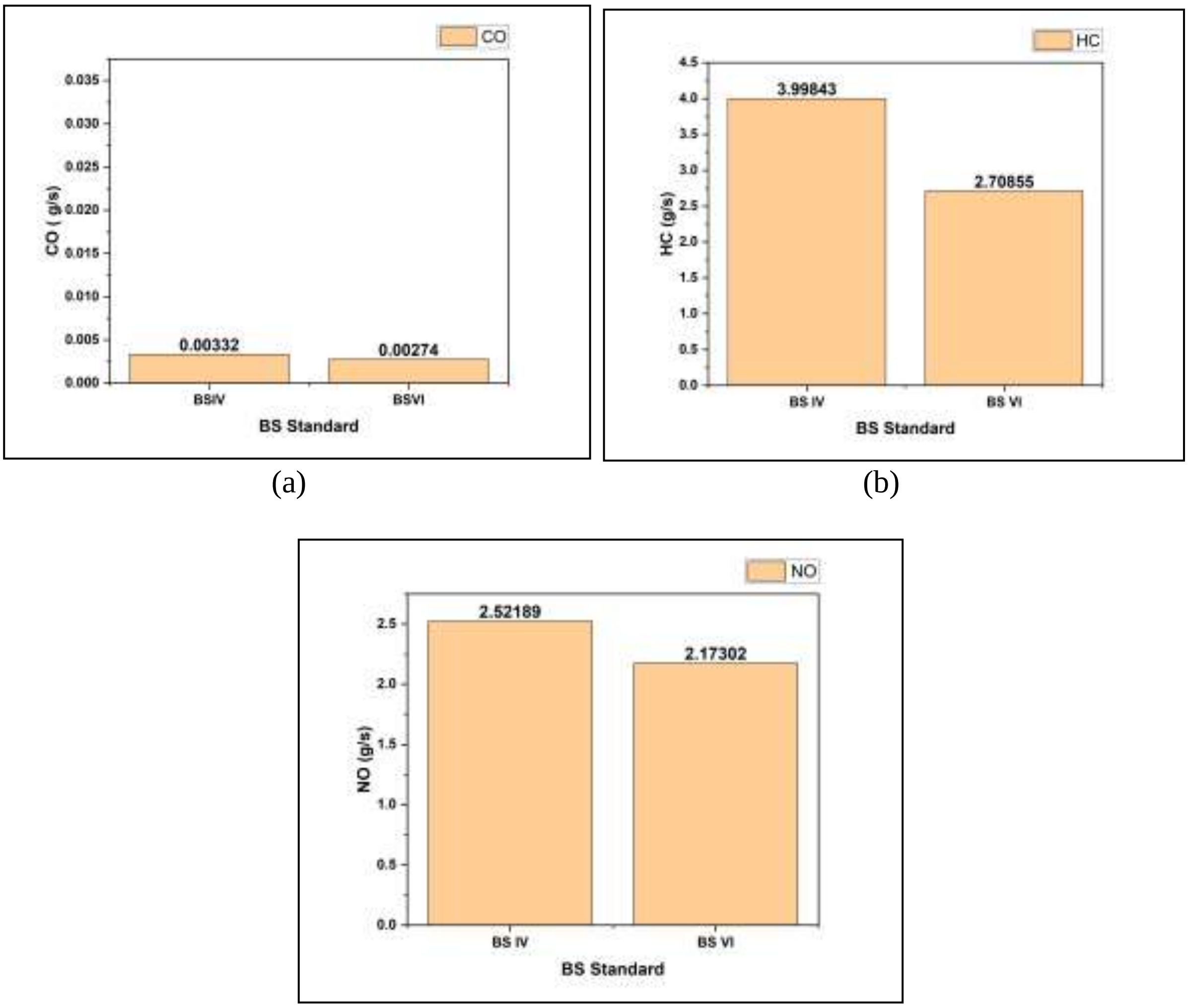


(a) (b)

(c)

Fig. 13. Emission measured for BSIV and BSVI vehicles in the city area:
(a) CO, (b) HC, and (c) NO

It was observed that there was a significant decrease in the emissions in the city area, whereas, in the highway area, the reduction in emissions was nominal compared to the reduction in the city areas. In the city areas, CO, HC and NO emissions were reduced to 41.73, 46.90 and 64%, as shown in Figure 13, whereas, in the highway areas, CO, HC and NO emissions were reduced to 17.46, 32.25 and 13.83%, as shown in Figure 14.



