A report on

EXHAUST EMISSION OF CO, HC, AND NOx FROM PETROL DRIVEN PASSENGER CARS IN MEGACITY DELHI

submitted in the partial fulfilment of the requirement for the award of degree of

MASTER OF TECHNOLOGY

(Environmental Engineering)

by

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VINEET KUMAR RAI

Certificate

This is to certify that VINEET KUMAR RAI, M.Tech student in the Department of Environmental Engineering has submitted a project report on "EXHAUST EMISSION OF CO, HC AND NOx FROM PETROL DRIVEN PASSENGER CARS IN MEGACITY DELHI" in partial fulfilment of the requirement for award of degree of Master of technology in Environmental Engineering during the academic year 2015-2017.

It is a record of the student's research work prepared under my supervision and guidance.

DR. RAJEEV KUMAR MISHRA

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Declaration of Originality

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ABSTRACT

Environmental pollution is a prime worry to mankind. In India, around 64 % of climatic contamination is being brought about by vehicular emission. As we have a scope of diesel and petrol driven vehicles employing on the street, it is basic to screen the emission of vehicles to research the reliance and connection between the emission levels and vehicle-related parameters. Considering the limitations of information gathering, time allotment and understanding the strength of petrol driven passenger cars of Maruti and Hyundai over the fleet of cars in India, a case study of various models of petrol driven passenger cars of Maruti and Hyundai reporting at the authorized service station of Sanjay Motors service station,Rohini Sec-17, New Delhi, was taken up and the tailpipe emissions alongside individual vehicle-related parameters were observed for idle and fast idle test conditions. Out of a several vehicle-related parameters, vehicle age and vehicle mileage were observed to be the most crucial ones, and indicated genuinely great connection with CO, HC and NO emission. It has been additionally observed that CO, HC and NO emission levels for fast idle test condition are lower than those for idle test condition, which may turn out to be valuable for possible standardization in future

The result of the analysis identifying with the impact of different vehicle-related parameters on CO, HC and NO emission of petrol-driven passenger cars of Maruti and Hyundai has prompted the valuable inductions, which can be utilized not just to predict the emission of vehicles as for vehicle age and mileage, additionally for the automobile manufacturing and maintenance sector to help them to create such environmentally pleasant petrol-driven passenger cars having long-lasting compliance of pollution control systems with respect to vehicle age and mileage while ensuring regular and realistic monitoring and maintenance of pollution control systems exclusively. This would go far towards lessening the vehicular pollution from petrol-driven passenger cars in the country.

Keywords: Exhaust emission, Vehicle-related parameters, Control system, Petrol-driven.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Environmental pollution is a prime worry to mankind. Environmental quality is being influenced in different ways and means through anthropogenic exercises. Extensively, human exercises produce three principle source of air pollution: stationary or point, portability, and indoor. In developing countries, particularly in the rural regions, indoor air pollution from utilizing open fire for cooking and heating might be a serious issue. Industries, power plants, process and production houses situated in various parts of the country pollute the air as the stationary sources. Yet, in urban areas of developing as well as developed countries, predominance of mobile sources of pollution like vehicular pollution is conspicuous with reference to the general air quality issue.

Various countries have focused on vehicles and related segments, (for example, fuel) to control the danger of air pollution. Outstanding effective activities are: exchanging over of open transport from diesel to CNG in Delhi, exchanging over of Vikrams (tuk-tuks) from diesel to power in Kathmandu valley, moving from leaded to unleaded gasoline fuel in numerous countries and so forth. Still the pollution issue in urban areas may keep on looming expensive due to always blossoming vehicular population, which is outpacing any such measure and street organize advancement. The emissions from road vehicles were disaggregated at the state level, with separate estimates for 30 cities. The study found that 90% of total emissions from the transport sector were from on-road transport and heavy vehicles were the largest emitters of PM2.5 and BC. Two-stroke vehicles contributed significant amounts of OC emissions(Apoorva Pandey & Venkataraman, 2014). In a study in Delhi by (Nagpure, Gurjar, Kumar, & Kumar, 2016), the exhaust and nonexhaust emissions from on-road vehicles were estimated using a vehicular air pollution inventory (VAPI) model for the 1991 to 2020 period. The study considered gaseous, PM, and mobile source air toxics together with VOCs and PM10. The study found that non-exhaust emissions (PM10) contribute significant emissions relative to tailpipe emissions and emphasized the need for more stringent emission norms and emission control strategies.

Against 3.6 million vehicular population in 2001 in Delhi, it rose to almost 7.4 million in the year 2012 (i.e., an expansion of about 108%). During a similar period, Delhi's population has expanded by just 19.56% (from 13.8 million to 16.5million) and street length by only 14% (from 25,000 km to 28,508 km) respectively. The situation is similar across a number of cities in India and the developing world. This shows the exigency of controlling vehicular pollution. Pollution from vehicles frequently bring about expanded mortality and morbidity and is revealed through symptoms like cough, headache, nausea, irritation of eyes, various bronchial issues and impact on visibility. The pollution from vehicles are released as CO, unburnt HC, Pb compounds, NOx, residue, suspended particulate matter (SPM) and aldehydes, among others, for the most part from the tail pipe. A current review reports by WHO that one out of each 10 school kid in Delhi suffers asthma that is worsening because of vehicular pollution. Likewise, two of the three most critical health related issues in Bangkok are created via air pollution and lead contamination, both of which are contributed enormously by motor vehicles.The situation is alike in a number of other mega-cities across the globe – be it Mexico City, Sao Paulo and Santiago in Latin America or Bangkok, Jakarta, Manila, Dhaka in Asia or Ibadan and Lagos in Africa or the urban communities of Eastern Europe, the recent USSR and the Middle East. As indicated by the World Health Organization (WHO), 3 million deaths a year are linked to exposure to air pollution. WHO has identified SPM as the most evil one as far as its impact on health.

Remarkably, SPM is not homogeneous. It has various constituents and is measured and characterized in different ways i. e., (i) TSP (add up to suspended particulates): with particle diameters $< 50\text{-}100\ \mu m$ and tested with high volume samplers (ii) RSPM (particulate matter): inhalable particles having a diameter $<10\ \mu m$ enter 8through the nose, by breathing (iii) Thoracic particles that are roughly equivalent to RSPM particles (iv) PM: fine portion with a diameter $< 2.5\ \mu m$ that infiltrate to the lungs; and (v) Black smoke that is a measure of the blackness of a particulate sample and gives a relative value for the soot content of the sample. Because of the high health damaging potential of the particulates, recent studies have begun giving careful consideration to PM10 and PM2.5 particles.

The distinctive air pollutants because of vehicles can have impacts at all the three levels – local (e.g., smoke affecting visibility, ambient air, noise etc.), regional (e. g., smog, acid rain etc.) and global (e. g., global warming. The vehicles, other than being the noticeable sources of air pollutants, additionally represent various external impacts, for example ,such as congestion, noise, accidents, road wear and tear and ‘barrier effects’.

1.2 Need and importance of the work

As due to exponentially increment in the population of vehicles in the country and there is a high demand for more production among the makers of the passenger cars, it is fundamental to investigate the impact of vehicle-related factors on the emission of1pollutants from tailpipe. Specifically reference of petrol-driven passenger cars , it is important to evaluate the emission levels of CO, HC and NO from various models of the petrol driven passenger cars.

With a greater emphasis on controlling the emission from vehicles, BHARAT Stage (I,II,III,IV,V) standards have been adopted in India as per Euro norms and now it is required for the producers of the vehicles to furnish every one of the vehicles with suitable pollution control systems. Despite the fact that the vehicle leaving the industrial facility should have pollution under control yet the consistence status of the being used vehicles with respect to vehicle-related factors is generally non known and the literature covering this aspect is scantily available. Apparently, if the behavior of the vehicle as far as the emission levels concerning any vital vehicle-related factors like vehicle age, vehicle mileage and effect of maintenance is properly understood, appropriate steps can be taken in like manner to monitor the emissions from the vehicle defeating the impact of such factors. In the present study, the petrol driven passenger cars detailing for maintenance at the approved workshop of Sanjay Motors, Rohini Sec-17, New Delhi have been inspected in a period of time and the information relating to vehicle-related factors and CO, HC and NO emissions have been collected. The data have been analyzed to learn the impact of different vehicle-related parameters on the emission level of petrol driven passengers cars.

1.3 Objectives of the study

Considering the significance of the effect of vehicle emissions and its critical allegiance to the issue of air pollution, the work has been undertaken with the following objectives:

- Review of literature to ascertain the important vehicle-related parameters and methodologies of the measurement of the emissions from petrol-driven passenger cars,
- To quantify and investigate the effect of vehicle-related parameters (such as vehicle age, vehicle mileage, time since last inspection) on CO, HC and NO emission characteristics of petrol-driven passenger cars.

- To analyze the data with a view to correlate, if any, of vehicle-related factors with CO, HC and NO emissions and to suggest suitable steps and remedies for the pollution control of petrol-driven passenger cars. With these objectives in view, the literature review, materials and methods, analysis of data, results and discussion followed by recommendations and conclusion have been presented.

1.4 Organization of the dissertation

The dissertation has been organized in 5 chapters. A brief outline of the chapters is presented hereafter:

The chapter 1 presents the introductory part of the dissertation which has been sub-divided into introduction, need and importance of the work, objectives of the study and the organization of the dissertation. Chapter 2 deals with the review of literature, in which pertinent literature from various sources has been reviewed so as to enable the Study to be taken up in right perspective and planned manner. The materials and methods have been described in chapter 3, which incorporates the actual methodology of the field work and data collection. Next to this chapter is chapter 4 which covers the analysis of data, results and discussion. In this chapter the analysis of the field data has been carried out and the results have been discussed critically. The recommendations and conclusions based upon the outcome of the study have been incorporated in chapter 5.

CHAPTER 2

REVIEW OF LITERATURE

2.1 General

In India, around 64 % of the atmospheric pollution is being brought about by vehicular emissions. The measure of vehicular exhausts and the resultant air quality is a reason for extraordinary concern.The air is highly contaminated with implications on public health (Gupta and Goel, 1997). With the exponentially rising number of different types of vehicles and activity blockage of streets, the circumstance has expected disturbing measurements at many places in the world. As the air contaminants, for example, carbon monoxide, oxides of nitrogen, hydrocarbons, lead and particulates emitted from vehicles have harmful and harming consequences for human health, the emphasis is given on such procedures and approaches that have a tendency to limit the emission of such contaminants. In an offered to do as such, the efforts are being made towards furnishing the vehicles with emission control systems agreeing to pertinent regulatory standards.

It is viewed as that the vehicle produced by the manufacturers with the end goal of offer must consent to emission standards as relevant at the time of exit of the vehicle from the manufacturing plant premises. However, as the vehicle begins utilizing on the street after its sale from some show room, it experiences the impact of vehicle age and vehicle mileage. In this way, it is additionally expected that the conduct of pollution control system may likewise be influenced because of the impact of different vehicle-related parameters including vehicle age, vehicle mileage and periodic inspection and maintenance.(Abhinav Pandey, Pandey, & Mishra, 2016)

It is, along these lines, important to investigate the emission qualities of the vehicles regarding vehicle-related parameters with a view to determine in the matter of how the tailpipe emission from the vehicles could be monitored by receiving appropriate methodologies. In this point of view, the observing of the vehicles alongside the gathering of appropriate information is of central significance. As we have a scope of diesel and petrol-driven vehicles playing on streets, it is coherent to concentrate the consideration on every part of the vehicle fleet. In any case, from the perspective of the requirements of the information accumulation and the time period of the proposed study about and understanding that the fleet of petrol-driven passenger cars in Delhi is commanded by various models of petrol-driven passenger cars. About to complete case study of different model of petrol-driven passenger cars revealing at the authorized service station of Sanjay Motors,Rohini sec-17,New Delhi.

The petrol-driven passenger cars of different model reporting at the service station during the period of data collection were observed in regard of their tailpipe emissions of CO, HC, NO and individual vehicle-related parameters.

2.2 The technological development of automotive technologies in terms of emission and fuel efficiency

Since the motors vehicles are the great methods for transportation in service and also in private sectors, their number is expanding step by step. The huge development of motor vehicles in the urban areas is likewise contributing a significant substantial measure of air pollution. This prompted administrative controls gone for controlling vehicle-generating air pollution. However, regardless of the sensational drop in vehicle emission levels the urban air quality has not enhanced fundamentally because of expanding number of vehicles presented in the market in recent times.

With the strict emission guidelines forced by the administrations of many countries, many vehicle manufacturing companies have, enhanced in design of the engine regarding meeting the forced emission standard and making them more fuel-effective. In addition, numerous advancements have been created to treat the exhaust gases to decrease toxic emission. Significant vehicle emissions, their sources and a portion of the emission reducing technologies are described below.

