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On-Road Real Time Emission Characteristics of Diesel Vehicles in Delhi City

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ABSTRACT

Road Transport plays a significant role in contribution of Greenhouse gases and air pollutants in Delhi city. Despite lot of improvements in vehicle efficiency, the transport sector plays a major source of air pollution in India. It has been identified that the Diesel cars plays a pivotal role in emitting five times more respiratory suspended particulate matter and Nitrogen Oxide (NOx) than those run on gasoline fuel. On-road vehicle tests of eleven light commercial diesel cars were conducted on eleven days using AVL DitestAnalyzer, Onboard Diagnostic Reader (OBD). The total length of roads for the tests was 8.5 km. Data's were obtained for 32 samples of diesel car in a center spot of Delhi city. The driving mode impacts of idling, cruising, acceleration, deceleration on distance and emissions were analyzed. Results show that cars spend an average of 21% of the time in idling mode, 40% in acceleration mode, 36% in deceleration mode, and only 24% at cruise speed. The average emission factors of CO, CO2, total hydrocarbons (THC), and HC + NOx for the selected vehicles are 0.30 g/km, 85.7 g/km, 0.035 g/km, 0.36 g/km, 0.40 g/km. The vehicle emission rates vary significantly with factors like speed and acceleration. The test results reflect the current emission status of cars in Delhi city. The measurements clearly shows that the low speed conditions with frequent acceleration and deceleration significantly in congestion conditions of road traffic and signalized intersections are the main factors that aggravate vehicle emissions of HC and NOx. The aggravated vehicular emissions are higher than the legislative norms of Bharat Stage IV Standard and it is expected that the alleviating congestion, enforcing rules on speed limits and reducing the movement of vehicles on prominent spots of Delhi would reduce the HC and NOx Emissions while resulting in improving the fuel economy.

Key words: Diesel car, Driving characteristics, Exhaust emission, Traffic Congestion, On-road emission testing

1. INTRODUCTION

The Transport section is considered as an important source and contributor to air pollution and its health effects in urban areas; as of the whole, diesel emissions are worst and its effects on environment pose a great risk comparing petrol vehicles [1] due to unlimited control of NOx emission. Since 2000 India's vehicle population has increased dramatically with an average of rate of last two decades has increased up to 10% [2]. From 2000 year onwards, the vehicle registration is constantly increasing six fold times higher the vehicle population in 2000 (Figure 1). The vehicle pollution has become a major concern in polluting environment in metro-cities of India [3]. In order to develop strategies for mitigating vehicular emissions, research studies have been carried out in Delhi to strengthen the technical and legislative policies [4]. The vehicle emission simulation model has been used to study the vehicle emission characteristics for a sustainable greener transport system [5], and it has been feasible to create vehicle emission inventory by utilizing the model results [6]. To investigate the vehicular emission features of any Indian vehicle fleet before coming to the market, the emission testing is carried out mostly by chassis dynamometer where is efficiently carried out to frame the emission factors but those emission factors largely differs from the on-road real time driving conditions [6]. The vehicle driving cycle surveys are conducted in different Indian cities to assess the emission levels [7]. The research carried out in Light Commercial Vehicles (LCV) andHeavy Duty Commercial Vehicles (HDCV) carried out under actual driving cycle to classify the emission levels in association with the normal driving conditions according to BS IV emission standards [8].

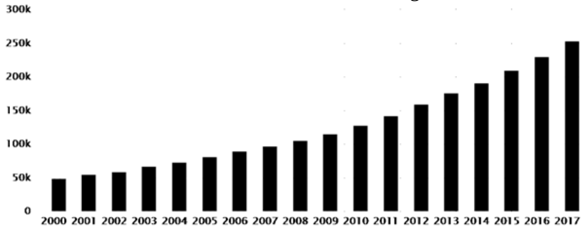


Figure 1: Total no. of Registered Motor Vehicles (Source: Ministry of Road Transport and Highways)

The on-road vehicle emission assessment by portable equipments under urban dynamic conditions [9] has proved that the method is unique in convenience and suitable to measure the emissions in reality. This method also proves that the urban transport plays a dominant role in cities mobilization and main source of environmental pollution. These research studies contributed to a lot to the comprehension of Delhi's air pollution due to vehicle. As Heavy Duty Commercialized Diesel Vehicles emitting more pollutants leads causing higher level of pollution in urban hot spots provoked the researchers to create more models with the intention of implementing strategies to reduce pollution including retrofit and alternative fuel technologies [10]. However, due to limitations of sophisticated equipment and technology, the research study in this paper mainly focused on Light Commercial Vehicles. The research in diesel engine cars focused on the combustion characteristics of diesel engines in relation to emissions of different diesel vehicles in appropriate driving conditions of real time. The real time exhaust emission measurement evaluates the automobile exhaust emissions to correlate with the effects of air pollution as well as framing new strategies and emission reduction control measures [11].

In order to understand well the environmental effects of diesel vehicle exhaust, we have applied on-board diesel vehicle emission testing equipment to do on-road light commercial diesel vehicle emission testing in Delhi city. In this way, we are able to generate data's for diesel exhaust emission in a dynamic traffic environment at Delhi comparing with BS IV standard in order to develop medium and long term emission control strategy for light commercial diesel vehicles, with broader implications for entire nation India.

