Vehicular Air Pollution Modeling For Diesel Driven Vehicles

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Abstract--- Pollution in air is generated by the developments, which typically occur as the country gradually shifts towards industrialization, due to city growth, increasing traffic, rapid economic development, and higher levels of energy consumption. Indian cities are among the most polluted cities in the world. The main source of air pollution in Indian metropolitan cities is petrol and diesel driven vehicles. They particularly emit CO, CO_2, HC, NO_X and O_2. The growing vehicular population has resulted in increased air pollution, which in turn has affected the people's health, who live along the transportation corridors. Increase in vehicular population, has resulted in decrease in quality of air and the environment. There are several health impacts that are associated with respiratory infections, asthma etc,. A number of studies have been done by the foreign countries, but this is not suitable for the Indian cities. This may be due to heterogeneity of vehicles, multiplicity of modes and the difference in geometrics of road. Therefore the need arises to study about the emission rates. In this study, equipment by the name five gas analyzer is used to find out the emission rates of different types of vehicles under static and dynamic conditions. The factor considered under static conditions is the age of the vehicles. Whereas under dynamic condition factors considered are the road roughness, age of the vehicle and speed. From the emission rates a linear regression model is developed using SPSS software and sensitivity analysis is being carried out.

Keywords--Carbon Monoxide (CO), Nitrogen Oxides (NO_x),Hydrocarbons (HC), Roughness, Five gas Analyser.

I. INTRODUCTION

Pollution in air is generated by the developments, which typically occurs as the country gradually shifts towards industrialization, due to city growth, increasing traffic, rapid economic development, and higher levels of energy consumption.

Indian cities are among the most polluted cities in the world. The main source of air pollution in Indian metropolitan cities is petrol and diesel driven vehicles. These vehicles are consuming huge amounts of petrol and diesel for which the country has to pay in foreign exchange. Vehicular emissions contain sulphur dioxide (SO_2), Nitrogen Oxides (NO_x), Carbon Monoxide (CO), particulate matter (PM) and other products of combustion.

The growing vehicular population has resulted in increased air pollution, which in turn has affected the people's health, who live along the transportation corridors. More than 200 studies conducted in different parts of the world have shown a significant and consistent association between diesel emissions and increased deaths and cardio respiratory illness such as heart attacks and strokes, allergies, asthma, bronchitis and respiratory track infections. Short term exposure to diesel exhaust has been shown to produce various damaging effects on the respiratory track, while chronic high exposure has been linked to a significantly increasing risk of developing lung cancer. Hence, it was decided to undertake a study to find out the level of pollution that comes out of vehicle exhaust of diesel driven vehicles.

II. OBJECTIVE

- To find out the level of emission of vehicles under static and dynamic conditions.
- To find out the level of emissions by considering the age of the vehicle, speed of the vehicle and roughness level of the roads
- To develop the model and to conduct sensitivity analysis.

III. STUDY METHODOLOGY

The emissions coming out from the diesel vehicle exhaust such as CO, CO_2, HC, NO_x and O_2 was measured by using five gas analyzer. These measured emission rates were compared with the standards.