2.2.1 Sources of automobile emission

It is observed that vehicular contamination sources are of various types and a heterogeneous mix of various makes and models is playing on street. The mix could be as far as fuel utilized i. e., gasoline, diesel, compressed natural gas (CNG), liquefied petroleum gas (LPG) or blended fuels or engine type, viz. Two-stroke or four-stroke and/or combinations of these. Gasoline-powered engines are of two sorts, i. e., four-stroke and two-stroke. Different sources of emissions from the two sorts of motors are given in Table 2.1. The exhaust emissions from gasoline-run vehicles consist of CO, HC,NOx, SO_2, and aldehydes, besides particulate matters including lead.

Table 2.1 Emission sources form Gasoline vehicles

	Source	Amount of emissions (%)		Remarks
		4-stroke	2-stroke	
1.	Crankase blow-by	20	0	Carburreted air-fuel mixture and combustion under pressure escape combustion chamber enter crank-base to be discharged in to atmosphere through vents.
2.	Evapourative Emissions	20	3	Fuel vapours lost to the atmosphere from tanks and carburettor
3.	Exhaust emissions	60	97	Exhaust gases emitted with pollutants through the tailpipe

Source: CPCB (1999)

The incomplete combustion of gasoline due to an imbalance in the air-fuel ratio leads to emissions of CO and HC especially from two-stroke engines. The two and three-wheelers having two-stroke engines require 2-T oil for the lubrication of engine, which is carried out through either pre-mixing mode or oil injection system. In either case, it is a total loss system, as the oil is burnt along with the fuel.

Since the burning quality of mineral based lubricating oil is very poor vis-à-vis gasoline, its major fraction that enters the engine, either remains unburnt or burns only partially. This unburnt and partially burnt oil comes through the exhaust and is responsible for smoke and SPM emission. The studies indicate that two-stroke engine's exhaust contains almost 15-25% of unburnt fuel (Pundir, 2001). In a perfect engine the total ignition of these fuels in presence of oxygen from air would change over all the hydrogen in the fuel into water and all the carbon in the fuel into carbon dioxide as products.Nitrogen noticeable all around would stay unaffected. In all actuality, the ignition procedure can't be perfect and automotive engines produce a few sorts of pollutants. Fuels are burnt at various fuel to air proportions in the engine and it prompts inadequate combustion at high temperature.Incomplete burning produces CO and unburnt HC and the ignition at high temperature prompts the development of NOx.

2.2.2 Tailpipe emission from petrol engines

Most passenger cars and light-duty trucks utilize spark ignition petrol engines, where premixed fuel-air mixture is ignited by the spark in the burning chamber toward the end of compression stroke. The conceivable deficient combustion of fuel-air mixture emits harmful pollutants. The emission from the petrol-fueled vehicle mostly depends on quality of fuel,driving habits, road conditions, vehicle maintenance,vehicle age etc. Most commonly emitted pollutants are listed in table 2.2.

Table 2.2 Pollutants from petrol engines and Causes of emissions

S.No.	Pollutants	Causes of emissions
1.	**CO**	Quite significant if the engine runs on rich fuel-air mixture, which is often the case in idling, re-starting etc.
2.	**HC**	Very lean and very rich fuel-air mixtur produces significant unburnt hydrocarbons.
3.	**NOx**	Relatively lower than in diesel engine, since the compression ratio is limited to 12 and the combustion temperature is not that high as in the case of diesel engine.
4.	**Particulate matters**	Lead, organic particulates (counting ash) and sulfates are the primary constituents of particulate matters. Leaded petroleum is the principle source of lead. Different source of particulate matters are the unburnt lubricating oil in the exhaust and ash forming fuel and oil added substances.
5.	**Toxic pollutants**	Benzene, 1, 3 butadiene and aldehydes are other toxic pollutants besides lead compounds.

2.2.3 Evaporative and refueling emissions

Petrol-fueled vehicles emit a significant amount of HC as evaporative emissions from their fuel system. Main sources of evaporative emissions are identified as follows:

Diurnal (breathing) – It is petrol loss from fuel tanks caused by expansion and contraction of gas in the tank with changes in air temperature.

Running losses – The hot engine and exhaust system can vapourize petrol when the vehicle is running.

Hot soak – The engine remains hot for a period of time after the vehicle is turned off and petrol evaporation continues when the vehicle is parked.

Refueling – Petrol vapours are always present in the fuel tanks. These vapours are displaced from the fuel tank when it is filled.

2.2.4 Tailpipe emission from diesel engines

Most medium and heavy-duty trucks and buses have diesel engine, as do some light-duty vehicles and passenger cars. Diesel engines, unlike spark-ignition engines, do not premix fuel with air before it enters the cylinder. Instead, the fuel is injected at high pressure at the end of the compression stroke.Once injected, the fuel is ignited by the compressed air in the cylinder. Compared with petrol engines, diesel engines have lower carbon monoxide and hydrocarbon emission since the engine works with excess air and combustion occurs mostly around stoichiometric mixture. Most commonly emitted pollutants are listed in table 2.3.

Table 2.3 Pollutants from diesel engines and Causes of emissions

S.No.	Pollutants	Causes of emissions
1.	**NOx**	Oxides of nitrogen are significantly high in diesel engine since it works on high compression ratio and the combustion takes place around stoichiometric region; that is, at high temperature
2.	**Diesel particulate matters (DPM) [Solid, SOF, SO_4, Sox]**	Diesel engine emits huge amount of particulate matters. When a large amount of fuel is added it will not burn completely and the cracking of the fuel takes place without oxygen and becomes soot.
3.	**Visible smokes**	Black smoke from diesel engine is due to the soot components of diesel particulate matters. Blue or grey smoke is generally due to vapourized lubricating oil and indicates an oil leak into the cylinder or exhaust system. White smoke is common when engines are first started in cold weather and usually

		goes away when the engine warms up.
4.	**Toxic air contaminants**	Diesel exhaust containing organic species like formaldehyde, benzene and polynuclear aromatic hydrocarbons etc. are suspected of causing cancer. .

2.2.5 Emission control technology for four-stroke spark-ignition engines

Awareness about the vehicle emission is expanding and there is pressure from the general population to decrease the vehicular emissions. Mechanically, the harmful emissions produced by four-stroke spark-ignition engine can be controlled in two ways, i. e., by engine design and by exhaust gas after treatment. Engine design measures are considered in designing and enhancing the current engine while exhaust gas treatment method can be incorporated in to the existing vehicle to go along to significant emission norms.

2.2.5.1 Engine design measures

2.2.5.1.1 Fuel injection system

Since carburettors can't keep up exact air-fuel ratio control under all conditions and are liable to change after some time they have been replace by electronic fuel injection systems. These systems give quick and exact control of the air-fuel ratio even during cold-start and engine warm up. Two fundamental methodologies have been developed i. e.,central (throttle body) injection system, with one or two centrally-located fuel injectors; and multi-port fuel infusion framework, with one fuel injector situated at the inlet to every chamber.The multi-port system reduce cylinder-to-cylinder variations in air-fuel proportion and simplify intake manifold design,simplify intake manifold design,since arrangement of fuel puddles in the intake manifold is no longer an issue.Central fuel injection systems (having less parts) are less expensive, while multi-port systems have better emission and performance.

2.2.5.1.2 Exhaust gas recirculation (EGR)

Exhaust gas is blended with the intake air, This diminishes the oxygen concentraion in the charge, expanding its particular heat by heat capacity of the carbon dioxide and water vapor contained in the exhaust. Both of these variables bring down the ignition temperature and hence, the formation of oxides of nitrogen.

Likewise, the emitted quantity of exhaust of gas is decreased. In the event that the amount of recycled exhaust gas is too high,emission of soot, carbon monoxide and hydrocarbons increment result of a deficient amount of air. The recycled amount of exhaust gas must, therefore, be limited (15% to 25%) as has been shown in the concerned researches.

2.2.5.1.3 Fast-burn techniques

The time required for combustion should be limited so as to decrease knocking and to enhance efficiency.One of the methods to accomplish this and in the same time, to diminish emission is to design a compact shape of combustion chamber in such a way that swirl is created that whirl is created during the induction process or during the last phases of compression and locating the start plug at the inside. The flame spreads quickly due to turbulence, giving a higher combustion rate and shorter combustion duration in in fast burn chamber. Reducing the tendency to knocking allows an increase in compression ratio, thereby, further increasing efficiency.

2.2.5.1.4 Ignition systems

The ignition timing dramatically affects exhaust emission and additionally on the fuel consumption. Here and there, even with the correct settings, the advancement or retardation of ignition timing occurs and the energy required for the good combustion in traditional coil and distributor system is insufficient. The transistorized coil and distributorless electronic ignition systems are replacing traditional coil and distributor systems in order to provide enough energy and flexible control of ignition timing.

2.2.5.1.5 Cold start emission control

In cold conditions, fuel does not evaporate easily and fully. It is necessary to enrich the mixture by providing more fuel than normal so that even partial fuel vapourization produces an ignitable mixture. The rich mixture and poor combustion under cold start conditions cause high HC and CO emissions. It is important to reduce the time spent while operating in this mode using cold start emission control devices like automatic chokes (under thermostatic or electronic control) and inlet air heaters.

2.2.5.2 Exhaust after treatment

The two after treatment technologies that have been widely used on spark ignition vehicles are air injection and the various types of catalytic converters .

2.2.5.2.1 Air injection

To provide the needed oxygen under rich or stoichiometric conditions, additional air is injected into the exhaust manifold. This air is provided either by a separate air pump or by a system of check valves This air oxidizes the HC and CO of exhaust gases into H_2O and CO_2 at minimum temperature of 600 ^{0}C and 700 ^{0}C respectively without catalyst. Air injection is also used with oxidizing catalytic converter.

2.2.5.2.2 Catalytic converters

A catalytic converter converts harmful emissions of hydrocarbons, nitrogen oxides and carbon monoxide to harmless water and nitrogen and to carbon dioxide. Table 2.2 shows the harmful emissions from a car with and without a catalytic converter. It is obvious that the catalytic converters are very effective in checking the harmful emissions in the various stages of vehicle driving *viz.* constant speed, slow acceleration, medium acceleration and rapid acceleration.

Table 2.4 Emission of CO (mg/s) for a car with and without a catalytic converter

Descript ion	**Constant Speed**	**Slow acceleration**	**Medium acceleration**	**Rapid Acceleration**
Without a catalytic	260	270	600	950
Convertr With a catalytic Convertr	6.4	14	43	110

Source: CPCB

Reactions occurring on the automotive exhaust catalysts are very complex as listed below. The major reactions are the oxidation of CO and HC and the reduction of NOx. Also, water gas shift and steam reforming reaction occur. Intermediate products such as N_2O and NO_2 are also found. The NOx storage concept is based on incorporation of a storage component into the three-way catalyst (TWCs) to store NOx during lean conditions for a time period of minutes.(Sugawara & Nikaido, 2014)

2.2.5.2.3 Pre-heating of catalytic converter

Most by far of harmful vehicle emissions are formed during cold engine starts. It is said that the catalytic converter has extreme impact at temperatures exceeding 350 0C. Typically, it takes two minutes running before this temperature is attained. If both the engine and catalytic converter are cold when starting, the environmental loading is especially high since fuel consumption is considerably higher than normal. Most efforts to solve this prolem have concentrated on preheating the catalyst, either electrically or by moving it closer to the engine. presently, researchers have demonstrated an even more innovative solution that is, starting the car with hydrogen. The by product of hydrogen combustion is only water, so the warm up period is emission free.

2.3 Approaches to the design of low-emission vehicles

2.3.1 Fuel efficiency

The demand of high octane fuel for increased compression ratio can be met by using different oxidants in place of lead. Use of these fuels would be expected to significantly increase emissions of reactive aromatic hydrocarbons . However, this increased potential is counterbalanced by the improved emission efficiency of catalytic converter.For instance, they contain less benzene, a cancer-causing volatile organic compound. The result is a decrease in emissions of VOCs, nitrogen oxides, and pollutants that contribute to the formation of smog.

2.3.2 Charcoal canisters

Gasoline evaporates readily from both the engine and from the fuel tank. Typically, a canister is installed in the front of a car in the engine compartment and hooked up to both the fuel tank and engine so as to collect gasoline vapours.

2.3.3 Alternative fuels

These are alternatives to conventional petrol and have the potential to reduce pollution. They do not contain toxic compounds, such as benzene, and they are simple compounds that do not form complex hydrocarbon by-products during combustion.

2.3.3.1 Liquefied Petroleum Gas (LPG)

It is a by-product of petroleum refining and natural gas production. It comprises Basically of propane stored in liquefied form at a pressure of 5-10 bars.The advantages of LPG are slightly lower emissions, basically of carbon monoxide and hydrocarbons and a higher octane number. The disadvantages are higher weight of tank, less space for luggage,marginally decreased performance and a shorter range compared with conventional gasoline.