1.1 Study Area and Test Driving

Experiments were carried out in Delhi via IIT Delhi Main road - outer ring road of Gamel Abdul Nasser Marg(urban highway of IIT Delhi) – VedantDesikaMandir Marg (arterial road) – ShaheedJeet Singh Marg (arterial road) – Sri Aurobindo Marg (arterial road) area – Outer ring road of Gamel Abdul Naser Marg (urban highway of IIT Delhi) – IIT Delhi Main road as shown in Figure 1.1. It is of approximately 8.5 km in length and is connected to various educational institutions such as IIT Delhi, Jawaharlal Nehru University etc., research labs, local market and residential areas. The composition of testing roads is similar to actual distribution of road classes in Delhi city. We actually selected eleven light dutycommercial vehicles for this research work, most of them under 5 years of service at the time of testing. The tested cars (Table 1.1) are of kind most frequently used in Delhi city and are representative of the city's vehicle fleet, since these types are come under the top ones sold in Indian NCR (National Capital Region) Market.

Figure 1.1: Route Mapfor on-road emission in real time driving condition at Delhi city

All vehicles tested in the study were tested in the same method for three trips per day to investigate the emissions in peak and off-peak hour. As the pre-cleaning methods in the set-up takes place at-least 1h30min for one trip, we have scheduled three times per day to assess the level of emissions in free flow and congested flow of traffic in Delhi city. It is noticed that the driving modes of acceleration, deceleration, idling, cruising will be different in peak and off-peak hour. It is observed that generally the HC and NOx emissions are higher and goes to the peak in higher speed of the vehicle.

Day.No	Manufacturer/Type of Car	Fuel Type	Engine capacity (cc)	Kerb Weight (kg)	Engine Power (KW)	Year of Manufacture	Vehicle Distance Travelled (km)
1	Toyota Etios 1.4 GD	Diesel	1364	1015	50	2015	80421
2	Maruti Swift Dzire	Diesel	1248	900	52	2015	289856
3	Maruti – Suzuki Ertiga	Diesel	1498	1235	68	2015	362252
4	Maruti Swift Dzire	Diesel	1248	910	55	2015	186839
5	Maruti Swift Dzire	Diesel	1248	920	55	2018	64345
6	Maruti-Suzuki Ertiga	Diesel	1498	1240	75	2015	192369
7	Maruti Swift Dzire	Diesel	1248	905	60	2017	64419 km
8	Maruti Swift Dzire	Diesel	1248	912	56	2015	290204 km
9	Maruti-Suzuki Ertiga	Diesel	1498	1220	70	2015	192938 km
10	Maruti Swift Dzire	Diesel	1248	900	58	2017	65036km
11	Maruti Swift Dzire	Diesel	1248	921	61	2015	290398 km

Table 1.1: Basic Information of the Cars selected for Emission Testing

1.2 Methods and Equipments

In this research work, we used AVL DitestAnalyzer with power backup connected with the vehicle through OBD (On-board Diagnostic Recorder) and exhaust tail pipe of a car with a probe attached to a tar tube with AVL setup instrument (Figure 1.2). The vehicle speeds were recorded by GPS Logger and vehicle parameters by Torque Pro connected with OBD (On-board Diagnostic Recorder) which can provide second by second data as well as vehicle location while it is moving. During pre-heating phase, the standard gases need to be checked and these gases are used to be in zero before start the real world emission testing. To investigate the temporal variations of vehicle emissions, second-by-second data on fuel consumption, air-fuel ratio and vehicle pollutant concentrations were collected. Figure 2.2 depicts a schematic diagram of emission test set up in a diesel vehicle.

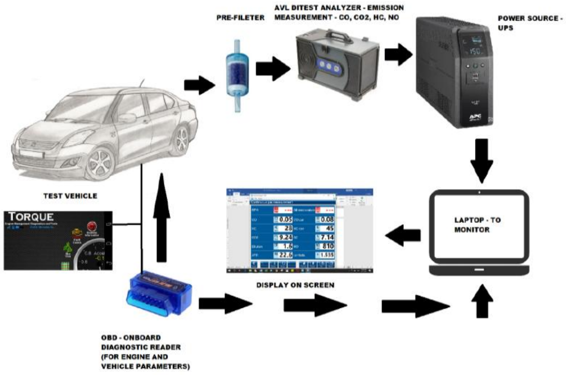
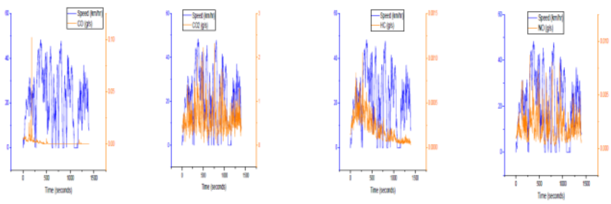