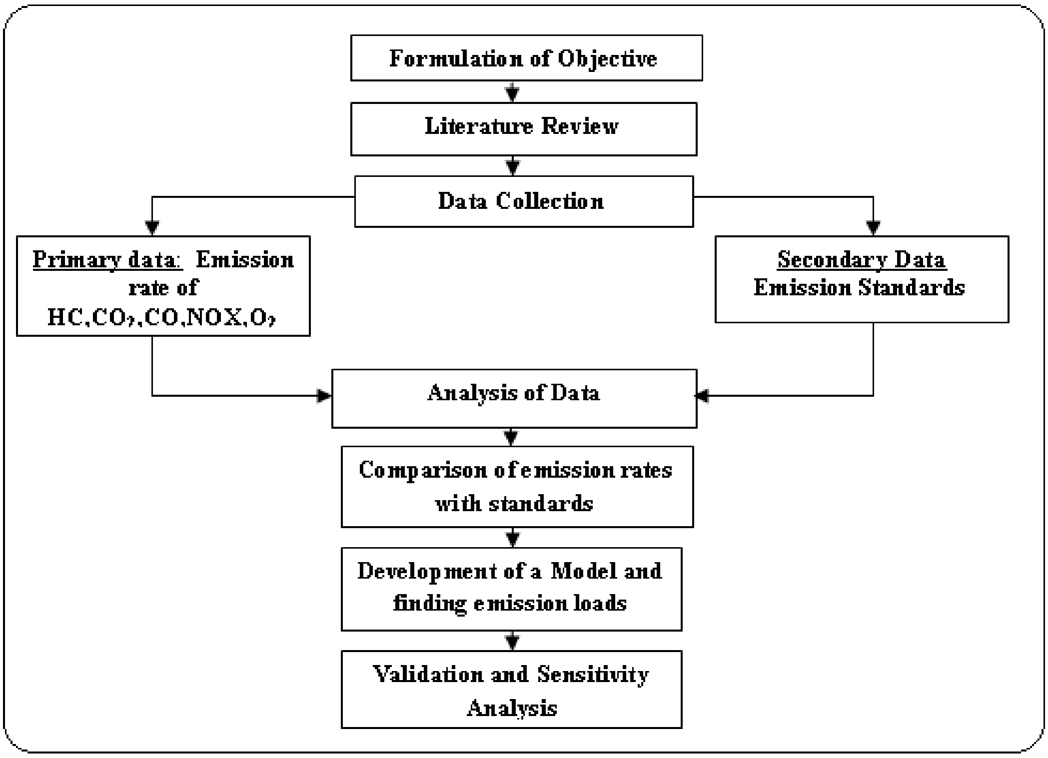

Fig. 1. Methodology Flow Chart

IV. FIVE GAS ANALYSER

Five gas analyzer is a highly sophisticated instrument, which is used to measure the vehicle emission exhaust. A picture of five gas analyzer is shown in Fig. 2. It can measure five parameters (CO, CO_2, HC, NOx and O_2).The probe of the five gas analyzer is connected to the vehicle exhaust. The amount of emissions coming out from the vehicle exhaust is measured under static and dynamic condition. In case of dynamic condition battery inverter is used.

Fig. 2. Five Gas analyser

V. STUDY AREA

The study area selected for this research work comes under zone 8, 9 and 10 of the Chennai City. The Metropolitan City of Chennai is one of the rapidly growing cities in India. The gradual increase in population has resulted in increase in vehicular population, which had resulted in increased air pollution. The study area stretches include Ashok Nagar 1st and 4th avenue, Besant Nagar 1st, 3rd and 7th avenue, Velacheri main road, Mandaveli 1st street and Kasturibai Nagar 3rd street. Figure 3 shows the location of study area. These road stretches are selected as they have different roughness values.

All the study area stretches comes under residential area excluding Velacheri Main Road which comes under commercial area. The details of study area is shown in Table 3. The factors which affect driving patterns along the study area stretches are the carriageway width, the nature of road surface and shoulder width. The vehicle features and traffic features was not considered due to the time limit. The road stretches selected was the collector streets except the velacheri main road which is a sub arterial road

Fig. 3 Location of the study area

The vehicle features and traffic features was not considered due to the time limit. The road stretches selected was the collector streets except the velachery main road which is a sub arterial road. In collector streets the vehicle can travel at an average speed of 30 to 37 km/h in a normal day with traffic. In order to take various speeds in to account, the vehicle was driven in early hours of the day when there was less traffic at a varying speeds of 25 km/h, 45 km/h and 65 km/h.

TABLE I. DETAILS OF STUDY AREA

Sl. No	Study Area Stretches	Carriageway Width In meter	Shoulder width In meter	Roughness of The Road(IRI)
1	Ashok Nagar 1st avenue	10.5	2	6.743
2	Ashok Nagar 4th avenue	10.5	2	5.505
3	Besant Nagar 1st avenue	9.2	2	5.373
4	Besant Nagar 3rd^{t} avenue	9.2	2	5.018
5	Besant Nagar 7th avenue	7.5	2	4.927
6	Velacheri main road	8.1	2	4.053
7	Mandaveli 1st	7.5	1	3.715
8	Kasturibai Nagar 3rd street	7	1	3.57

VI. SAMPLE SIZE FOR STATIC CONDITION

Data were collected both for static and dynamic conditions. The samples are divided in to two types for static conditions i.e. both light and heavy duty diesel vehicles. Totally hundred sixty samples out of which sixty comes under light duty vehicles and hundred come under heavy duty vehicles. The light duty vehicle indicates the passenger cars of direct injection type. In heavy duty vehicles hundred samples are considered out of which fifty come under MTC buses and fifty come under private buses. This is clearly explained in Table II.