2.3.3.2 Natural gas

It is a mixture of hydrocarbons that exists in the gaseous state at normal Temperature and pressure. Its main constituent is methane,, however different alkanes are likewise found in it.It emits about 70% less carbon monoxide and has a great deal less ozone-forming potential than standard petroleum gasoline. It is additionally more affordable than gasoline. The biggest drawback of natural gas is that it must be compressed to fit in a car or truck or bus, so heavy tanks are required to store it, and the pressure required (200 – 300 bar) is high enough to place extensive safety demands on the system.The pressurized form of this gas is known as compressed natural gas (CNG). The infrastructure of distribution of CNG is also comparatively high.

2.3.3.3 Alcohols (methanol and ethanol)

Alcohols provide greater power and acceleration and much less inflammable Than gasoline, so it is, and has been, for many years, the fuel of choice for high performance racing cars. Alcohols emit less CO, NOx and VOCs than conventional gasoline. However, they have lower energy content, are more expensive, and have a shorter driving range. Poor cold-start is another drawback. Gasohol, a 90% gasoline and 10% ethyl alcohol mixture, was widely marketed in the late 1970s.8Although no longer advertized as gasohol, alcohol is presently added to some premium grade gasoline to increase octane ratings.

2.4 Progress in the development of low-emission vehicles

2.4.1 Hybrid vehicles

Any vehicle is hybrid when it combines two or more sources of power. These vehicles have a battery pack, an electric motor and a small petrol, diesel oralternative-fuel engine. The engine is used when extra power is needed for accelerating or for driving long distances. As a result, a hybrid vehicle has very low emissions but a greater range and better acceleration.Some Japanese companies have already introduced hybrid car in the market.

2.4.2 Electric vehicles

Dissimilar to traditional motor vehicles, which are powered by heat energy produced during the combustion of gasoline, electric vehicles are powered by electricity. The electricity is generated by chemical reactions that occurs in batteries. Rechargeable lead-acid batteries are commonly used. The main advantage of electric cars is that there are no tailpipe emissions and in this sense indeed, they are the only zero-emission vehicles.. There are many disadvantages to an electricvehicle. Electrical energy costs are substantial, initial vehicle cost is also high. Its batteries are heavy and take up a great deal of room – the whole trunk area and more. The measure of battery power limits its driving range to about 80 km.

In addition, its acceleration is poor. Infrastructure for recharging batteries along the road side has to be developed. Although the tailpipe emission is zero but pollution from electric vehicle is not zero. Disposal and management of used lead acid battery is itself a problem from the pollution point of view.Every year electric vehicles are likely to cause disposal problem of batteries in comparison to petrol engines.

2.4.3 Fuel cell vehicles

Fuel cells are electrochemical devices that directly produce DC electricity without combustion . Like batteries, fuel cells have anodes, cathodes, an electrolyte, and positive and negative terminals. However, unlike batteries they do not require long recharging times. Fuel cells produce electric power as long as they are supplied with fuel- hydrogen plus oxygen or air. Since hydrogen is not readily available, a reformer can be used to convert more common fuels such as gasoline, natural gas, ethanol, or methanol into hydrogen to power the fuel cell. Fuel cells offer most of the advantages of battery-powered electric vehicles without most of the disadvantages The main by-products produced when running solely on hydrogen fuel are only water vapour and heat. However, the available fuel cell vehicles are still extremy costly.For example, fuel cells cost about $4,500 for a 100-horsepower drive train. It is still high compared with the to $2,000 to $3,000 for a piston engine and automatic transmission.

2.5 Economics of Vehicular Pollution Control

In general, the vehicular emissions can be controlled at three stages: (i) Stage 1 or pre-combustion stage where the quality of fuel can be upgraded; (ii) Stage 2 or combustion stage where engine modifications are needed; and (iii) Stage 3 or post-combustion stage where exhaust treatment devices like catalytic converters are required. As a consequence the policy instruments employed can be oriented at any of these three stages and can be directed towards either producers (fuel or vehicle producers) or dealers (petrol pump owners or vehicle dealers).Besides these, there are few 'non-technical' instruments that can be aimed at consumers / individuals, requiring behavioural adaptations either in the mode of transport or necessitating periodic maintenance check to minimize the pollution levels. Needless to say any instrument intended for these behavioral changes would either be before stage 1 (i.e., stage 0) or after stage 3 (i.e., stage 4). (Kathuria, 2002).

Table 2.5 Emission control technology costs for gasoline-fueled vehicles

- S.No.	Technology	Engine cost increase, %	Fuel Consumption Change
1.	Lean-burn engine with carburettor and conventional ignition	1.0	-2
2.	Pulse air and exhaust gas circulation	4.5	3
3.	Lean-burn engine with carburettor and programmed ignition	2.0	1
4.	Recalibrated conventional engine with electronic fuel injection	8.0	2
5.	Lean-burn engine with electronic fuel Injection	9.0	-7

6.	Lean-burn engine with oxidant catalyst	4.5	-3
7.	Open-loop three-way catalyst Carburetor	4.1	2
8.	Lean-burn engine, closed-loop, electronic fuel injection, variable intake oxidation catalyst	15.0	-7
9.	Closed-loop, electronic fuel injection, three-way catalyst	13.0	3

Source: European Conference of Ministers of Transport (ECMT, 1990)

2.6. Old motor vehicles and pollution potential

A vehicle operator knew from his experiences that as motor vehicle gets more seasoned there is dynamic loss of power, the fuel and lubricating oil utilization become higher and density of smoke (visible) in the tailpipe emission wind up observably higher too. And after pass of certain time period, there comes a moment when it is no longer possible to run the vehicle. This is clearly due to the "natural" wear of the engine, i.e., the ring/piston group. The sizes of the ring/piston get smaller and that of the cylinder bigger, widening the "gap" between the piston and cylinder or the air-tightness ends up recognizably lesser.

Luckily, almost all the engine's wearing parts can be replaced by new one, oversized ring/piston or by standard sized ring/piston if the cylinder is that of sleeve system. After the change of worn-out parts or upgrade, the engine become as good as new and the power yield, the fuel and oil utilization return to original level and more importantly the tailpipe emission also comes returns to that state when vehicle was new. Along these lines, earlier the vehicles' year of manufacture, the more fuel is consumed and more pollutants are emitted through tailpipe. It is, therefore, important to take up the inspection and maintenance of vehicles with a view to limit vehicular emissions. In this context, the test methodologies available for inspection/maintenance of vehicles are discussed here.

2.7 Measurement Techniques

Several different techniques have been developed to measure vehicle emissions. Each of these techniques has strengths and weaknesses, which should be considered while analyzing emission measurements.

2.7.1 Federal Test Procedure

The first large-scale sampling of vehicle emissions was for the purpose1of certifying manufacturer compliance with new-car emissions standards prescribed in the Clean Air Act Amendments (CAAA) of 1970. The U.S. Environmental Protection Agency (EPA) established an elaborate testing protocol, called the Federal Test Procedure (FTP), so that all vehicles could be tested under identical preparation and driving conditions. The FTP emissions are measured in gramme per mile (gpm) and then averaged together, weighted by the relative amount of driving under each section of the cycle, to achieve a composite gpm exhaust emissions rate. The FTP includes measurement of fuel evaporation during the driving cycle (running losses), for a short period after driving ceases (hot soak), and as the vehicle sits in an enclosed chamber during a multi-hour temperature cycle (diurnal).

2.7.2 Idle Testing

An idle emissions test measures pollutant concentrations in the tailpipe exhaust of a stationary vehicle . The test was proposed in the 1970 CAAA as a quick and inexpensive means to identify in-use vehicles with irregularly high emissions. Unlike the FTP, idle testing includes no transient vehicle operation and no engine load. Idle testing is not used for NOx emissions testing since NOx emissions are always low during idle. HC and CO emissions during idle also may not be representative of emissions when a vehicle is driven under load. The 1977 CAAA required tha all urban areas with poor air quality use idle testing in vehicle inspection and maintenance (I/M) programme. The first I/M programmes used tailpipe probes to measure the concentrations of HC, CO, and CO_2 in the exhaust of idling vehicles. An enhancement of the basic idle test involves putting the car in neutral and revving the engine to 2500 rpm in an attempt to simulate the vehicle's emissions under loaded conditions.

2.7.3 IM-240

The IM240 test utilizes 240 seconds of the FTP driving schedule to quantify hot stabilized emissions during transient and loaded mode vehicle operation. It is the centerpiece of guidelines developed by the EPA to meet the Enhanced I/M programme order of the 1990 CAAA. Upgraded I/M was intended to address several weaknesses of original I/M programmes by 1) measuring emissions, including NOx, during loaded mode vehicle operation and 2) separating vehicle testing from vehicle repair by requiring a centralized network of contractor- run test-only facilities. Although desired for Enhanced I/M, no practical tests are available to measure evaporative HC emissions in an I/M setting.However, it is additionally the most time-consuming and costly test.

2.7.4 Acceleration Simulation Mode (ASM)

Many states opposed the use of centralized IM240 testing refering the length of the test and the burden to motorists of driving further to a small number of centralized test stations. The California Bureau of Automotive Repair (BAR) build up an alternative test method to the IM240 called the Acceleration Simulation Mode (ASM) test. Emissions are measured in exhaust concentration utilizing a tailpipe test, similarly as in the idle test. The ASM test can be considered an change over the idle test as in that, emissions are measured when a vehicle is under load. However, the ASM does not measure emissions under varying loads and speeds, as does IM240. In addition, NOx emissions, which are not measured during idle testing, are measured under the ASM test.

2.7.5 Remote Sensing

Remote sensors measure the changing intensity of a light beam directed across a roadway as the beam interacts with a passing vehicle's exhaust plume. The first generation sensors utilized an infrared source and a series of filters to isolate specific wavelengths that are absorbed by the CO, HC, and CO_2 in vehicle exhaust. A video camera set nearby the remote sensor records every vehicle's license plate information, which is stored together with the emission measurement . Remote sensors measure pollutant ratios, for example CO/CO_2 and HC/CO_2,however can't quantify absolute concentrations because the amount of exhaust dilution is not known.However, since more than 99% of fuel carbon atoms are emitted as CO, HC or CO2, the emissions ratios can be combined with known fuel properties (e.g., fuel carbon content) to calculate the mass of each pollutant emitted per gallon of fuel burnt (Bishop et al., 1989 and Zhang et al., 1993). Oxidation process at surface of dumped mine waste may produce acid water drainage, which can affect the surface and groundwater quality (Ramanathan et al, 2000). Fuel-normalized emissions factors can be calculated for any emissions test, including the FTP, IM240, and ASM, as long as measurements of both CO and CO2 are available. In recent years, remote sensors have been developed for the measurement of on-road emissions of NOx and individual hydrocarbons or other emissions gases such as ammonia (Zhang et al., 1996; Jimenez et al., 1999b and Popp et al. 1997). Multi-date infra red Landsat images were utilized to study the environmental changes in Sierra Leone, West Africa, especially to understand the impact on hydrogeomorphology (Butler, 2007). An attempt has made to delineate the magnesite ore deposits in Salem using hyperspectral remote sensing data, which reveals that potential of using narrow band hyperspectral data for further mapping of impact mining on environment (Thangavelu, Shanmugam, & Bhattacharya, 2011). The driving mode can be estimated by a calculation of the physical load encountered by the vehicle as a result of aerodynamic drag, tire rolling resistance, inertial and gravitational acceleration forces, and engine friction (Ross, 1994; Jimenez et al., 1999a and Singer 1998). To address concerns about measuring emissions during cold start driving,remote sensors are sometimes located on highway off-ramps or on surface thoroughfares that cannot be accessed directly from residential streets.

2.7.6 On-Board Diagnostics

A new technology that can possibly contribute important information about vehicle emissions is the on-board diagnostic (OBD) computer system required on all new cars sold after 1995. The OBD system is designed to monitor over 50 parameters of vehicle and engine operation. The OBD systems have encouraged manufacturers to design better and more durable engine and emissions controls, including more broad monitoring and backup systems. In addition, OBD systems are recognizin manufacturing flaws on individual vehicles before they leave the plant.A drawback to OBD systems is that they do not quantify tailpipe emissions directly; rather, they predict when emissions are likely to exceed standards, based on extensive monitoring of engine and emissions control parameters.Along these lines, the usefulness of OBD data is currently limited to determining failure rates of the vehicle fleet.

It is worthwhile to mention here that Central Pollution Control Board, Delhi, has also prescribed the categories of I/M test types for in-use vehicles and relevant standards which are given below.

Table 2.6 In-use emission norms for Petrol/CNG/LPG-driven vehicles (measured at idling)

S. No.	Vehicle type	CO (g/km)	HC+NOx (g/km)
1.	BHARAT Stage -II compliant 2&3 wheelers (2/4 stroke)	1.6	1.5
2.	BHARAT Stage -III compliant 2&3 wheelers (2/4 stroke)	1.0	1.0
3.	BHARAT Stage -III compliant Four Wheelers passenger cars	2.3	0.35
4.	BHARAT Stage -IV compliant Four wheeler passenger cars	1.0	0.8

Source: CPCB (2017)

The literature was reviewed extensively in respect of the work done by various investigators towards monitoring the effect of vehicle-related parameters on emissions from the vehicle's tailpipe, which is described here. The salient findings of the literature review in respect of materials and methods have been incorporated in the pertinent chapter.