Figure 1.2: Schematic diagram of real world emission measurement system

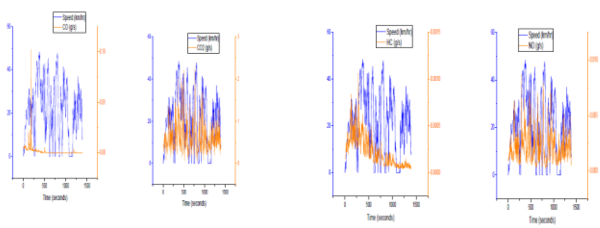
2. MEASURED RESULTS

2.1 Variation of Pollutant Concentration with Time and Speed

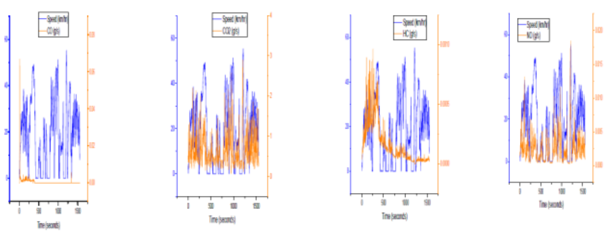
For the eleven light commercial vehicles selected for on-road emission testing 49,790 second-by-second data points (in total) were obtained consist of measurement of speed, exhaust gases of CO, CO_2, HC, NO concentrations and emission factors in peak and off-peak hour. The Vehicle Emissions are closely related to variation of speed and acceleration.



(i) Off-Peak hour on Day 1 – Sample 1



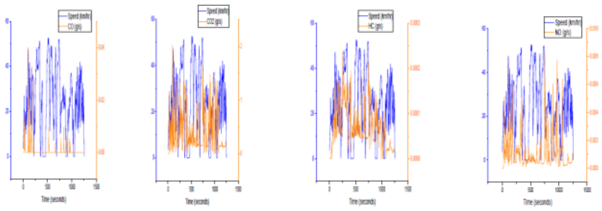
(ii) Off-Peak hour on Day 2 – Sample 2



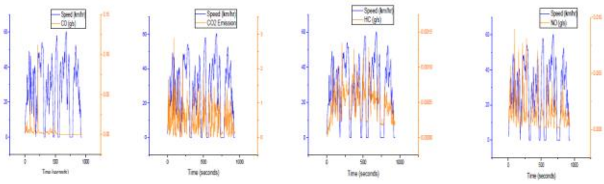
(iii) Peak hour on Day 1 – Sample 3

Figure 2.1 (a): Variation of Exhaust Pollutant Concentrations in Peak and Off-Peak hour on Day 1

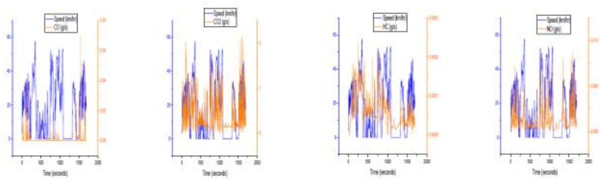
Real world driving conditions using PEMS (Portable Emission Measurement System) shows that there is a breaching in limit of Hydrocarbon and NOx emission in different driving modes in peak and off-peak hour. The above figure 2.1(a) shows the vehicle emits more emission to ambient air in peak hour due to constant low speed in congestion and idling in traffic intersections on road. Also it is noted that the sudden increase in vehicle speed emitting more emissions than comparing average speed in urban roads. The fluctuations in driving speed increases the pollutant concentration clearly shows the stark reasons behind the uneven pollution level of diesel engine contribution to the environment even if it is implemented with highly advanced technological emission control devices of modern day vehicles. The **figure 2.1 (b - k)** below shows the variation of Exhaust Pollutant Concentrations of reset of vehicles tested on-road real time exhaust emission characteristics.



(i) Off Peak hour on Day 2 – Sample 4

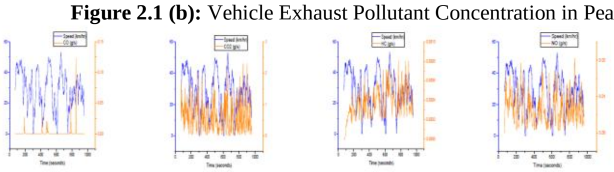


(ii) Off Peak hour on Day 2 – Sample 5

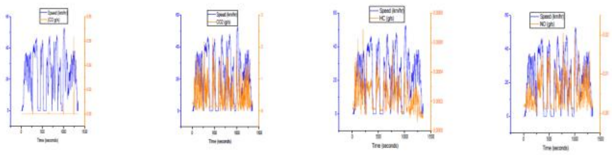


(iii) Peak hour on Day 2 – Sample 6

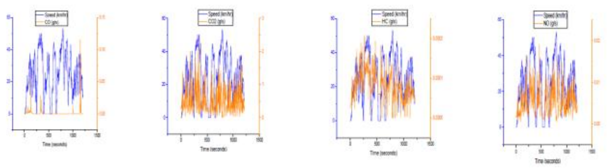
Figure 2.1 (b): Vehicle Exhaust Pollutant Concentration in Peak and Off-Peak hour on Day 2