TABLE II. SAMPLE SIZE FOR STATIC CONDITION

Sl.no	Type of vehicle	Sample size
1	Light Duty vehicles (i. e) passenger cars Direct Injection Engine	60
2	Heavy Duty Vehicles a)MTC Buses b)Private Buses	50 50
TOTAL		160

Under static condition, direct injection type vehicle emission status was checked using five gas analyzer, which is shown in Table III, and IV .

TABLE III. DATA RANGE FOR DIRECT INJECTION FIVE SEATER CARS

Age of Vehicle (in yrs)	Level of Emission Of Different Types Of Gases									
	CO (%)		HC (ppm)		CO_2 (%)		O_2 (%)		NO_X (ppm)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
6	1.89	1.95	454	589	17.34	19.5	20.17	21.95	474	593
5	0.34	1.55	362	495	16.77	18.9	17.2	18.9	405	527
4	0.21	0.89	308	475	15.0	16.9	18.7	19.3	307	335
3	0.16	0.97	302	393	12.1	17.5	16.1	19.4	307	335
2	0.14	0.97	328	378	10.12	17.4	12.0	19.6	355	398
1	0.04	0.92	325	375	8.75	10.4	10.34	12.51	335	377

TABLE IV. DATA RANGE FOR PRIVATE BUSES

Age of Vehicle (in yrs)	Level of Emission Of Different Types Of Gases									
	CO (%)		HC (ppm)		CO_2 (%)		O_2 (%)		NO_X (ppm)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
6	1.88	2.45	735	785	18	18.8	22	23.7	823	897
5	1.6	2.25	615	747	17.4	18.6	21	23	741	865
4	0.86	2.45	532	743	9.54	19.3	17.5	20.4	635	827
3	0.54	0.98	300	473	4.22	9.56	13.5	16.5	395	587
2	0.43	0.82	176	298	4.2	5.83	11.7	12.3	277	384
1	0.35	0.72	167	188	2.36	4.65	10.2	14.3	247	284

From Table IV, we can infer that as the age of the vehicle increase, emission rate increases which shows that age of the vehicle and emission level are directly proportional. While comparing the emission rate between private buses and government owned MTC buses it is observed that level of CO is very high in MTC buses. Overall from the table, MTC buses have higher level of pollution than private buses. This is probably due to the inadequate maintenance of the vehicle.

VII. SAMPLE SIZE FOR DYNAMIC CONDITION

The sample collected for dynamic condition is only for light duty vehicles (i. e) passenger cars. The passenger cars are of two type's i. e five and eight seater passenger cars. Both the passenger cars are divided into indirect and direct injection engines. Totally one hundred and sixty samples were collected. Out of which eighty comes under five seater vehicle and the other eighty comes under eight seater vehicles. In both the type of vehicle thirty comes under indirect injection engine and fifty comes under direct injection engine. This is explained in the following Table V

TABLE V. SAMPLE SIZE FOR DYNAMIC CONDITION

Sl.no	Type of Vehicle	Sample Size	Age of the Vehicle(in years)
1	Five Seater vehicle a)Indirect Injection Engine b)Direct Injection Engine	 40 40	 9-13 1-5
2	Eight Seater Vehicle a) Indirect Injection Engine b) Direct Injection Engine	 40 40	 9-13 1-5
TOTAL		160	

VIII. DYNAMIC CONDITION

A. *Indirect Injection System*

An indirect injection diesel engine delivers fuel into a chamber off the combustion chamber, called a prechamber or ante-chamber, where combustion begins and then spreads into the main combustion chamber, assisted by turbulence created in the chamber. This system allows for a smoother, quieter running engine, and because combustion is assisted by turbulence. The prechamber had the disadvantage of increasing heat loss to the engine's cooling system and restricting the combustion burn, which reduced the efficiency by 5%–10%.

B. *Direct Injection System*

Direct injection injectors are mounted in the top of the combustion chamber. The problem with these vehicles was the harsh noise that they made. Fuel consumption was about 15 to 20 percent lower than indirect injection diesels, which for some buyers was enough to compensate for the extra noise. The vehicles such as direct five seater, direct eight seater, indirect five seater and indirect eight seater are driven along Ashok Nagar 1^{st} and 4^{th} avenue, Besant Nagar 1^{st}, 3^{rd} and 7^{th} avenue, Velacheri main road, Mandaveli 1^{st} street and Kasturibai Nagar 3^{rd} street. Along these stretches the emission rates of different type of vehicle for different age, roughness and speed varying between 25kmph, 45km/h and 65km/h is obtained. Sensitivity analysis was conducted and the results were obtained. Sensitivity analysis for direct and indirect five seater vehicle is shown below.