(a) (b)

(c)

Fig. 14. Emission measured for BSIV and BSVI vehicles in the highway area:
(a) CO, (b) HC, and (c) NO

The reduction observed is due to modification in engine design, optimization of power requirement by vehicle and modification in the catalytic converter. Also, the reduction of Sulphur content in the fuel is another reason for reduced emission. The Sulphur concentration in BS4 fuel is 50 parts per million; it is five times lower in BS6 fuel, which has a Sulphur value of 10 parts per million. Selective Catalytic Reduction (SCR) and Diesel Particulate Filter (DPF) were incorporated into the BSVI emission norms to analyse and reduce the emission levels of BS6 vehicles; however, this was not part of the BS4 emission norms.

4.4 Effect of speed on emission

Speed and emissions scatter graphs were plotted for the vehicles. It was observed that there are several peaks and variations in emission observed in the area for a particular speed range. In the city, the speed range was found to be 40-50 km/h, in which the highest values of emissions were observed, and the variation was also observed to the maximum, as shown in Figures 15, 16, 17 and 18.

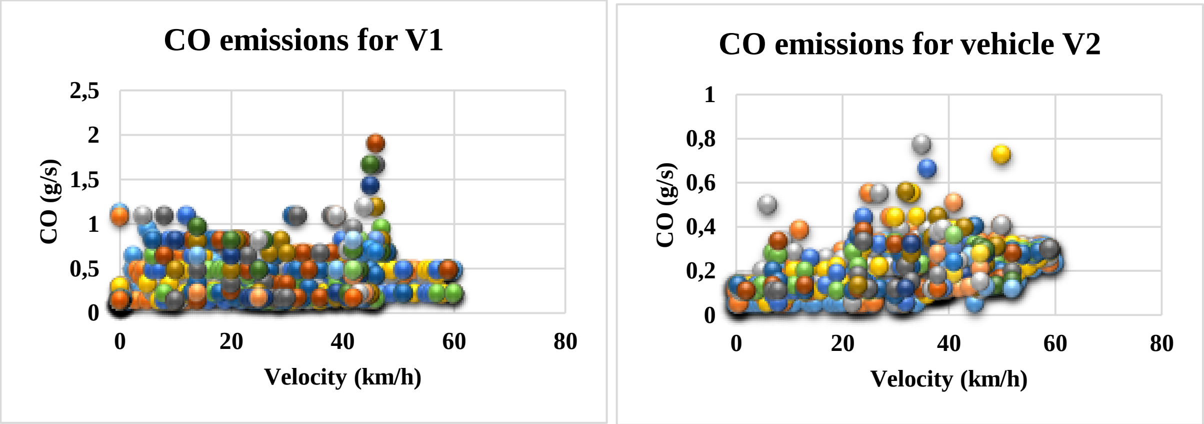


Fig. 15. CO emissions with speed scatter diagram of vehicles V1 and V2 in the city area