(i) Off Peak hour on Day 3 – Sample 7

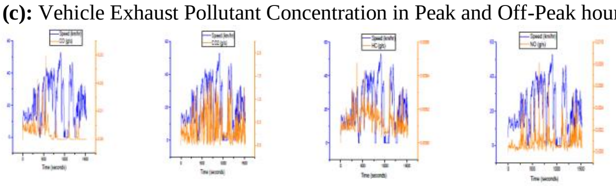


(ii) Peak hour on Day 3 – Sample 8

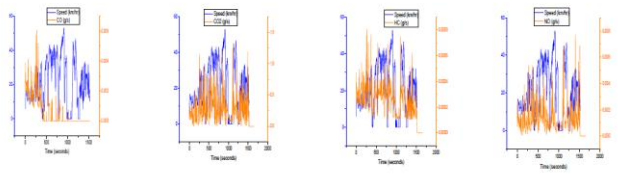


(iii) Peak hour on Day 3 – Sample 9

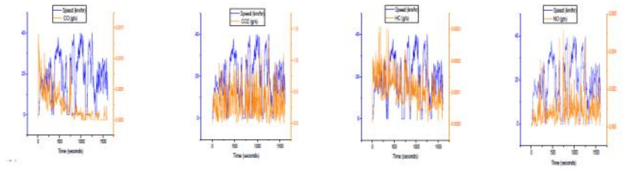
Figure 2.1 (c): Vehicle Exhaust Pollutant Concentration in Peak and Off-Peak hour on Day 3



(i) Off Peak hour on Day 4 – Sample 10

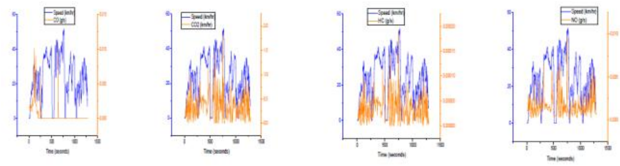


(ii) Peak hour on Day 4 – Sample 11

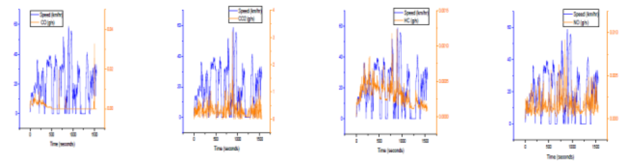


(iii) Peak hour on Day 4 – Sample 12

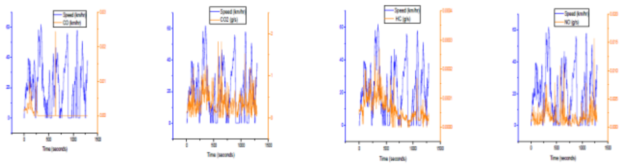
Figure 2.1 (d): Vehicle Exhaust Pollutant Concentration in Peak and Off-Peak hour on Day 4



(i) Off Peak hour on Day 5 – Sample 13

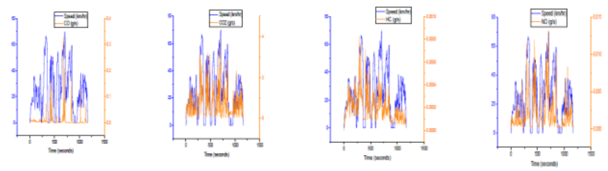


(ii) Peak hour on Day 5 – Sample 14

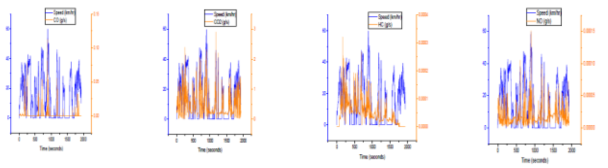


(iii) Peak hour on Day 5 – Sample 15

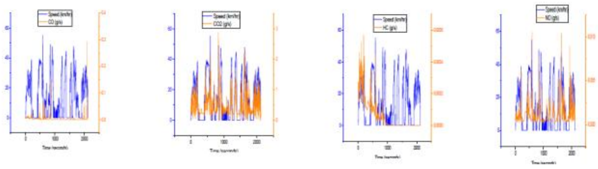
Figure 2.1 (e): Vehicle Exhaust Pollutant Concentration in Peak and Off-Peak hour on Day 5



(i) Off Peak hour on Day 6 – Sample 16

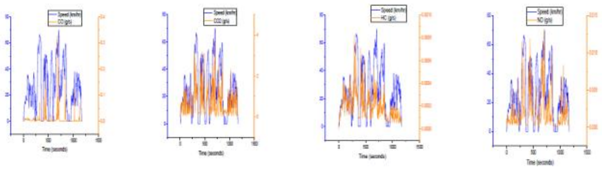


(ii) Peak hour on Day 6 – Sample 17

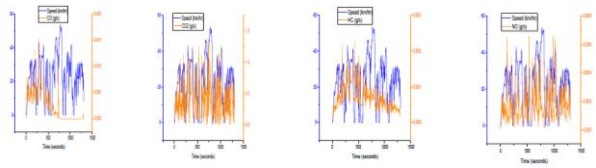


(iii) Peak hour on Day 6 – Sample 18

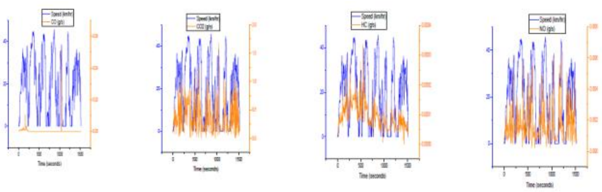
Figure 2.1 (f): Vehicle Exhaust Pollutant Concentration in Peak and Off-Peak hour on Day 6