(Abhinav Pandey et al., 2016) while worked on emission and various vehicle related factors and correlate with CO and HC emission.

Pandey (2006) has covered various aspects relating to vehicular emissions including the control strategies and use of alternative fuels.

J. Gallagher and R. Livo (1991), while working on emission and age distribution of vehicles in the Colorado I/M programme, reported that the vehicle age and maintenance have an impressive effect on CO emissions.

L. H. Watkins (1991) in his work on air pollution from road vehicles assessed that the total amount of air pollutants, especially CO and HC, has not been decreased significantly because of continued increase of motorization whereas another reason is believed to be an increase in the annual mileage which occurs practically all over the globe and reflects the human life level.

Asif Faiz (1993) reported that the share of road traffic for CO is more than 90 % and that of HC close to 100 %, while studying the automotive emissions in developing countries, he implicated such emissions for global warming, acidification and urban air quality.

Bishop et al. (1989) and Zhang et al. (1993) developed a device to remotely measure the emissions of a vehicle as it is driven on the road. The license number of the vehicle was used to retrieve the information about each vehicle (age, type and mileage etc.) from registration records.

Singer and Harley (1996, 2000) measured the fuel-normalized emission for tens and thousands of vehicles throughout Los Angeles area and these factors have been combined with fuel sales data to estimate total exhaust emissions of the on-road vehicles.

Wenzel and Ross (1998) reported that different component malfunctions resulted in very different emissions consequences. In general, malfunctioning vehicles with high CO emission tended also to have high HC emissions, while vehicles with high NOx, emissions tended to have relatively low CO and HC emissions.

Shih et al. (1997) reported that small changes in how a vehicle is driven can also affect the tailpipe emission. For instance, how a driver shifts gears on a vehicle with a manual transmission, or how smoothly a driver depresses and releases the accelerator, may affect the emission rates.

Goodwin and Ross (1996) and An et al. (1997) studied the effect of engine load on vehicle emission and found that the relationship between emissions and load depended on the fuel delivery and emission control technology, but as a general rule, NOx emissions almost always increase with increasing load. Further, under high speed and acceleration requirements, vehicles of present times are designed to have excess fuel injected into the engine's cylinder and this enrichment of the air/fuel mixture, in turn, leads to elevated CO and HC emissions.

Knepper et al. (1993) performed a study of repeated FTP tests on the same vehicles and reported that CO and HC emissions from malfunctioning vehicles can change by over a factor of seven on independent FTP tests although the uncertainty is much less for properly functioning vehicles.

To overcome this difficulty, analysts have typically used the forms of the log-normal (Stephens 1994) and gamma (Zhang et al. 1994) distributions to model vehicle emission data.

Pollock et al. (1999) calculated the mean emissions based on the logarithmic transformation and found that the emissions of any high emitting vehicles in the sample are given much less weight in the estimated mean emission level, and the models tend to underestimate fleet emissions.

Stedman et al (1997) demonstrated the usefulness of considering a collection of average values representing fairly large, unbiased subset of emission measurements in the context of remote sensing measurements taken over a five day period and the five averages were then averaged to obtain an estimate of fleet-average emissions about which a symmetric confidence interval could be constructed.

Some researchers have utilized non-parametric techniques, such as bootstrap sampling (Pollock et al. 1999 and Frey et. al. 1999), since such techniques do not require an assumption regarding the distribution of the underlying population.

Identifying polluter characteristics has been the focus of much I/M programme-research. Most studies have found increasing vehicle age and mileage to be associated with increasing vehicle emissions and emissions test failure. Washburn et al. (2001) and Bin (2003) found that vehicle type, manufacturer, country of origin, engine characteristics, and type of fuel are also critical factors.

Heirigs and Gordon (1996) reported the results of an experimental programme in Arizona in which back-to-back IM240 tests were conducted on a sample of vehicles that failed their I/M test after waiting at least 15 minutes for a test lane to open.

Some researchers have developed factors to convert emissions measured in I/M programmes to projected emissions under FTP test conditions. These are developed by running regression models on the measured I/M and FTP emissions using a relatively small sample of vehicles tested under both test conditions (Austin et al. 1997 and DeFries and Williamson, 1997). However, such factors are only valid on a fleet-average basis, not for the emissions of individual vehicles (DeFries et. al. 1999). Another approach is to compare instantaneous emissions measured during a specified engine load (Jimenez 1999 and McClintock 1999), which would allow remote sensing measurements, for example, to be compared with FTP, IM240 and even to ASM emission test results.

Bishop and Stedman (1996) argue that average emissions increase as vehicles age because of poor maintenance practices and tampering. A minority of vehicles on the road disproportionately contributes to aggregate emissions . Most studies suggest that, on average, 10% of vehicles produce 50–60% of all vehicular emissions, although claims range from 20% being responsible for 50% of emissions, to 5% generating 80% of emissions. These differences stem mainly from how high-emitters are defined or classified and from the methodology used to measure vehicular emissions and activity (Wolf et al. 1998).

Beaton et al. (1995), Calvert et al. (1993) and Rajan (1996) have found that the high-emitter problem spans all model-years. Because vehicle emissions and fuel efficiency standards are distinct entities, the relationship between fuel economy and emissions is unclear. Indeed, more fuel-efficient vehicles have lower emissions only in the absence of emission controls, thus equating engine and tail-pipe emissions.

Washburn et al. (2001) use three-stage least squares regression to estimate simultaneous equations for CO, CO_2, and HC. The data used ranges from standard I/M testing to remote sensing and roadside pullover. I/M tests vary from complete IM240 to idle and 2-speed (idle + cruising) tests. Finally, pollutant emission measures also vary, from g/mile or g to concentrations (percentage, ppm).

Overall, this variability creates much uncertainty when comparing the results of various studies.The enhanced I/M programme was said to be important because a regulatory impact analysis (RIA) prepared by the EPA in 1992 predicted that Enhanced I/M would be an unusually cost-effective way of reducing mobile-source emissions (USEPA, 1992). Partly as a result of the US studies, the World Bank has become an enthusiastic proponent of I/M programmes for mega cities in developing countries (Faiz et al., 1996).

Riveros et. al. (2002) used and exemplified the emission curves for Volkswagen, a popular carmaker in Mexico, with a larger number of its vehicles also used for public transport and found that knowledge of this curve could be used to stimulate the production of less polluting models and to compare manufacturer’s vehicles in different countries and to compare I/M programmes.

Kazopoulo et. al. (2006) performed the measurements of exhaust emissions for a sample of 100 vehicles to characterize the emission levels and to develop emission standards for CO and HC under a basic I/M programme and set, by measuring the actual distribution of emissions in the sample of Labanese vehicles, the emission standards such that a maximum of 20% of the vehicles would fail.

2.8 Concluding remarks

From the previous analysis on tailpipe emission only one experiment was held in Gorakhpur city which is not sufficient for the present vehicular population and it is required for further more analysis. Likewise, the availability of the data including vehicle-related parameters and emissions is additionally meager in literature. It is, therefore, important to take up a study involving data acquisition and analysis programme for assessing the relevance with and impact of various vehicle-related parameters in respect of the tailpipe emissions from vehicles. In this perspective, it is essential to test the effect of various vehicle-related parameters on tailpipe emissions and to develop a correlation, wherever feasible, between the vehicle-related parameters and emission levels for predicting the emission from the vehicles using such vehicle-related parameters.

In the present work, in view of the limitations of time and resources, an attempt has been made to quantify the effect of vehicle-related parameters on petrol-driven passenger cars of Maruti and Hyundai Udyog Limited on their CO, HC and NO emissions for idle and fast idle test conditions.

Remarkably, as the provisions of idle test method is applicable in India, whereas the fast idle test method is being adopted by many developed countries like, U. K. and U.S.A. etc., the relative standing to the two test methods has also been presented considering its significance in standardization practice, which might be taken up in future in India as well. The materials and methods, collection and analysis of data, results and discussion and important recommendations and conclusion have been presented in subsequent chapter.

CHAPTER 3

MATERIALS AND METHODS

The field study attended a sample of about 75 petrol-driven passenger cars of Maruti and Hyundai. The testing procedure was taken up at the authorized service station of Sanjay Motors, The vehicles were stopped at the final inspection bay of the workshop randomly prior to any maintenance task in the specified way.

The testing of emissions included the estimations of CO, HC and NO which was conducted in two modes. The first was the idle engine mode, and the second was the fast-idle mode which infers a rotary speed of 2,500 as per EPA and CPCB guidelines. In addition to these estimations, individual vehicle data and vehicle-related parameters were also recorded.

The literature review has revealed that there are two testing methods in I/M programs I. e., basic and advanced. The most common basic emission test in I/M programmes is the measurement of CO, HC and NO concentrations in the exhaust while the vehicle is idling. The idle test was originally developed for vehicles with little or no emission control, and for these vehicles it can detect a large proportion of malfunctioning or maladjusted engines (Hickman 1994).To help reduce the false failures associated with the idle test, some I/M programs require pre conditioning at 2500 revolutions per minute (rpm) with no load for 3 minutes before a final idle test failure determination is made. This preconditioning helps guarantees that control system is in normal closed-loop operation and the catalytic converter is adequately warmed up.

After passing the high-idle test, the conditioning is normally adequate for estimation at normal idle . More than 33% of vehicles that fail the initial test pass after extended preconditioning (Tierney 1991). While measuring CO and HC exhaust emissions from a sample of 625 cars in Israel using the idle and fast idle (3,000 rpm) tests, Anilovich and Hakkert (1996) observed that emissions in the idle mode were higher than the fast idle mode and these data were found to be consistent with data obtained by Armstrong et al. (1987). Also, unlike the idle test, which is conducted at a single speed and expresses emissions in terms of percentages for CO and parts per million (ppm) for HC, the IM240 test is conducted at a range of accelerations in terms of grammes per kilometer (g/km) for NO, HC, and CO (Walsh, 1994 and Harrington et. al., 2000).

However, the idle tests have some advantages over the others-

1. Idle test is capable of monitoring gross emitters.

2. The basic idle test uses comparatively cheap equipment which is adoptable even with the lack of technical know-how to operate more sophisticated equipment as in the advanced tests.

3. Idle mode emissions for CO and HC are high compared with those of other driving modes (Colls, 2002) and idling as well as low speed ranges involve a large proportion of total driving time in urban zones (Tong et al., 2000).

After selection of the testing methods, a total number of about 75 vehicles, distributed across model years ranging between: 2000 and 2017 were tested. This sample size seems relatively small at a glance and indeed it was observed that the level of error on the recorded measurements was high. However, such a sample gives a clear indication of the condition of Swift, Santro, Wagnor, and Alto in Delhi area.

The data were collected in the format of the Data Collection Sheet (as shown in Appendix-A) and included vehicle registration number, vehicle model and model year, vehicle age, vehicle mileage, time since last inspection, engine capacity, compression ratio, number of cylinders, bore □ stroke, fuel distribution system, level of inspection/maintenance, emission control system etc. Testing1of vehicles was conducted in summer (June-July, characterized by relatively warm temperatures around 38ºC, in the forenoon and afternoon hours (10 a.m. to 3 p.m.) and under hot start conditions for 2/3 minutes or until concentrations stabilized.

The testing was performed in two modes –

- IDLE engine mode
- FAST IDLE mode

The vehicle model codes, vehicle model or brand names along with the idle RPM designated by the manufacturer and the fast idle by USEPA are given in the concerned table.

Table 3.1 shows the different models of the petrol-driven passenger cars which underwent the study.

Table 3.1 Vehicle model and model codes

S. Number	Vehicle Code	Vehicle Model	IDLE RPM (Designated)	FAST IDLE RPM
1.	MS	M-Swift	850	2200-2800
2.	MRF	M- Alto (Lx/Vx)	710	2200-2800
3.	MRD	M- Wagon *R*	820	2200-2800
4.	HS	H- Santro	850	2200-2800

A AVL DIGAS 444 was used to measure instantaneous as well as fast idle mass concentrations of CO (%),HC (ppm)and NOx(ppm). The analyzer uses NDIR (Non-dispersive Infrared) method to measure CO,HC and NOx levels. The operating principle explained through a diagrammatic sketch is shown in Figure 3.1, while the salient features of the relevant analyzer are presented in Figure3.2. The analyzer was new and factory–calibrated prior to its operation (the next SPAN calibration was scheduled after the measurements were conducted). The equipment was facilitated with Manual-zero calibration mode and was zeroed before and after each fast and fast idle test by placing the sampling probe about 2 m above the floor and away from the exhaust pipe or chemical fumes so as to establish a base set of gas ratios before testing. The set-up for gas analyzer is presented in Figure 3.3. Following zeroing, the sampling probe was inserted into the vehicles' exhaust pipe up to a horizontal depth of 300 mm (or 10 inches) by ensuring that the vehicle's exhaust system as well as the sampling probe itself is free from leakages, if any.