The results obtained are tabulated as shown in Table XVIII .From the Table XVIII we are able to infer that there is a steep increase in level of emission with respect to age of the vehicle and roughness and decrease in speed in case of direct five and eight seater vehicle. In case of indirect five and eight seater vehicle gradual increase in age of the vehicle and roughness and decrease in speed.

IX. MODELS

A model is a simplified representation of the real world system. Models can be physical models or mathematical models. Mathematical models use symbolic and mathematical equations to represent a system. The system attributes are represented by variables, and the activities are represented by mathematical functions that interrelate the variables.

In the context of the above, models were proposed to built to study the effect of various factors which affects the emission of various gases such as CO, HC, CO_2, O_2 and NO_X coming out from the vehicle.

X.MODELING OF EMISSION RATES

The emission rates are being modeled under static and dynamic conditions. Static condition means the emission rates of the vehicle are being modeled when the engine is switched on. Dynamic condition means the emission rates of the vehicle are modeled when the vehicle is moving.

A. *Static Model*

The static model is used to predict the rate of emission of various gases when the engine is switched on. The rate of emission is modeled for Private buses, MTC buses, indirect and direct injection engines for cars.

B. *Model Formulation*

The model to predict the emission rate of various gases in static condition is of the following form

$$Y=a_1x_1 + a_0 \text{..................} \quad (1)$$

Where, y = Dependant Variable

x_1 = Independent Variable (Age of the Vehicle)

a_1 = Co-efficient of independent variable

For the models the independent variables used, is the age of the vehicle. The following table shows the regression model developed for Private Buses.

TABLE VI REGRESSION MODEL FOR PRIVATE BUS

SL.NO	Various Type Of Gases	Regression Model	R^2
1	CO	Y = 0.340x_1+0.05	0.658
2	HC	Y = 132.995x_1+23.135	0.902
3	CO_2	Y = 3.405x_1-0.326	0.842
4	O_2	Y = 2.555x_1+8.001	0.882
5	NO_X	Y = 135x_1+117.834	0.909

The following table shows the stepwise regression model developed for MTC Buses

TABLE VII .REGRESSION MODEL DEVELOPED FOR MTC BUSES

SL.NO	Various Type Of Gases	Regression Model	R^2
1	CO	Y = 0.799x_1-0.826	0.825
2	HC	Y = 120.191x_1+65.247	0.827
3	CO_2	Y = 3.701x_1+1.391	0.863
4	O_2	Y = 2.887x_1+8.900	0.863
5	NO_X	Y = 127.714+86.806	0.838

The following table shows the stepwise regression model developed for indirect injection engine for cars.

TABLE VIII. REGRESSION MODEL DEVELOPED FOR INDIRECT INJECTION ENGINE FOR CARS

SL.NO	Various Type Of Gases	Regression Model	R^2
1	CO	Y = 0.137x_1+0.378	0.474
2	HC	Y= 25.117x_1+315.285	0.756
3	CO_2	Y = 1.014x_1+10.320	0.892
4	O_2	Y = 0.913x_1+13.426	0.932
5	NO_X	Y = 52.700x_1+131.753	0.884

The following table shows the stepwise regression model developed for direct engine for cars

TABLE IX. REGRESSION MODEL DEVELOPED FOR INDIRECT INJECTION ENGINE FOR CARS.

SL.NO	Various Type Of Gases	Regression Model	R^2
1	CO	Y = 0.119x_1+0.422	0.201
2	HC	Y = 26.171x_1+301.833	0.817
3	CO_2	Y = 1.9874x_1+7.544	0.840
4	O_2	Y = 1.86x_1+10.673	0.811
5	NO_X	Y = 33.203x_1+302.540	0.752

C. Dynamic Model

The dynamic model is used to predict the emission rate for the vehicles which are moving. The rate of emission depends upon the vehicle and the road conditions. The rate of emission is modeled for indirect and direct injection type of engines especially for cars, which are four and six seater.