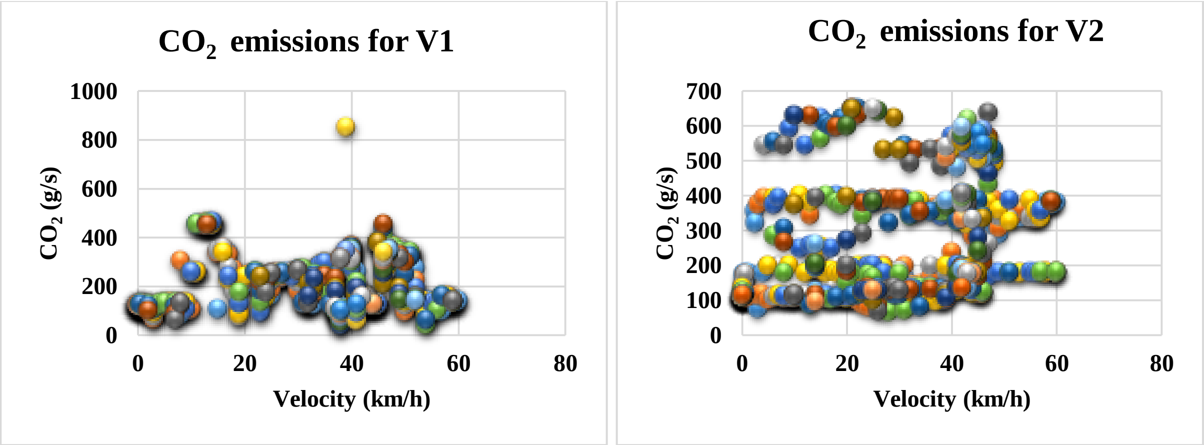


Fig. 16. CO$_2$ emissions with speed scatter diagram of vehicles V1 and V2 in the city area

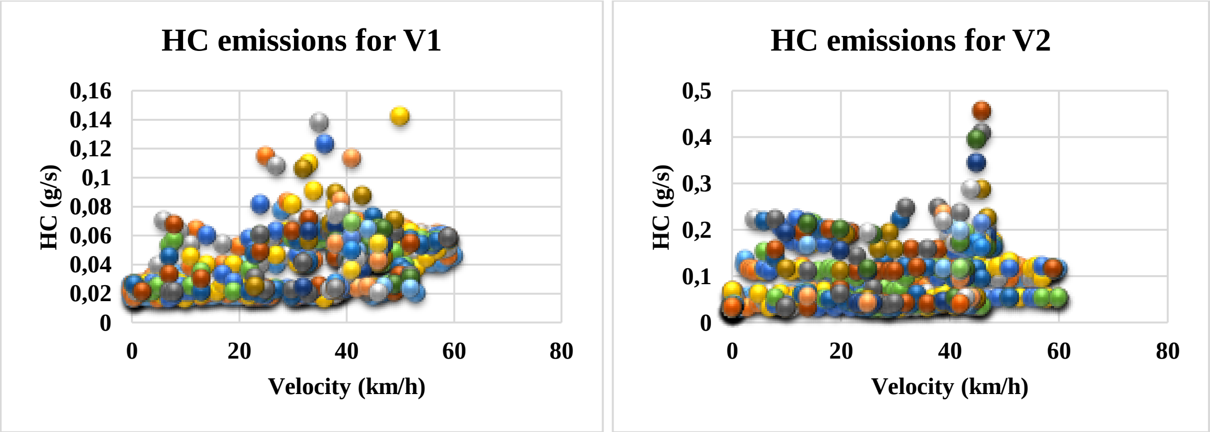


Fig. 17. HC emissions with speed scatter diagram of vehicles V1 and V2 in the city area

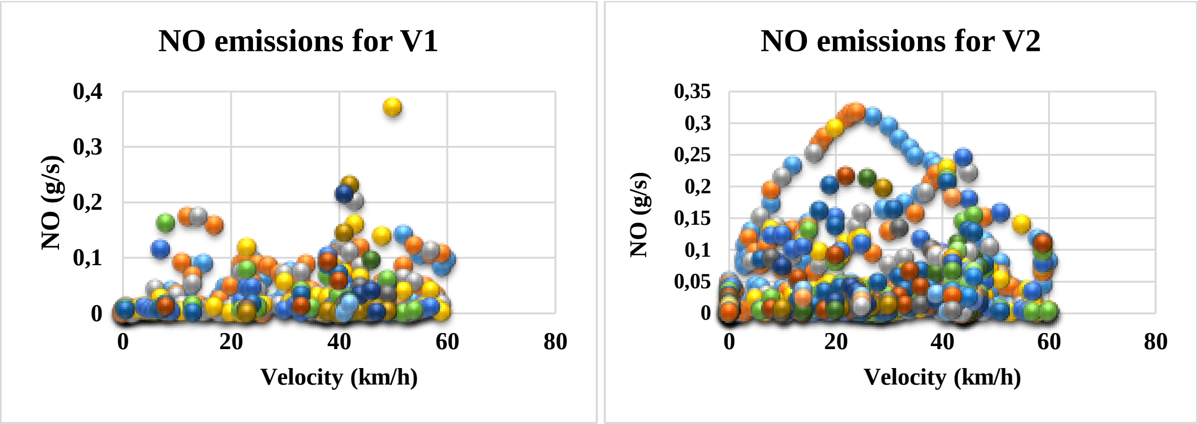


Fig. 18. NO emissions with speed scatter diagram of vehicles V1 and V2 in the city area