Since all the vehicles were provided with single exhaust pipe, no provision was made for testing dual-pipe exhaust system. The instrument was able to eliminate the moisture and hence the errors from concentration readings. Also, by virtue of the presence of a printer portal, the data were printed on the spot.

Therefore, the entire study is divided into five main groups as depicted in Figure3.4-

- Characteristics of tested vehicles: registration number, model/model year, vehicle age, vehicle mileage, time since last inspection, engine capacity, compression ratio, number of cylinders, bore X stroke, fuel distribution system, level of inspection/maintenance, emission control system etc.,
- Sampling of 75 petrol-driven passengers cars of Maruti and Hyundai,
- Measurement of exhaust (tail pipe) emission characteristics (in two modes viz. idle and fast idle) CO (%) and HC (ppm) and NO (ppm),
- Assessment of vehicle-related factors on emission levels.
- Development of predictive equations for vehicular CO, HC and NOx emissions with respect to vehicle age and mileage

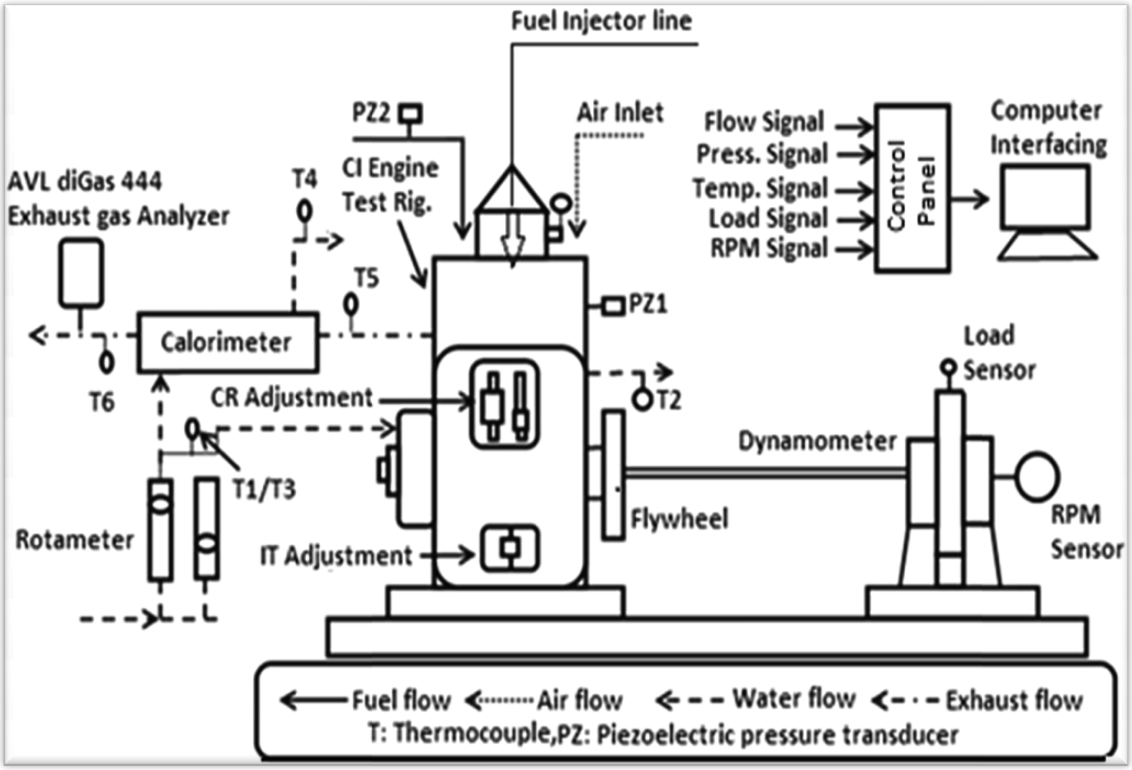

Fig. 3.1 Operating principle of auto exhaust analyzer

Measurements	Accuracy
Temperatures	±1°C
Speed	±1 rpm
Time	±0.5%
Smoke meter	±1%
CO	±0.03% vol
CO_2	±0.5% vol
HC	±10 ppm vol
O_2	±0.1% vol
NO	±50 ppm vol
Pressure	±0.2%
Crank angle	±.05 deg
Calculated results	**Uncertainty**
Thermal Efficiency	±1%
Time	±0.5%
Fuel volumetric rate	±1%

Fig. 3.2 Salient features of the auto exhaust analyzer

Fig. 3.3 Front view of the auto exhaust analyzer set up

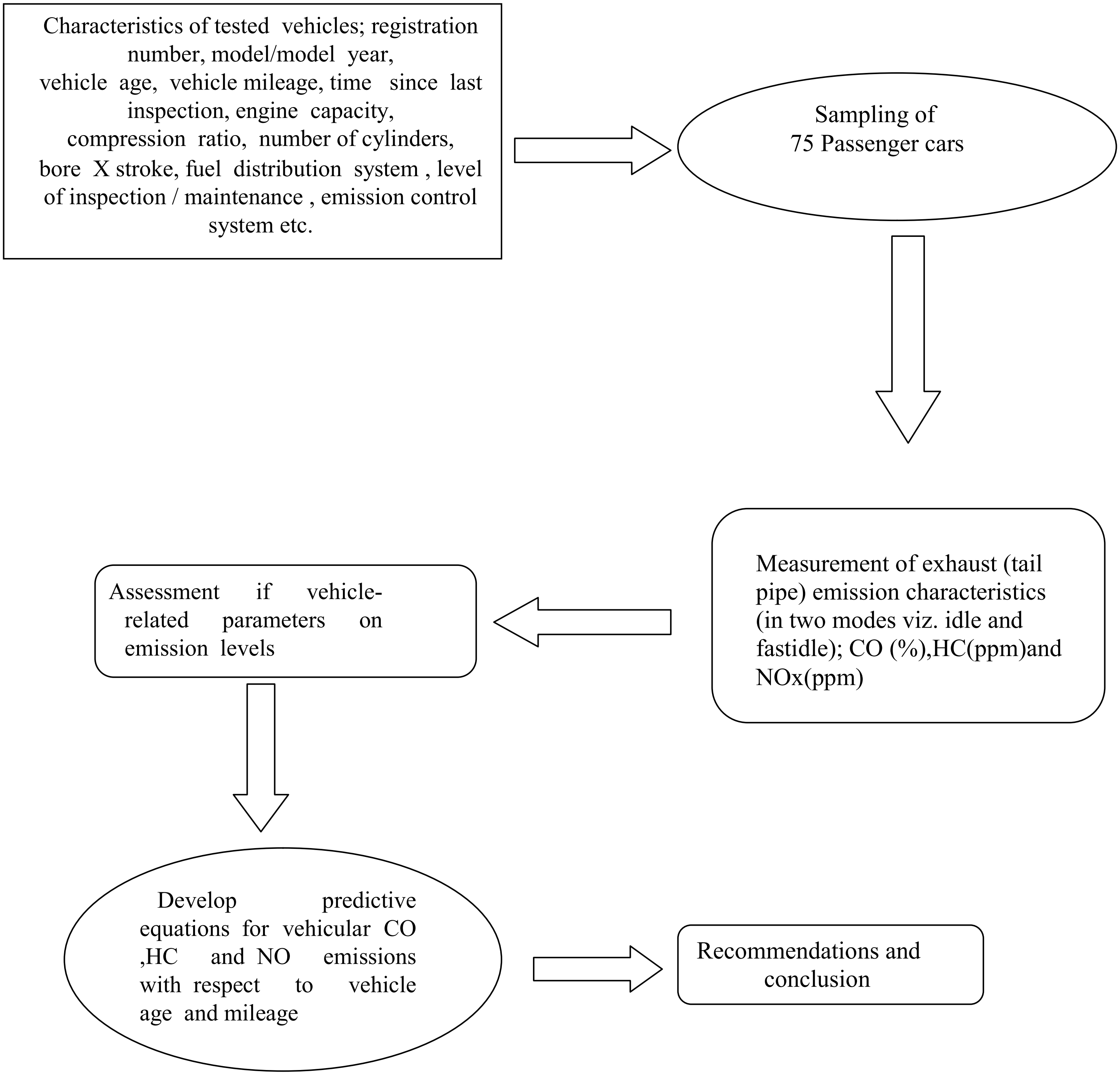

Fig. 3.4 Methodology of the study

The data collected in the study are given in Appendix – B, which have been analyzed in the next chapter .

CHAPTER 4

ANALYSIS OF DATA, RESULTS AND DISCUSSION

With a reference to study the impact of multiple vehicle-related parameters on the tailpipe emissions, the data retrieved during the field study carried out in the workshop of Sanjay Motors, Rohini Sec-17, New Delhi in respect of petrol-driven passenger cars of Maruti and Hyundai are analyzed here. Considering the applicability of two testing methods, namely, idle and fast idle tests, CO, HC and NO concentrations with vehicle-related parameters like vehicle age, vehicle mileage, time since last inspection,level of inspection/maintenance, etc. are plotted and, wherever, applicable, model-wise variation is also considered.

4.1 Effect of vehicle age on CO, HC and NO emissions:

The emissions of CO ,HC and NO from different models of petrol-driven Maruti and Hyundai cars were also plotted with respect to vehicle age for idle and fast idle test modes and the results are shown in Figures 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.23, 4.24, respectively.

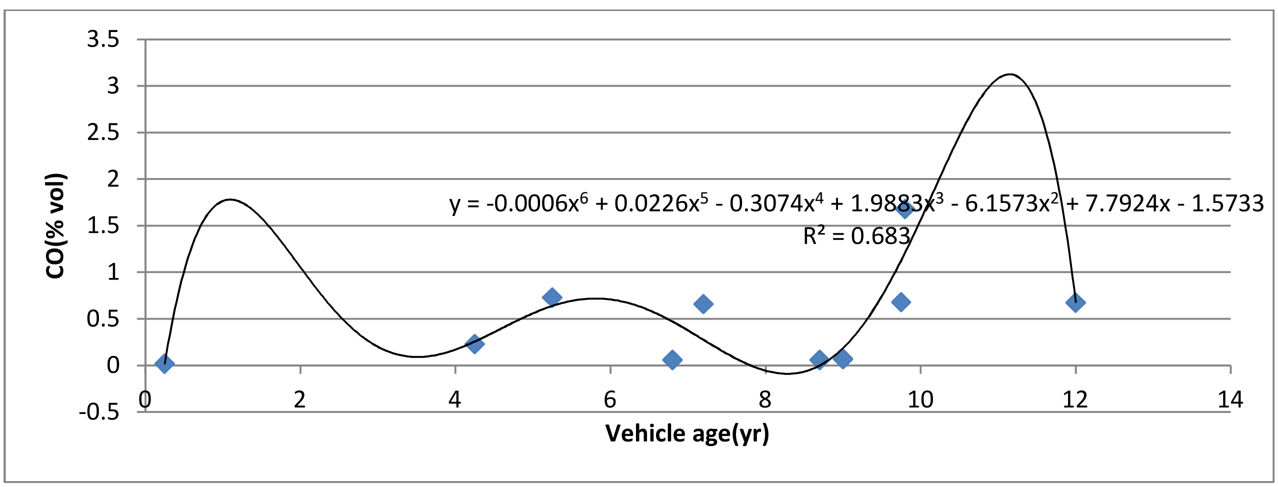

Fig.4.1 Vehicle age vs CO emission of Swift (Idle)

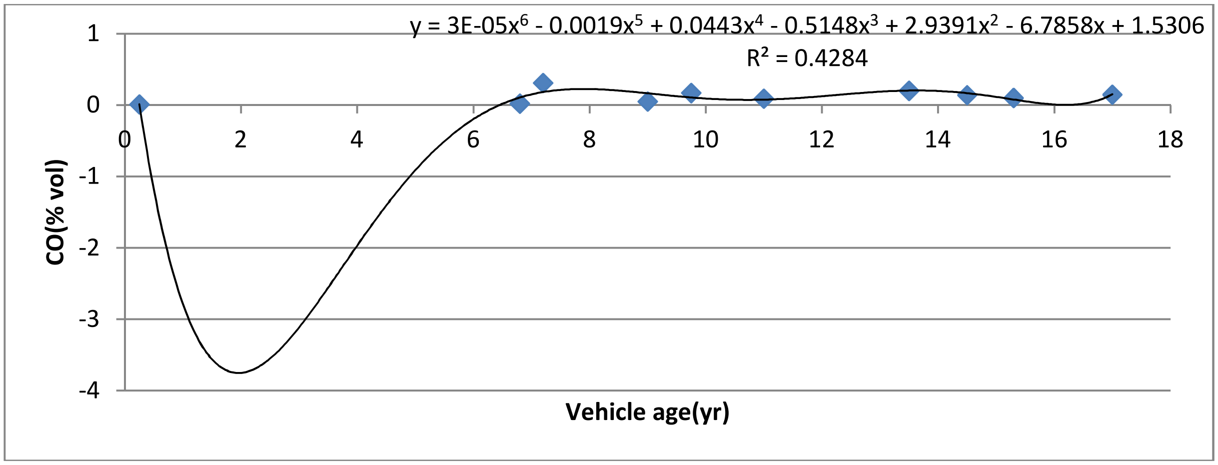

Fig.4.2 Vehicle age vs CO emission of Swift (Fast Idle)