(i) Off Peak hour on Day 7 – Sample 19

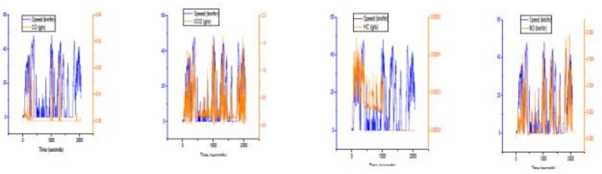


(ii) Peak hour on Day 7 – Sample 20

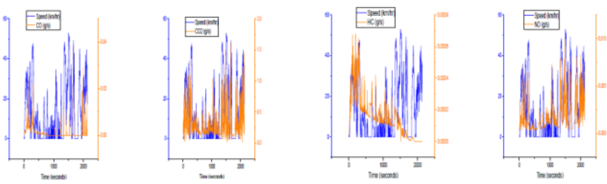


(iii) Peak hour on Day 7 – Sample 21

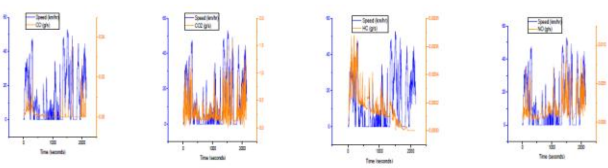
Figure 2.1 (g): Vehicle Exhaust Pollutant Concentration in Peak and Off-Peak hour on Day 7



(i) Off Peak hour on Day 8 – Sample 22

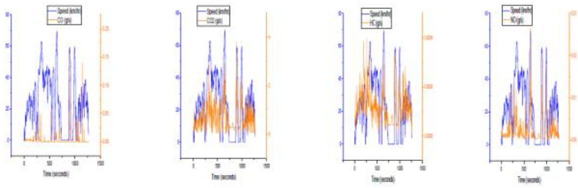


(ii) Peak hour on Day 8 – Sample 23

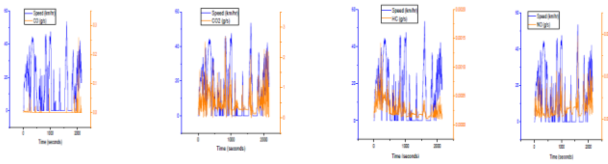


(iii) Peak hour on Day 8 – Sample 24

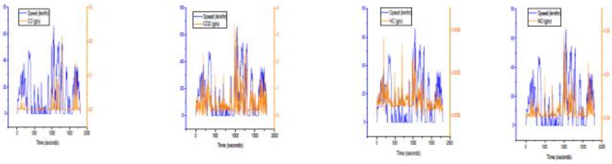
Figure 2.1 (h): Vehicle Exhaust Pollutant Concentration in Peak and Off-Peak hour on Day 8



(i) Off Peak hour on Day 9 – Sample 25

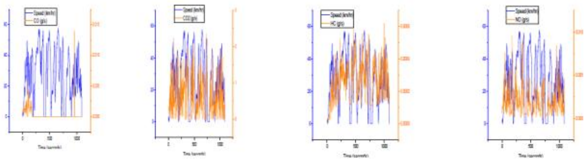


(ii) Peak hour on Day 9 – Sample 26

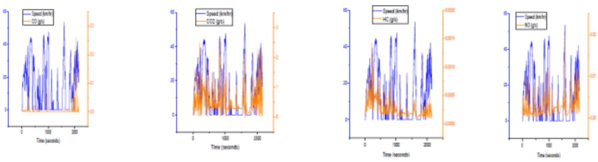


(iii) Peak hour on Day 9 – Sample 27

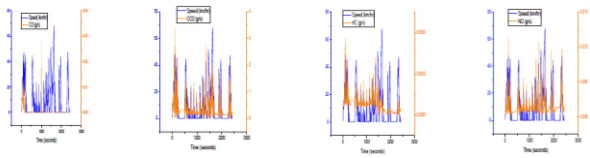
Figure 2.1 (i): Vehicle Exhaust Pollutant Concentration in Peak and Off-Peak hour on Day 9



(i) Off Peak hour on Day 10 – Sample 28

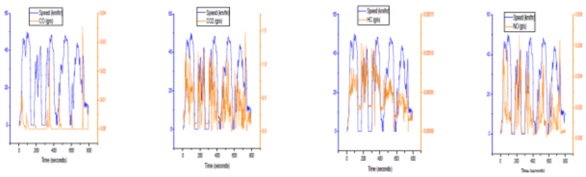


(ii) Peak hour on Day 10 – Sample 29

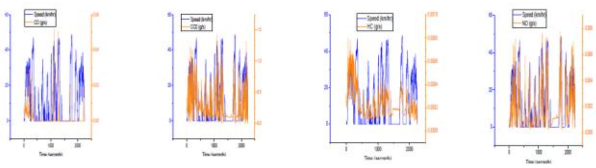


(iii) Peak hour on Day 10 – Sample 30

Figure 2.1 (j): Vehicle Exhaust Pollutant Concentration in Peak and Off-Peak hour on Day 10