D. Model Formulation

The model to predict the emission rate of various gases in dynamic condition is of the following form

$$Y = a_1x_1 + a_2x_2 + a_3x_3 + a_0$$

Where Y = Dependant Variable

x_1, x_2, x_3 = Independent Variables

a_1, a_2, a3 = Constant

For the model the independent variables taken are the age of vehicle, roughness and speed. The following table shows the regression model developed for direct eight seater vehicle

TABLE X. REGRESSION MODEL DEVELOPED FOR DIRECT INJECTION -EIGHT SEATER VEHICLE.

SL.NO	Various Type Of Gases	Regression Model	R^2
1	CO	Y = 0.342x_1+0.081x_2-0.0143x_3+0.128	0.582
2	HC	Y = 22.527x_1+122.960x_2+2.299x_3-67.510	0.871
3	CO_2	Y = 1.891x_1+0.408x_2+0.062x_3+4.030	0.899
4	O_2	Y = 1.2654x_1+0.291x_2+0.037x_3+13.188	0.870
5	NO_X	Y = 40.154x_1+143.918x_2+1.27x_3-47.380	0.941

The following table shows the stepwise regression model developed for direct injection five seater vehicles

TABLE XI. REGRESSION MODEL DEVELOPED FOR DIRECT INJECTION -FIVE SEATER VEHICLE.

SL.NO	Various Type Of Gases	Regression Model	R^2
1	CO	Y = 0.560x_1+0.168x_2-0.0001x_3-1.227	0.798
2	HC	Y = 58.947x_1+22.796x_2+0.761x_3+82.248	0.880
3	CO_2	Y = 1.006x_1+0.198x_2+0.013x_3+10.938	0.957
4	O_2	Y = 1.130x_1+0.229x_2+0.026x_3+9.974	0.933
5	NO_X	Y = 58.913x_1+25.664x_2+1.506x_3+76.466	0.877

The following table shows the regression model developed for indirect eight seater vehicle

TABLE XII. REGRESSION MODEL DEVELOPED FOR INDIRECT INJECTION -EIGHT SEATER VEHICLE.

SL.NO	Various Type Of Gases	Regression Model	R^2
1	CO	Y = 0.246x_1+0.037x_2-0.004x_3-0.474	0.421
2	HC	Y = 14.587x_1+15.741x_2+0.203x_3+719.556	0.727
3	CO_2	Y = 0.889x_1+0.301x_2+0.054x_3+18.200	0.806
4	O_2	Y = 0.594x_1+0.320x_2+0.33x_3+25.470	0.729
5	NO_X	Y = 12x_1+17.513x_2+0.738x_3+761.293	0.820

The following table shows the stepwise regression model developed for indirect five seater vehicle

TABLE XIII. REGRESSION MODEL DEVELOPED FOR INDIRECT INJECTION -FIVE SEATER VEHICLE.

SL.NO	Various Type Of Gases	Regression Model	R^2
1	CO	Y = 0.116x_1+0.240x_2-0.083x_3+1.853	0.875
2	HC	Y = 32.613x_1+26.480x_2+252.101x_3+1.53	0.784
3	CO_2	Y = 0.863x_1+0.197x_2+0.056x_3+9.421	0.840
4	O_2	Y = 0.724x_1+0.26x_2+0.033x_3+13.24	0.647
5	NO_X	Y = 24.799x_1+36.141x_2+1.364x_3+254.555	0.745

Where

x_1 = Age of the Vehicle

x_2 = Roughness

x_3 = Speed

In all type of vehicle, the emission of carbon monoxide with respect to speed is negative. This is because the emission of carbon monoxide is greater.

The negative sign in the model indicates that as the speed increases the rate of emission of Carbon Monoxide (CO) decreases.

X. MODEL VALIDATION AND SENSITIVITY ANALYSIS

A. Introduction

Validation is an important step in model development which determines the realistic feature of model. The model is also validated to know the percentage error from the real data.

Sensitivity Analysis provides insight into the nature of the variable under consideration. The purpose is to identify those factors to which the dependant variable is most sensitive. Thus it provides the decision makers with important information onto which to base decisions and most importantly provides guidance as to which factors are most worthy of further investigation.