It is also suggested that in city areas, designing the traffic flow in such a way that there is free flow and vehicle speed is between 30-40 km/h would help in reducing emissions. In highway areas, there was a two-speed range in which peaks and variation were observed to be 20-30 km/h and 50-60 km/h, as shown in Figures 19, 20, 21 and 22.

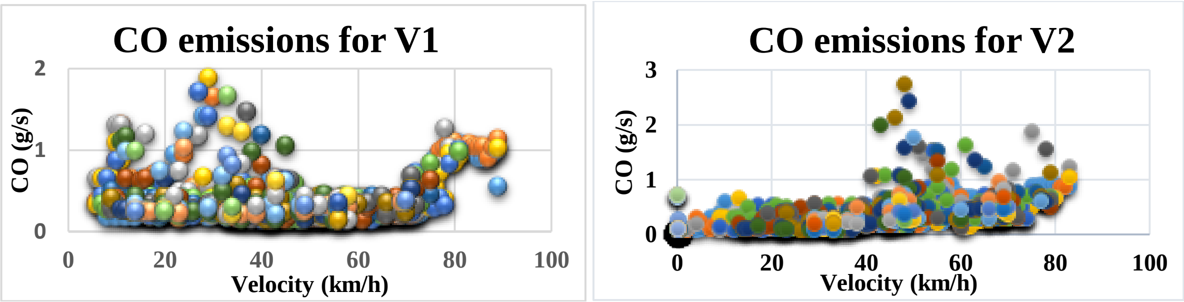


Fig. 19. CO emissions from vehicles on the highway area

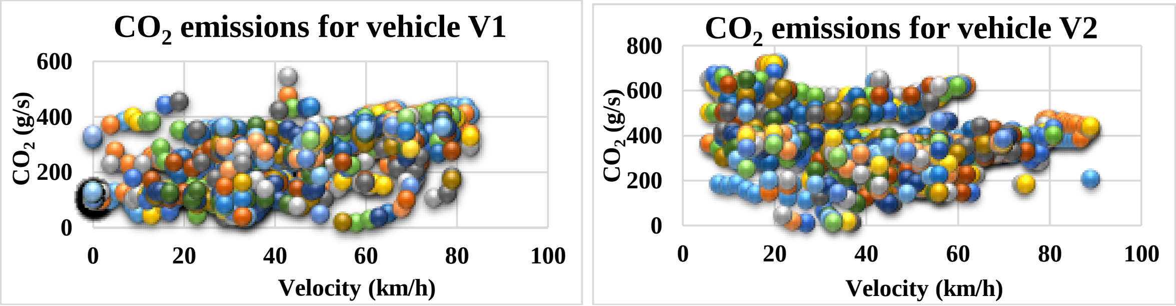


Fig. 20. CO_2 emissions from vehicles on the highway area

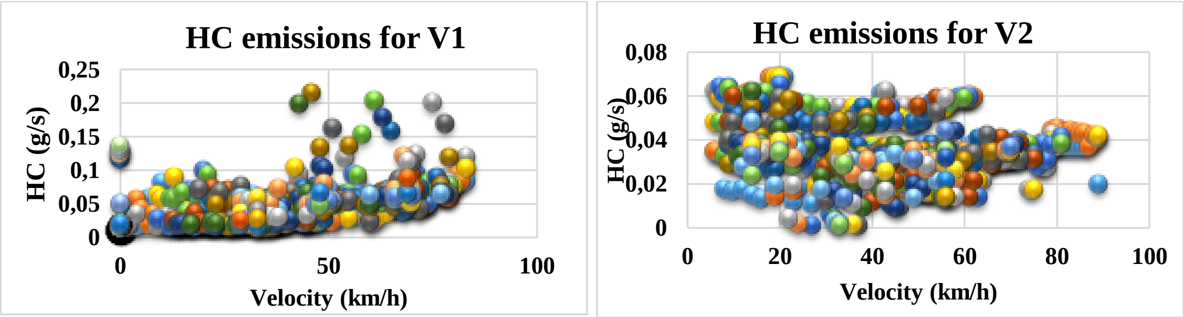


Fig. 21. HC emissions from vehicles on the highway area

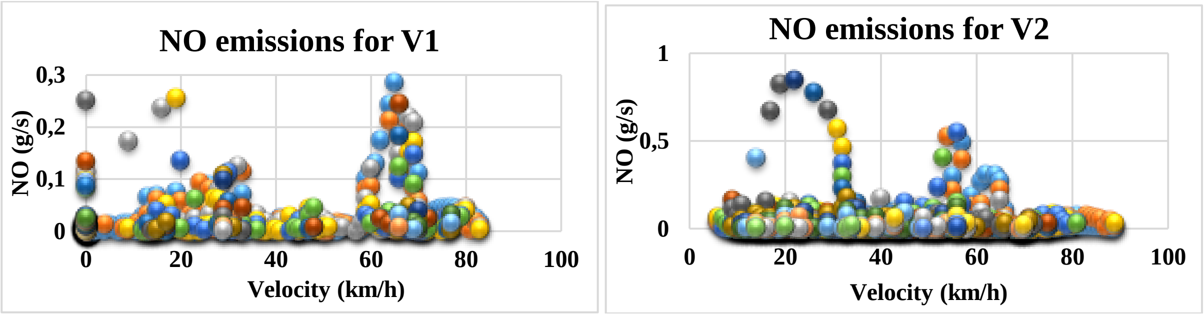


Fig. 22. HC and NO emissions from vehicles on the highway area

The optimum speed on the highway was found to be 80-90 km/h. During starting of the vehicle, the diesel vehicle emitted more pollutants than the petrol vehicle, which can be observed in Figure 23.