(i) Off Peak hour on Day 11 – Sample 31



(ii) Peak hour on Day 11 – Sample 32

Figure 2.1 (k): Vehicle Exhaust Pollutant Concentration in Peak and Off-Peak hour on Day 11

From the above graphical representation the pollutant levels fluctuates abruptly in relation to its speed and the reason for the pollutant level is due to the uneven traffic condition as it elevates the more and more pollution when the vehicle creeps under variation of speed in the middle of traffic. Generally in off-peak hour, the pollution level spontaneously goes down than comparing peak hour as the number of vehicles moves in ease without congestion in their lanes. It is clearly shows that the even distribution of traffic network flow and constant speed level by avoiding rapid acceleration and deceleration may limit the pollutant concentration ejected out to the environment through tail pipe. In the pollutant concentration, the carbon monoxide (CO) is mostly produced due to incomplete combustion of fuel and this is due to either of the causes such as rich fuel mixture (excess amount of needed fuel) or restricted air supply (due to dirty or plugged air filter). As a consequence of these incomplete hydrocarbons in an ideal combustion process produces more carbon-dioxide (CO_2) and water vapor (H_2O). Unlike the spark-ignition engines where the combustible mixture is predominately homogenous, diesel combustion is heterogeneous in nature. In Diesel Engine the diesel fuel is injected into the cylinder filled with high temperature compressed air. Emission is formed as a result of burning this heterogeneous air-fuel mixture depend on the prevailing conditions not only during combustion, but also during the expansion and especially prior to the exhaust valve opening. Mixture preparation during ignition delay, fuel ignition quality, residence time at different concentration of the different emission species in the exhaust is the result of their formation, and their reduction in exhaust system. Incomplete combustion products formed in the early stages of combustion maybe oxidized later during the expansion stroke. Mixing of unburned hydrocarbons with oxidizing gases, high combustion chamber temperature, and adequate residence time for the oxidation process allows more combustion. In most cases, once nitric oxide (NO) is formed it is not decomposed, but may increase in concentration during the rest of the combustion process if the temperature remains high.

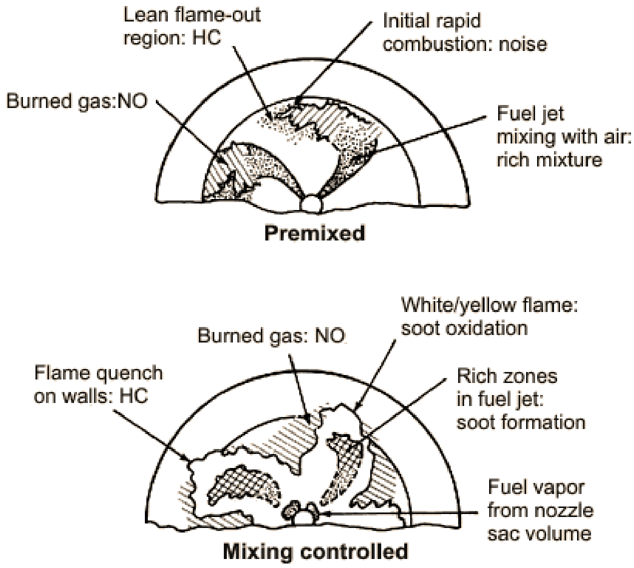


Figure 2.1 (l): Basic pollutant formation mechanism in DI (Direct Injection) Combustion System [12]

The above pollution formation mechanism is discussed as every diesel cars under the variation of DI (Direction Injection) in its specific type. The emissions formed during the heterogeneous air/fuel mixture depend on the conditions during combustion and expansion stroke as well as prior to exhaust valve opening. The reasons for the NOx emission are due to number of mechanisms during both pre-mixed and diffusion burning as well as poorly maintained EGR (Exhaust Gas Recirculation) valve.

3 RESULT ANALYSES AND DISCUSSION

The table 3 below shows the analysis of the average contributions of the eleven light commercial vehicles (LCV) on eleven days to time, speed, driving modes and emission factors during peak and off-peak hour. The average maximum speed followed is 54.46 km with the average distance of 8.5 km in 1550.34 counts on the entire vehicle fleet on eleven days. The average Idling, Acceleration, Deceleration and Cruising of the vehicle occupies 21.3%, 39.9%, 35.9% and 23.6% respectively in the average time scale of 353.18 s, 513.84 s, 455.87 s and 233.03 s. The Emission factors of CO, CO_2, THC, NO varies significantly with vehicle speed and its distance are 0.30 g/km, 85.7 g/km, 0.035 g/km, 0.36 g/km.