B. Model validation

The emission rates or the data obtained are not fully used for developing the model. The emission rates or the data obtained are divided in to seventy and thirty percent. Seventy percent of the data was used for developing the model and thirty percent of the data obtained used for validating the model. The coefficients of the various variables in the equation are supplied by the SPSS package the results of model validation for Carbon Monoxide (CO) is shown below in table 6.1 and a graph is drawn between predicted and observed Carbon Monoxide (CO), this is shown in figure 6.1

The calculated value of CO was 1.827% whereas the observed value was 1.442% and the error was to be 6.3042%. The predictive effective of the model can be seen in the fig. The models are derived with satisfactory $r^{2.}$

TABLE XIV. MODEL VALIDATION FOR CARBON MONOXIDE (CO)

Observed Carbon Monoxide (CO)	Predicted Carbon Monoxide (CO)	Percentage Error
2.74	3.08	-11.03
2.62	2.41	8.015
2.41	2.72	11.39
1.73	1.89	8.46
1.58	1.43	9.49
1.41	1.54	8.441
0.61	0.67	8.51
0.55	0.53	3.636
0.43	1.98	7.82
0.34	2.02	8.31

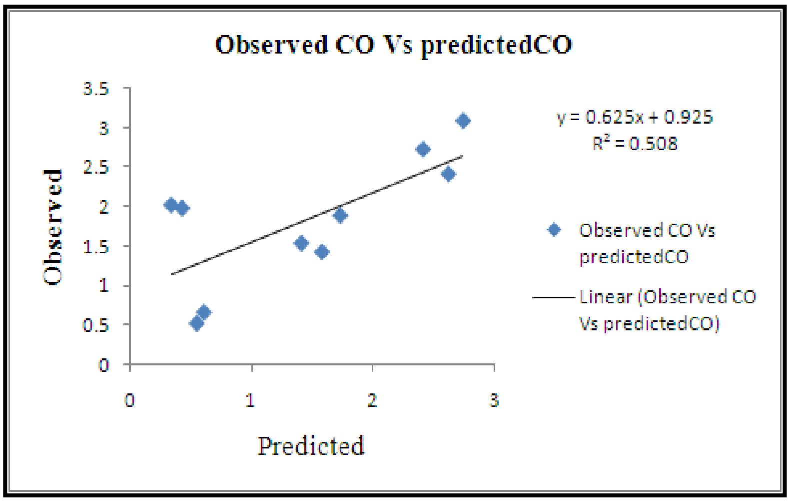

Fig. 4. Observed (CO) Vs Predicted (CO)

TABLE XV. MODEL VALIDATION FOR HYDROCARBONS (HC)

Observed Hydrocarbons (HC)	Predicted Hydrocarbons (HC)	Percentage Error
0.0518	0.0527	1.707
0.0503	0.0531	5.27
0.0487	0.0491	0.814
0.0497	0.0488	1.818
0.0481	0.0664	14.453
0.0468	0.0498	6.024
0.0392	0.0432	9.259

TABLE XVI. MODEL VALIDATION FOR HYDROCARBONS (HC)

Observed Hydrocarbons (HC)	Predicted Hydrocarbons (HC)	Percentage Error
0.037	0.0412	8.009
0.0363	0.0379	8.221
0.0327	0.0352	7.10027

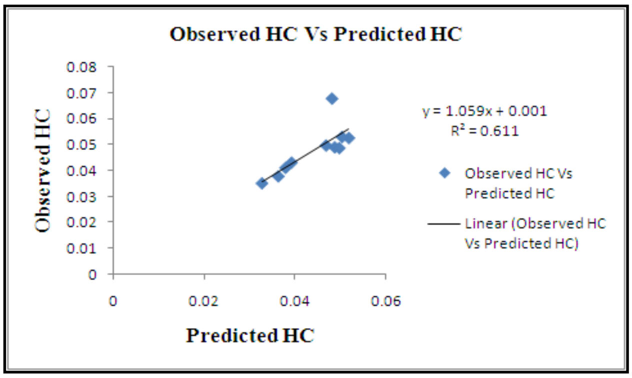

Fig. 5 Observed (HC) Vs Predicted (HC)

XI. CONCLUSIONS

- The emission of Carbon Monoxide decreases by 64 percent at a speed of 65Kmphr.With increase in age ,the emission of Carbon Monoxide increases by 70.35%.With increase in roughness, the emission of carbon monoxide is increased by 47.45%.
- The emission of Hydrocarbons has increased with the increase in speed, age and roughness. The emission of Hydrocarbons increases to 8.26% at a speed of 65Km/hr.The emission of Hydrocarbons increases to 16.02% with increase in roughness. The emission of hydrocarbons increases by 38.25% with increase in age of the vehicle.
- The emission of NO_X has increased with the increase in speed, age and roughness. The emission of Oxides of Nitrogen increases by 32.9% with respect to age,22% with respect to roughness and 15% with respect to speed.