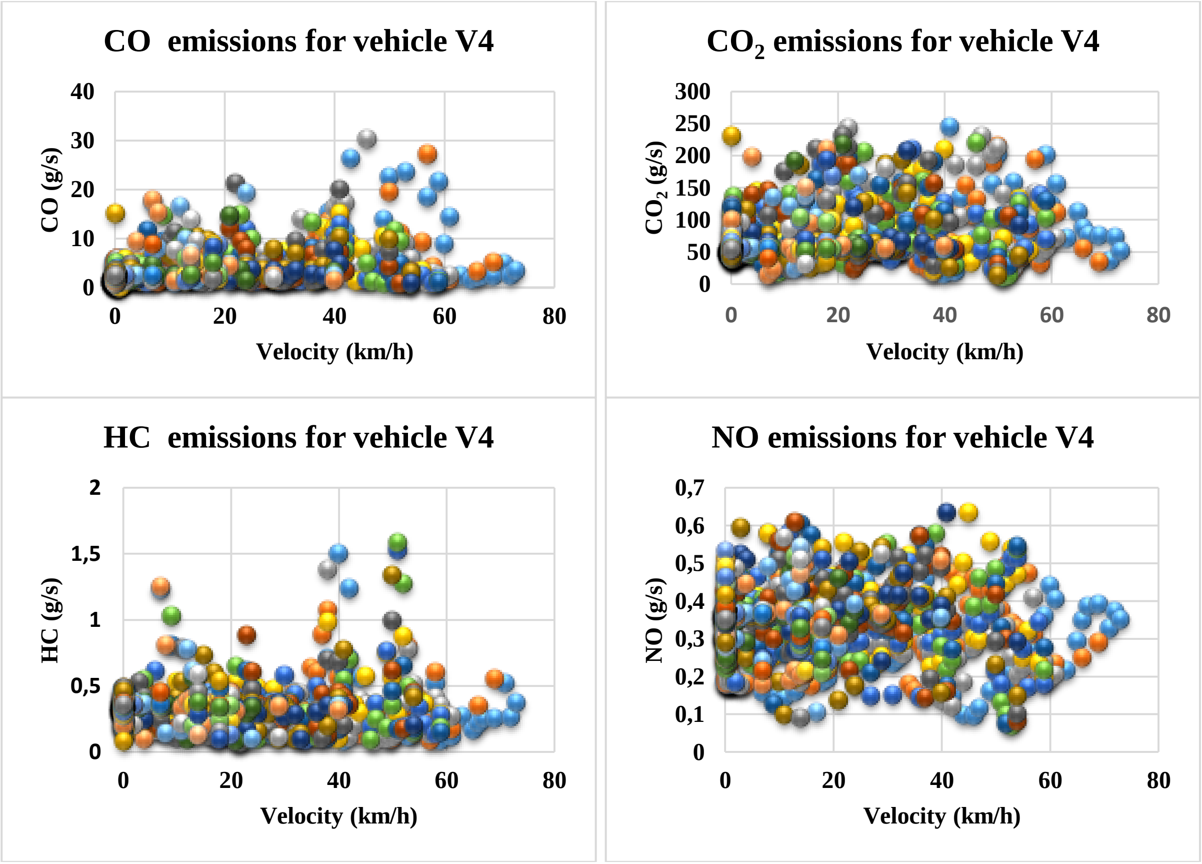


Fig. 19. Speed emission scatter graph for vehicle V4

5. CONCLUSION AND POLICY RECOMMENDATION

There is a need to upgrade the Modified Indian Driving Cycle as it does not reflect present driving conditions since real-world driving involves varied horsepower, average speeds, traffic congestion, road grades, and maximum acceleration rates compared to the authorized driving cycle. The emissions were reduced by 40 to 70% on highways compared to the city area. This is because of the steady driving conditions on the highways, whereas, in the city areas, there are frequent accelerations and decelerations. Compared to BS1V vehicles, the emissions in BSVI vehicles were found to decrease significantly in city areas, while in the highway areas, the reduction in emissions was nominal compared to the city areas. In the city areas, CO, HC, and NO emissions were reduced to 41.73, 46.90, and 64%, as shown in Figures 7 and 8, whereas in the highway areas, CO, HC, and NO emissions were reduced to 17.46, 32.25, and 13.83%. The reduction observed is due to modification in engine design, optimization of power requirement by vehicle, and modification in the catalytic converter. The reduction of the Sulphur content in the fuel is another reason for reduced emission. In the city, the speed range was found to be 40-50 km/h, for which the highest values of emissions were observed, and in the highway areas, there was a two-speed range in which peaks and variation were observed to be 20-30 km/h and 50-60 km/h. The peak and variation observed were due to sudden acceleration and deceleration and changes in the power demand of the vehicle.

The first recommendation will be the updating of the Modified Indian Driving Cycle as it was seen that they do not reflect present driving conditions. The new driving cycle should be more representative of real-world driving characteristics, such as higher speed and acceleration, than the current one. Instead of aggregating to a single driving cycle, it