Day	No. of Samples	Duration (s)	Max. Speed (km/h)	Avg. Emission factor (g/km)				% Idling	% Acceleration	% Deceleration	% Cruising	Idling (s)	Acceleration (s)	Deceleration (s)	Cruising (s)
				CO	CO2	HC	NO								
1	1	1396	48	0.2193	101.21	0.0344	0.3437	11	37.6	32.6	18.8	153	525	455	263
	2	1396	48	0.2243	103.51	0.0352	0.3515	40.1	123.9	118.2	149.2	154	466	409	367
	3	1556	50	0.1108	139.83	0.035	0.4902	40.1	123.9	118.2	149.2	334	495	423	304
2	4	1251	50	0.3971	73.281	0.0569	0.2135	10.2	40	32.2	17.6	128	500	403	220
	5	935	52	0.3133	65.991	0.062	0.1931	12.2	38.9	31.2	17.6	114	364	292	165
	6	1695	60	0.1786	79.58	0.0126	0.2679	30.4	31.4	26.4	11.8	515	532	448	200
3	7	888	58	0.1297	72.744	0.0445	0.8028	1.7	41.8	41.1	15.4	15	371	365	137
	8	1351	52	0.0245	77.87	0.0344	0.7662	16	36.4	34.6	13	216	492	467	176
	9	1210	58	0.1892	76.844	0.0117	0.7742	7.4	41.3	36.1	15.2	89	500	437	184
4	10	1350	57	0.3167	56.189	0.0175	0.1459	10.6	34.9	34.8	19.7	162	534	532	302
	11	1525	55	0.0991	47.749	0.0438	0.223	10.6	35	34.9	19.5	162	533	532	298
	12	1612	40	0.4058	62.188	0.0188	0.1524	10	34	33.6	22.5	161	548	541	362
5	13	1291	52	0.0728	52.712	0.0052	0.2502	7	38.3	33.7	21	90	495	435	271
	14	1551	60	0.181	60.194	0.0554	0.2917	17.2	33.8	29.3	19.7	267	524	455	305
	15	1291	60	0.0951	63.439	0.0109	0.3078	15.9	39	29.5	15.6	205	503	381	202
6	16	1166	70	1.0416	101.72	0.0271	0.2705	12.4	39.5	33.4	14.7	145	461	389	171
	17	1931	60	0.4588	112.3	0.0114	0.0043	32.3	29.8	27.9	9.9	624	576	539	192
	18	2125	58	0.7759	121.14	0.0154	0.3079	33.9	28.9	25.5	11.7	720	614	542	249
7	19	1292	50	0.0727	52.691	0.0053	0.2498	7	38.4	33.6	21	91	496	434	271
	20	1305	55	0.3558	57.966	0.1043	0.2607	9.3	37.7	32.1	20.8	122	492	419	272
	21	1522	40	0.0553	64.358	0.0167	0.2868	16.4	36.9	31	15.8	249	561	472	240
8	22	2062	50	0.1586	82.432	0.0235	0.3771	33.3	28.9	25.8	12	687	595	533	247
	23	2135	50	0.3164	82.056	0.0396	0.4707	32.8	29.6	25.3	12.3	700	632	540	263
	24	2155	52	0.1997	89.546	0.001	0.3925	30.6	29.7	28.1	11.6	660	640	606	249
9	25	1271	55	0.4454	97.212	0.0169	0.324	18.6	35.6	31.6	14.2	236	453	402	180
	26	2155	58	0.6113	132.97	0.0665	0.6572	38.1	27.6	22.9	11.4	822	595	493	245
	27	1807	65	1.028	113.54	0.0153	0.3906	28.1	28.9	26.5	16.4	508	523	479	297
10	28	1092	58	0.0366	74.192	0.0333	0.2422	8.2	44	34.9	13	89	480	381	142
	29	1836	60	0.3032	87.068	0.1603	0.4548	33.1	30.3	27.8	8.8	607	557	511	161
	30	2420	64	0.1164	116.41	0.018	0.4765	50.4	21.7	21	6.9	1220	525	508	167
11	31	797	50	0.1367	56.538	0.0065	0.2129	12.9	34.3	32.7	20	103	273	261	159
	32	2242	48	0.3617	166.94	0.0567	0.5669	42.6	26.2	22.5	8.7	954	588	504	196

Table 3: Emission Characteristics contribution of Light Commercial Vehicles (LCV) to the Time, Speed, Driving modes and Emission Factors

Fuel	Emission Standard	CO (g/km)	PM (g/km)	HC (g/km)	NO (g/km)	HC +NO (g/km)
Gasoline	BS -IV	1		0.1	0.08	-
Diesel	BS-IV	0.5	0.025	-	0.25	0.3

Table 4: Bharat Stage IV Emission Standard

From the above table 3, it is clear that the vehicular emissions are aggravated in HC and NOx comparing with Bharat Stage IV emission standard (Table 4). The main reasons for the aggravation of emissions is due to fluctuating low speed conditions and sudden acceleration and deceleration in an uneven flow of heavy traffic in Delhi city. Even though the induction of modern pollution control strategy the traffic congestion undoubtedly a menace to the environmental toxic pollution through progressive reduction in traffic speed in ensue of this to increase the journey time, fuel consumption, other operating cost and environmental pollution as comparing uninterrupted traffic flow [13]. In Delhi city, the traffic congestion is mainly due to intensive use of automobiles whose proprietorship has goes on massive rate in the recent decades. The privately owned commercial vehicles have lot of advantageous for facilitating their personal mobility, sensational security and improvement in status in most of the developing countries like India. In the way of efficient means of passenger transport, the opposite side effects of pollution are caused by using the light commercial vehicles on average rush hours each occupant of the passenger car causes about 11 times as much as congestion as a passenger on a bus [13].