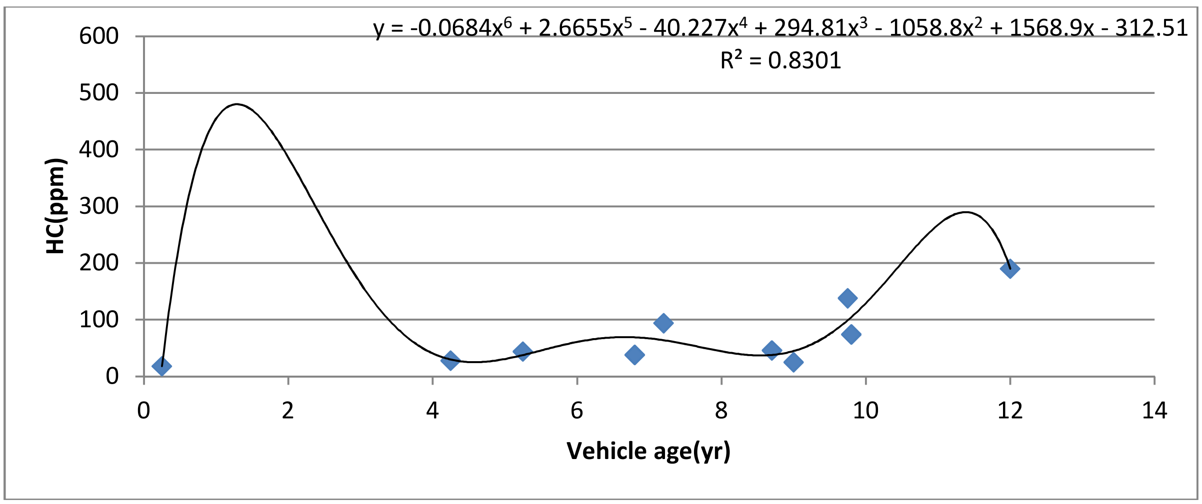

Fig.4.3 Vehicle age vs HC emission of Swift (Idle)

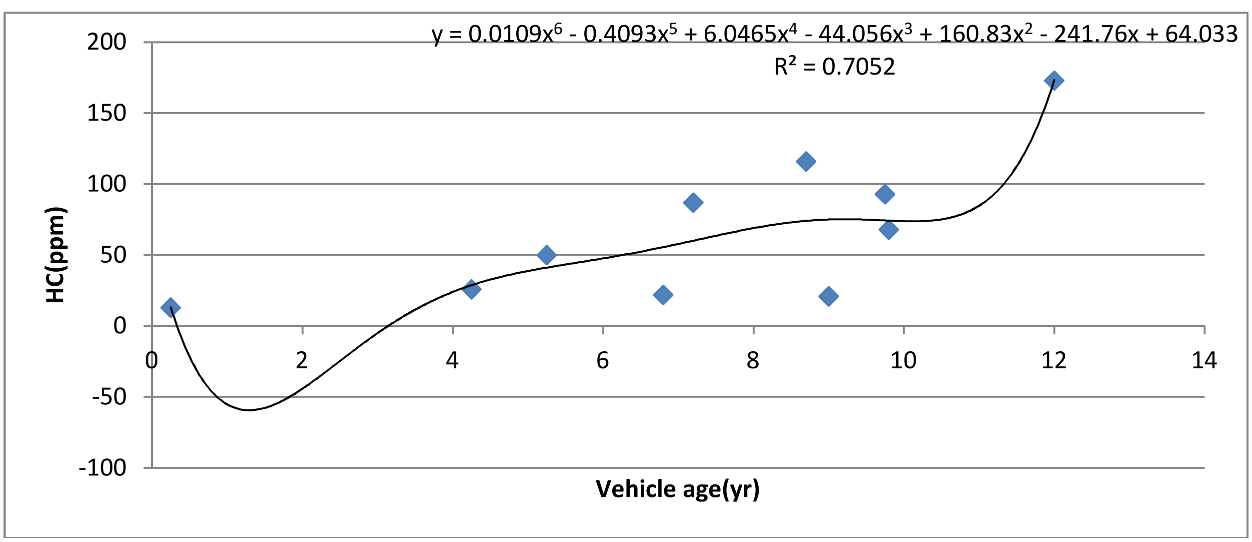

Fig.4.4 Vehicle age vs HC emission of Swift (Fast Idle)

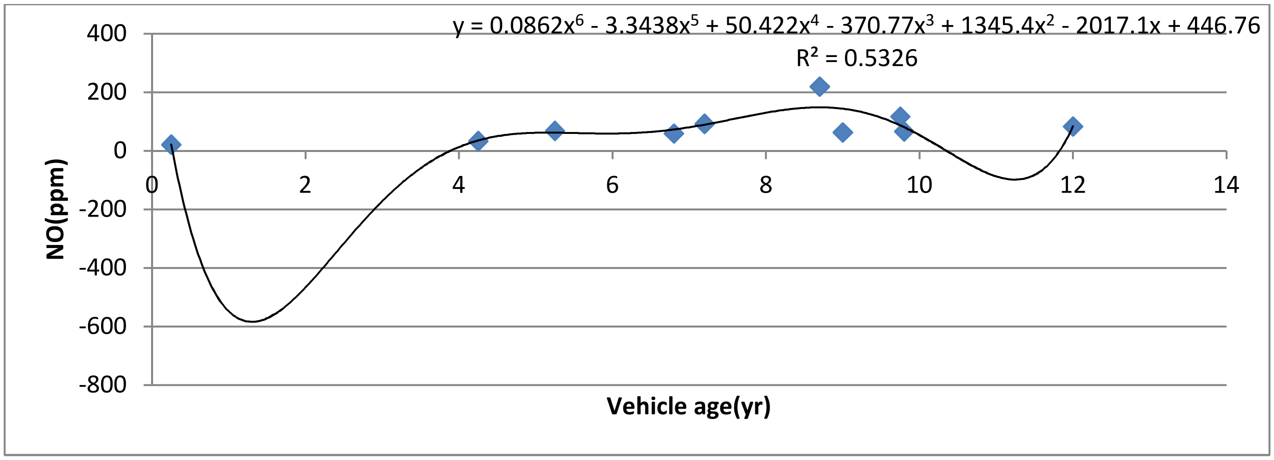

Fig.4.5 Vehicle age vs NO emission of Swift (Idle)

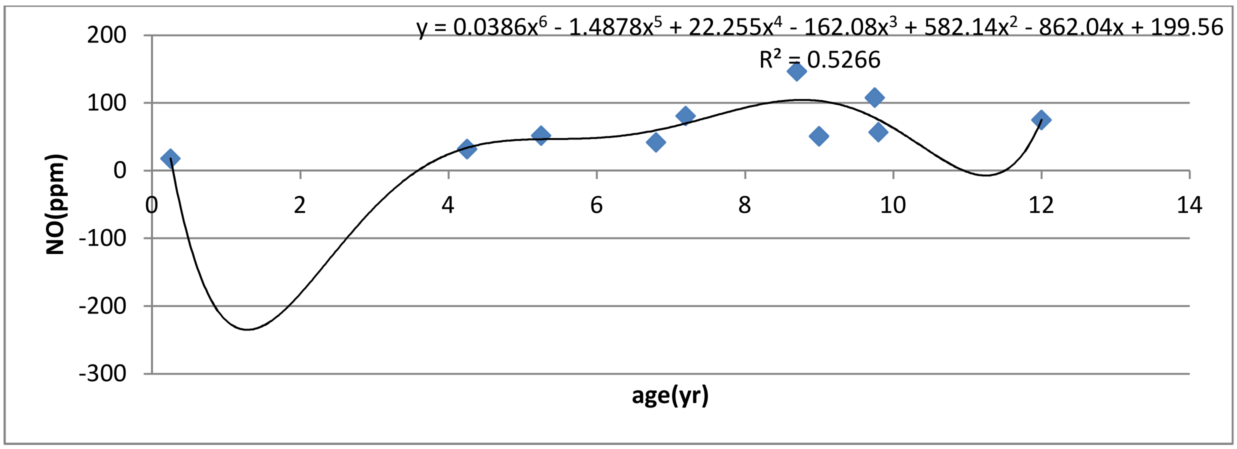

Fig.4.6 Vehicle age vs NO emission of Swift (Fast Idle)

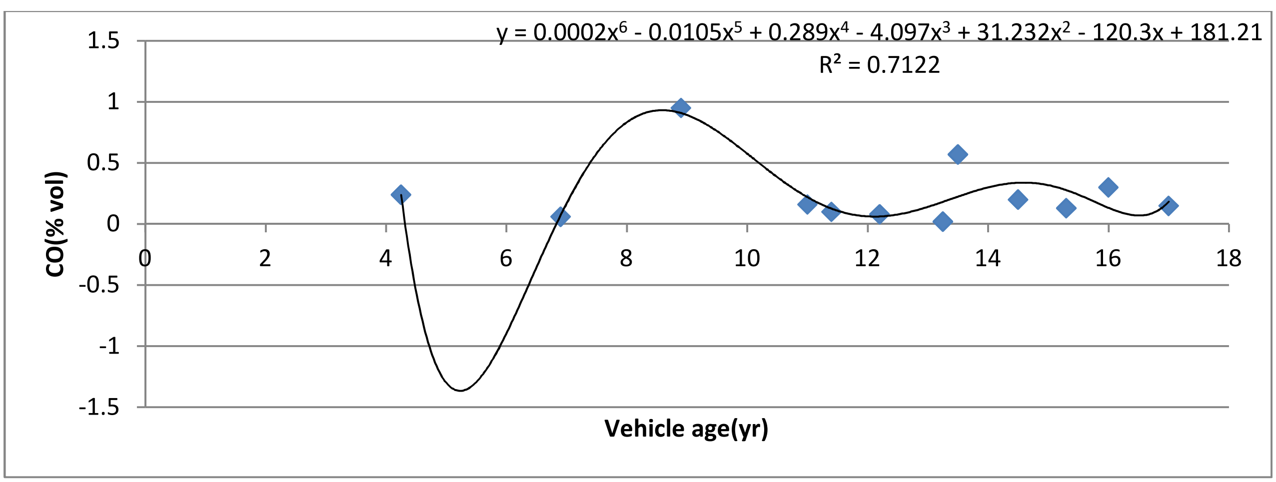

Fig.4.7 Vehicle age vs CO emission of Santro (Idle)

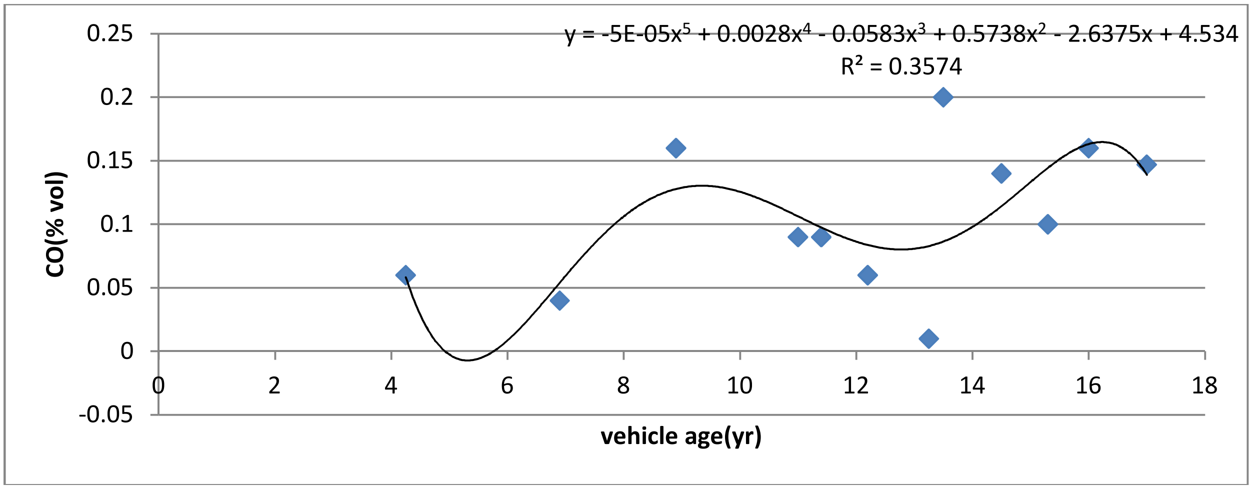

Fig.4.8 Vehicle age vs CO emission of Santro (Fast Idle)