should discriminate between different types of roads and locales. Apart from standard driving cycles for a country or region, the driving cycle for local areas should be developed for a better understanding of emissions from the area and effective designing of traffic regulations. There is a need for strategies such as congestion mitigation, a technique that can be used for reducing severe traffic congestion, shock wave suppression techniques that eliminate acceleration and deceleration events, both of which are linked to the stop-and-go behaviour seen in crowded traffic, and permitting free flow and using traffic speed control strategies to reduce overly high free-flow speeds to more acceptable levels. The traffic in the city should be designed with proper synchronization of traffic signals so that homogenous conditions can be achieved. The speed breakers result in sudden deceleration and acceleration, leading to rising emissions; therefore, unwanted or illegally made speed breakers should be removed. A real-time Air Fuel Ratio indicator should be installed in vehicles so that the user can track the car’s performance and if it crosses a range that depicts some problem in the combustion chamber that would lead to higher emissions than normal therefore prompting the user to get the car serviced for a better life and performance. At the time of service, especially for taxi vehicles, the catalytic converter should be inspected and changed every 100,000 kilometres. Engine issues, such as misfiring, can elevate the temperature above 1400 degrees, causing the substrate to melt and the converter to fail. Also, the deposits of lead on the active substrate limit the surface area available for reaction, thereby reducing the efficiency of the catalytic converter. The government urgently needs to establish an independent regulatory body at the state and national levels to monitor the air quality levels and enforce standards/norms to protect the health of its citizen.

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