When considering the highway speed and air quality it is easy to understand that the car burns more fuel in high speed but the reality is that the car burns most of the fuel at the time of acceleration to speed up against the wind resistance on road. The constant breaking of stop and creeping traffic burns more gas and hence it pumps out more pollutants in to the air [14]. In Delhi city the relationship between driving speed and pollution is non linear and the emission starts to go high when the average speed is below 45 km and these problems will be solved if the new rules and regulations enacted to keep the cars and other vehicles in a separate lane to reduce the volume of traffic with a permitted constant speed limit to be followed in city zones.

More over raising the emission regulation standard from BS (Bharat Stage) IV to BS (Bharat Stage) VI may alleviate the level of vehicular pollution; the technology of Selective Catalytic Reduction (SCR) unit will be implemented in BS VI diesel engines which converts nitrogen oxide (NOx) into Diatomic nitrogen and water (both are not toxic) with the aid of catalyst [15]. The SCR unit uses a diesel exhaust fluid named as Adblue which is made up of two parts such as urea and de-ionized water, where the urea is to be converted to ammonia and carbon-dioxide whenever the exhaust gas come into contact with the Adblue fluid and in turn, the ammonia converts NOx in to nitrogen and water vapor, thereby reducing pollutants.

Effective strategies in public transit and smart driving can be helpful in mitigate the impact on air quality as well as improving the efficiency of our high way network by reducing uneven stop and interrupted flow of traffic [14]. So the Government of Delhi has to take care of the needs of people movements by increasing the people carrying capacity of vehicle by nullifying the vehicle carrying capacity on roads for alleviating the free movement of traffic on this existing roads of Delhi with the implementation of efficient schemes in traffic flow and enhancing the public transportation facilities by introducing more door to door connectivity and discouraging the use of private vehicles through enactment of high road and congestion tax, parking charges and high penalty in breaching traffic rules at Delhi city. The introduction of radar based monitoring with the help of Artificial Intelligence (AI) can able to track and collect the traffic pattern, volume of traffic en-route, breaching limit and other factors would be used as a powerful tool to ensure the smooth flow of traffic on-road. Henceforth it is duty of the Delhi Government and Delhi police to focus on strict enforcement of traffic rules to ensure the road discipline to alleviate the traffic congestion a primary cause of polluting the environment.

4 CONCLUSIONS

The research work presents the On-road real time emission characteristics of light commercial diesel vehicles in Delhi city by focusing on driving patterns and emission factors. In comparison to laboratory measurements of chassis dynamometer, this research work reflects the real world emissions from actual light commercial vehicles on real roads under typical driving operational modes. These measurements are important for improving our knowledge of diesel emission vehicles in Delhi city. Based on more than 45,000 concurrent measurements of speed, acceleration, distance and pollutant emissions, we conclude that:

(1) The average vehicle speed is 21km/hr on test drive roads in most of the time. The average speed in the test drive is low for most of the cases since the test routes in Delhi city are packed up with large volumes of traffic. Therefore it not appropriate to compare this result with the constant high or average speed driving emission characteristics. Anyhow the results do reflect the real world emissions of light commercial diesel vehicles of Delhi city under distinctive vehicle operation modes. The results of this study could be transferred to other Indian cities and to high exposure situations, if the traffic conditions are similar to that in Delhi.

(2) The emission rates of CO, CO_2, THC and NOx are different at different speeds even under the same of rate of acceleration. The results shows that the fluctuation of low speed and frequent acceleration are the main causes of high emission levels and therefore it widely believed that strengthening traffic management may provide a positive solution of alleviating traffic and pollution.

(3) The Average Emission factors of CO, CO_2, THC, NO varies significantly with vehicle speed and its distance are 0.30 g/km, 85.7 g/km, 0.035 g/km, 0.36 g/km.

(4) Moreover it is anticipated that the NOx emissions from the diesel engines are important as they tends to undergo in a chemical reaction in the atmosphere leading to the formation of $PM_{2.5}$ and ozone. The solid type pollutant emitted from the diesel engine exhaust is known as Diesel Particulate Matter (DPM). The DPM is less than 1µm in diameter about $1/70^{th}$ diameter of a human hair composed of carbon particles (known as black carbon) but due to the limitations of our equipment and method, we were not able to measure the emissions of $PM_{2.5}$ in this study. This will be the scope of our future research and our study approach is also certainly applicable to gasoline cars.

(5) With the rapid development of economy in India, the number of motor vehicles growing very rapidly and act as a greatest contributor to the air pollution in metro cities of India. Our study shows that the irregularly maintained traffic, failure in enforcement of traffic rules and un-predictable congestion in Delhi city areas which exacerbated the urban air pollution. If this condition prevails, it will jeopardize the existing traffic network aggravating pollution in an inevitable situation. Even with the induction of BS VI emission standard, it is highly expected that the traffic pollution will not be controlled unless the better traffic management and stringent rules are practiced with full scale implementation in Delhi city. All the above, the public cooperation with Delhi Government and Delhi Police is vital to induce the norms to enforce in real world situation in Delhi city in order to abate and mitigate the vehicular pollution.

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