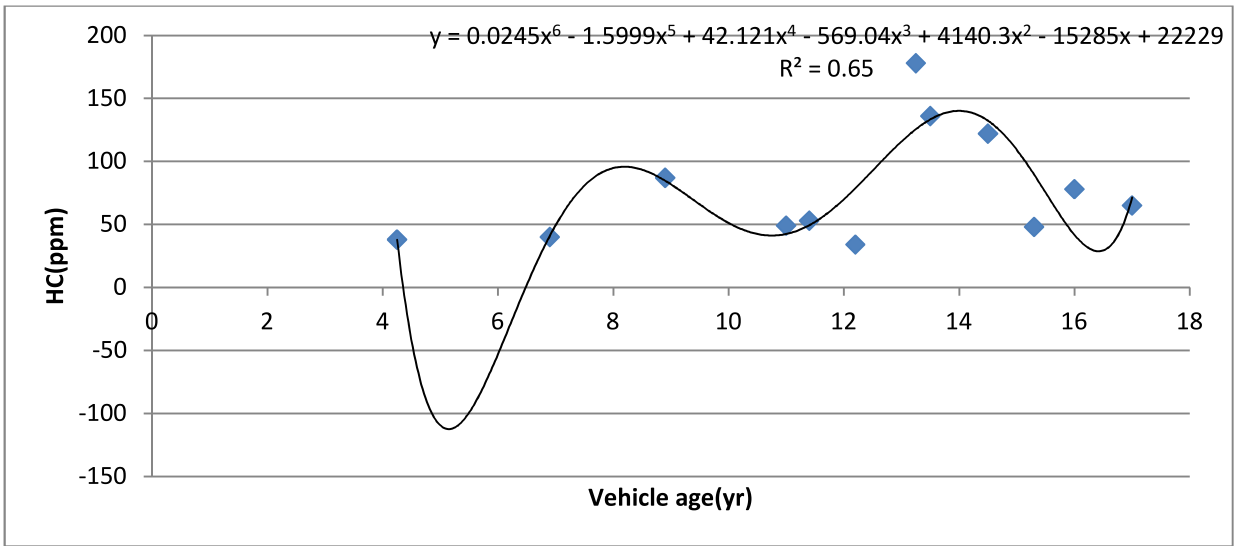

Fig.4.9 Vehicle age vs HC emission of Santro (Idle)

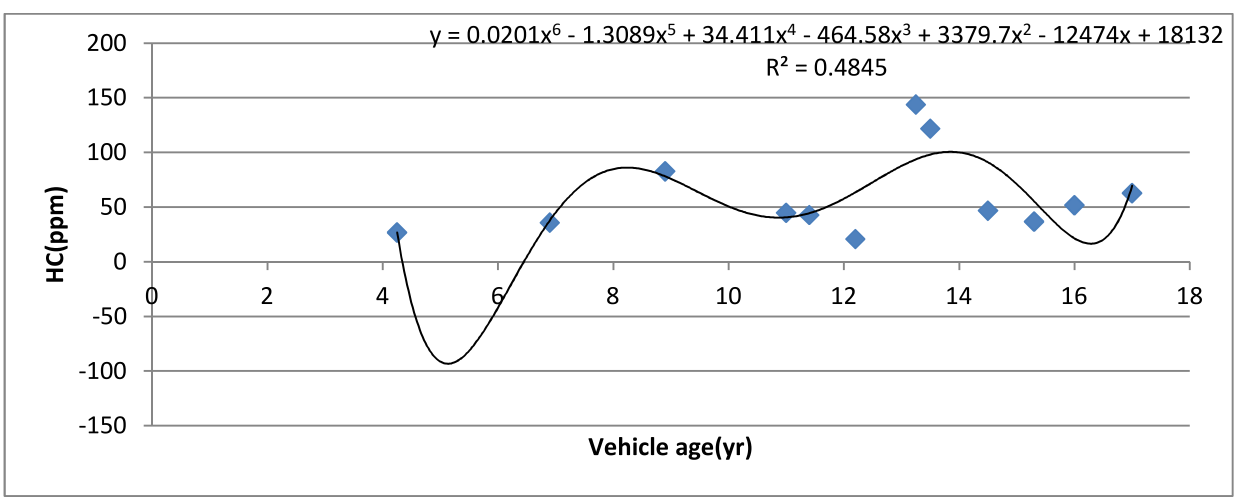

Fig.4.10 Vehicle age vs HC emission of Santro (Fast Idle)

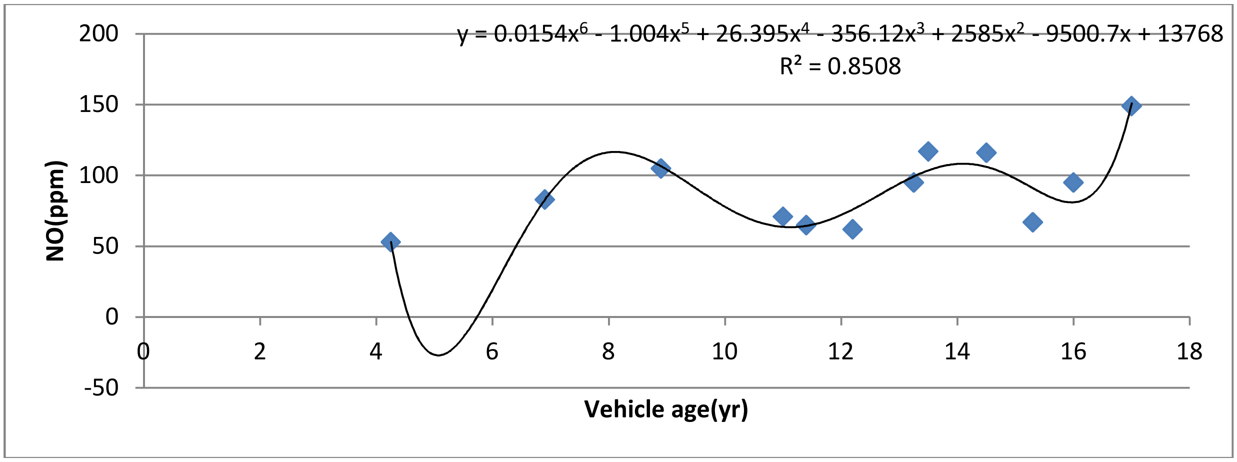

Fig.4.11 Vehicle age vs NO emission of Santro (Idle)

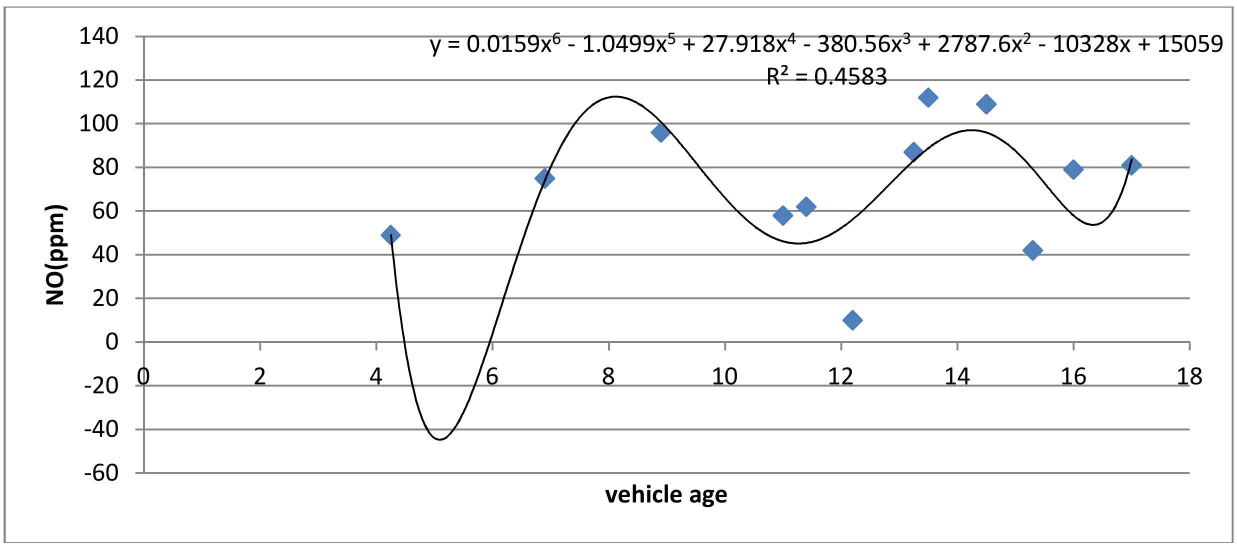

Fig.4.12 Vehicle age vs NO emission of Santro (Fast Idle)

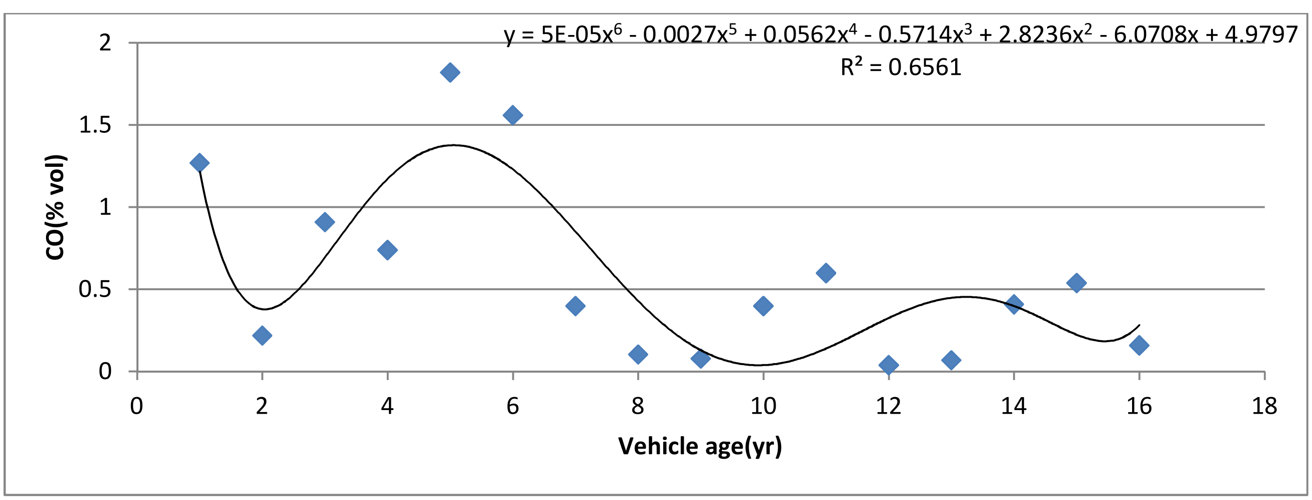

Fig.4.13 Vehicle age vs CO emission of Wagnor (Idle)

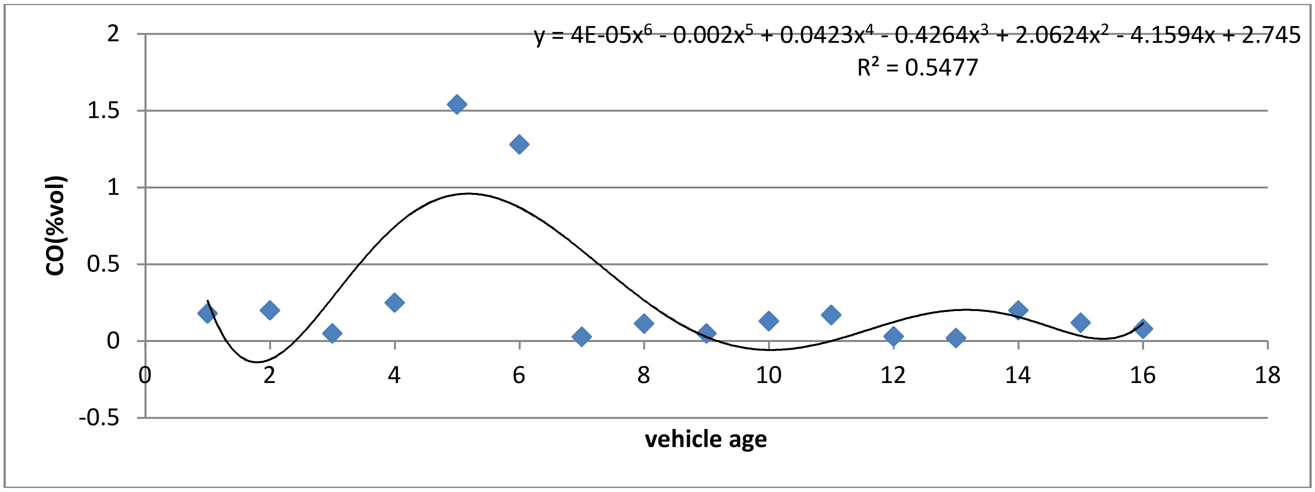

Fig.4.14 Vehicle age vs CO emission of Wagnor (Fast Idle)