XII. RECOMMENDATIONS

- Banned the use of old vehicles as the old vehicles causes much pollution
- The surface provided for riding should be smooth.
- The vehicle technology should be improved, so that the rate of exhaust emissions coming from the vehicle exhaust decreases.
- Tightening of mass emission standards for new vehicles.
- Optimum speed should be maintained.

XIII. SCOPE FOR FUTURE WORK

- Need to estimate emission rate for different vehicle technology and fuel.
- Develop emission inventory methodology for different parts of chennai city.
- Assess the influence of different characteristics on driving patterns.
- Traffic density and number of intersections, with different types of road such as arterial, sub arterial with varying speed should be considered.

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REFERENCES

[1] Aerde,M.V. and Yagar.S (1983). “Volume Effects on speeds of 2-lane highways in ontario”. Transportation research Part-A,17A,301-313.
[2] Andre, M and U.Hammarstrom(2000), “Driving speeds in Europe for Pollutant emissions estimation” Transportation research Part D : Transportation and Environment, S(5),321-335
[3] Bencala,K.E.., And Seinfield,J.H.(1979) “An air Quality model performance assessment package” Atmospheric Environment , England, 13,1181-1185
[4] Chock,D.P. (1978), “A Simple line model for dispersion near roadways” Atmosperic Environment, England, 12, 823-829
[5] N.N.Clark,M.Gautam,W.Swayne,etal.,(2003) creation and test cycle evaluation of a medium heavy duty truck”, SAE transactions,Vol.112, No.4, PP.2654-2668.
[6] Devlieser.I, deke,Keleere D, Kretzschmar JG.(2000). Environmental effects of driving behavior and congestion related to passenger.

[7] Environmental Protection Agency (EPA). (1992). ‘‘User’s guide for the industrial source complex dispersion models.’’ Office of Air Quality Planning and Standards, Washington, D.C.

[8] Juda, K. (1986). ‘‘Modeling of the air pollution in the Cracow Area.’’Atmospheric Environment, England, 20, 2449–2458.

[9] Luhar, A. K., and Patil, R. S. (1989). ‘‘A general finite line source model for vehicular pollution prediction.’’ Atmospheric Environment, England, 23(3), 555–562.

[10] McRae, G. J., and Seinfeld, J. H. (1983). ‘‘Development of a second generation mathematical model for urban air pollution—II. Evaluation of model performance.’’ Atmospheric Environment, England, 17(3), 501–522.

[11] Noll, K. E., Miller, T. L., and Claggett, M. (1978). ‘‘A comparison of three highway line source dispersion models.’’ Atmospheric Environment, England, 12, 1323–1329.

[12] Pasquill, F. (1979). Atmospheric diffusion, Wiley, New York.

[13] Petersen, W. B. (1980). ‘‘User’s guide for HIWAY2. Highway air pollution model.’’ EPA-600/8-80-018, Environmental Protection Agency, Washington, D.C.

[14] Petersen, W. B., and Rumsey, E. D. (1987). ‘‘User’s guide for PAL2. A Gaussian plume algorithm for point, area, and line sources.’’Atmospheric Sciences Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

[15] Pundir, P. P., Jain, A. K., and Gogia, D. K. (1994). ‘‘Vehicle emissions and control perspectives in India.’’ State-of-the-Art Rep., Indian Institute of Petroleum, Dehradun, India.

[16] Rao, S. T., and Keenan, M. T. (1980). ‘‘Suggestions for improvement of the EPA-HIWAY model.’’ J. Air Pollution Control Assn., 30(3), 247–256.

[17] Rao, S. T., Sistla, G., Keenan, M. T., and Wilson, J. S. (1980). ‘‘An evaluation of some commonly used highway dispersion models.’’J. Air Pollution Control Assn., 30(3), 239–246.

[18] Sistla, G., Samson, P., Keenan, M., and Rao, S. T. (1979). ‘‘A study of pollutant dispersion near highways.’’ Atmospheric Environment, England, 13, 669–685.

[19] Sivacoumar, R., and Thanasekaran, K. (1999). ‘‘Line source model for vehicular pollution prediction near roadways and model evaluation through statistical analysis.’’ Envir. Pollution, England, 104, 389–395.