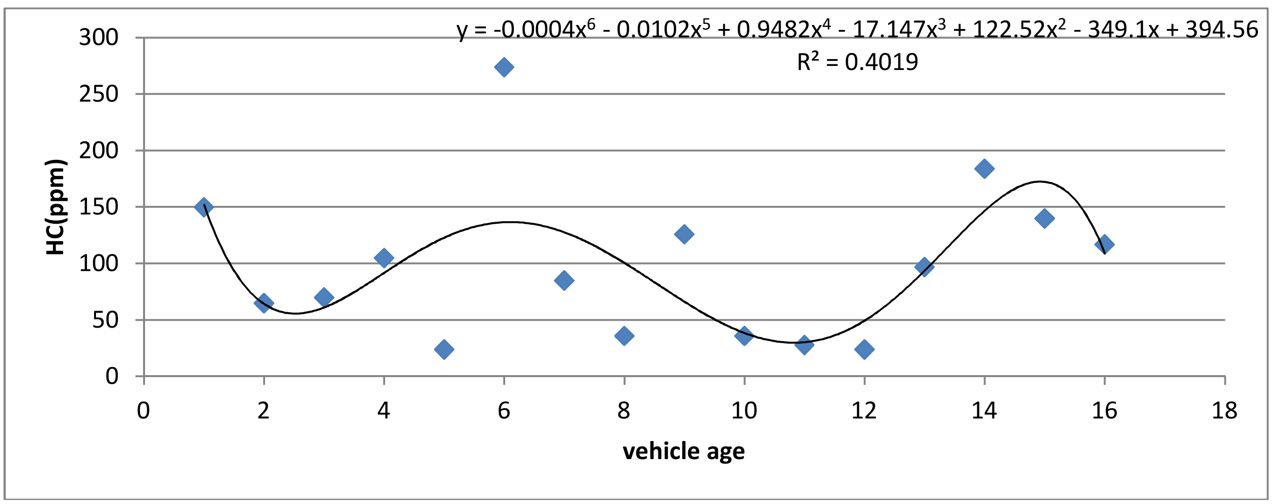

Fig.4.15 Vehicle age vs HC emission of Wagnor (Idle)

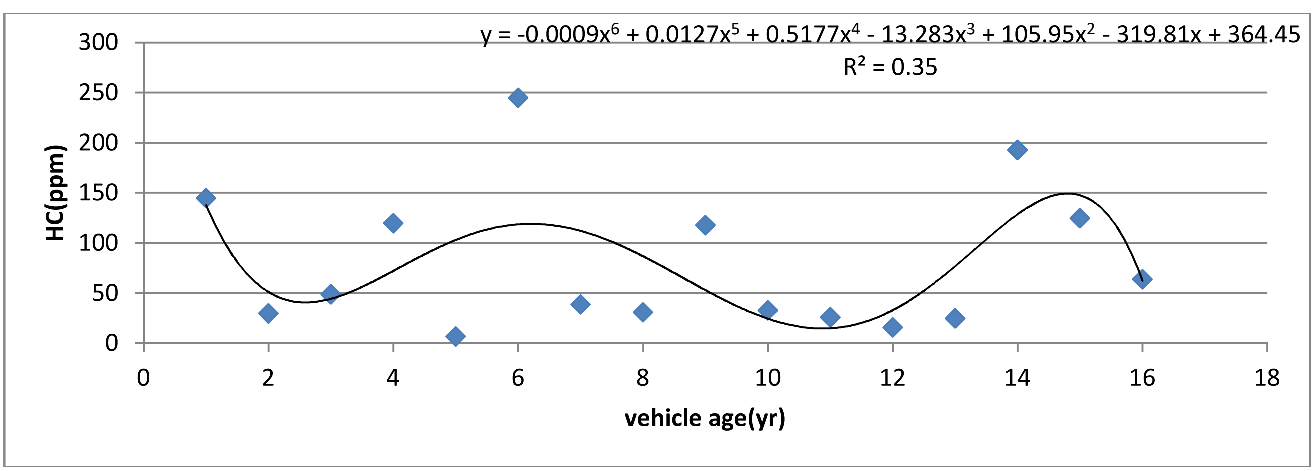

Fig.4.16 Vehicle age vs HC emission of Wagnor (Fast Idle)

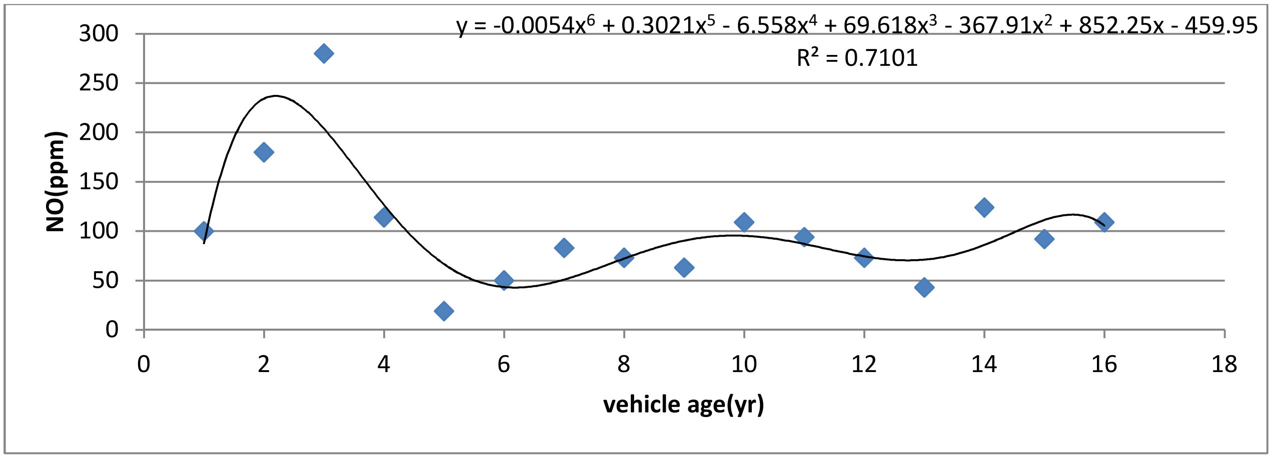

Fig.4.17 Vehicle age vs NO emission of Wagnor (Idle)

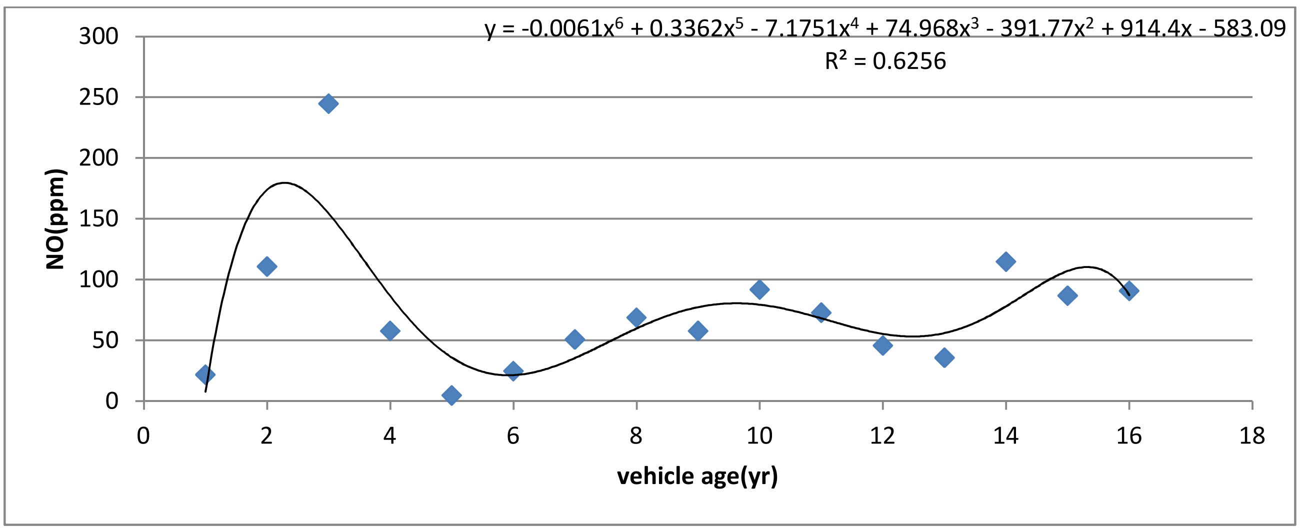

Fig.4.18 Vehicle age vs NO emission of Wagnor (Fast Idle)

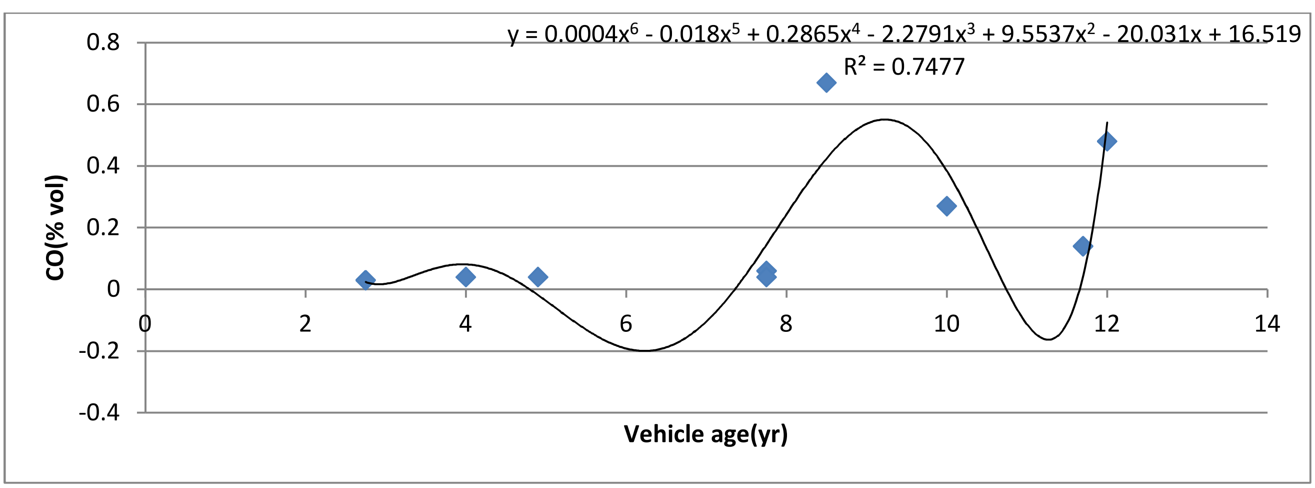

Fig.4.19 Vehicle age vs CO emission Alto (Idle)

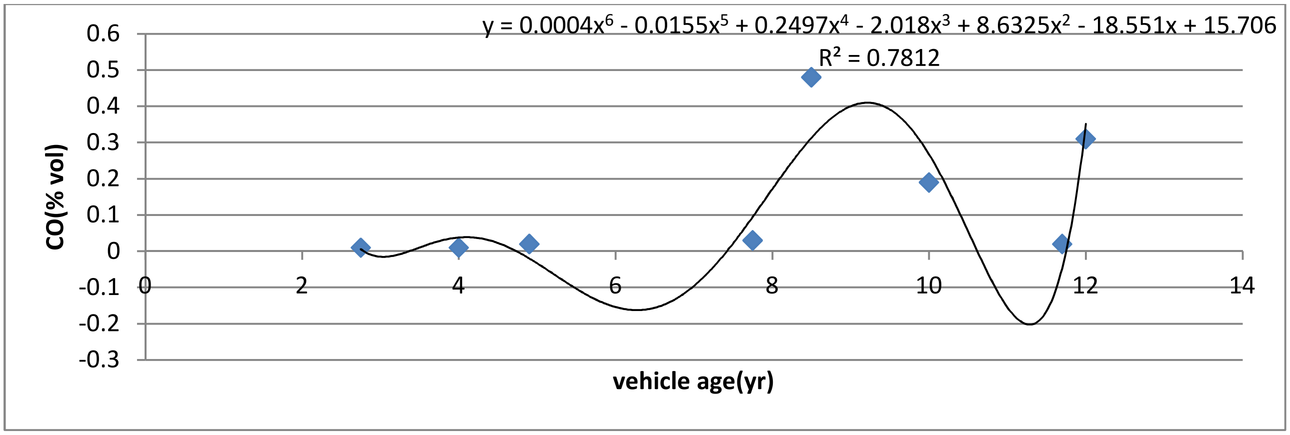

Fig.4.20 Vehicle age vs CO emission Alto (Fast Idle)

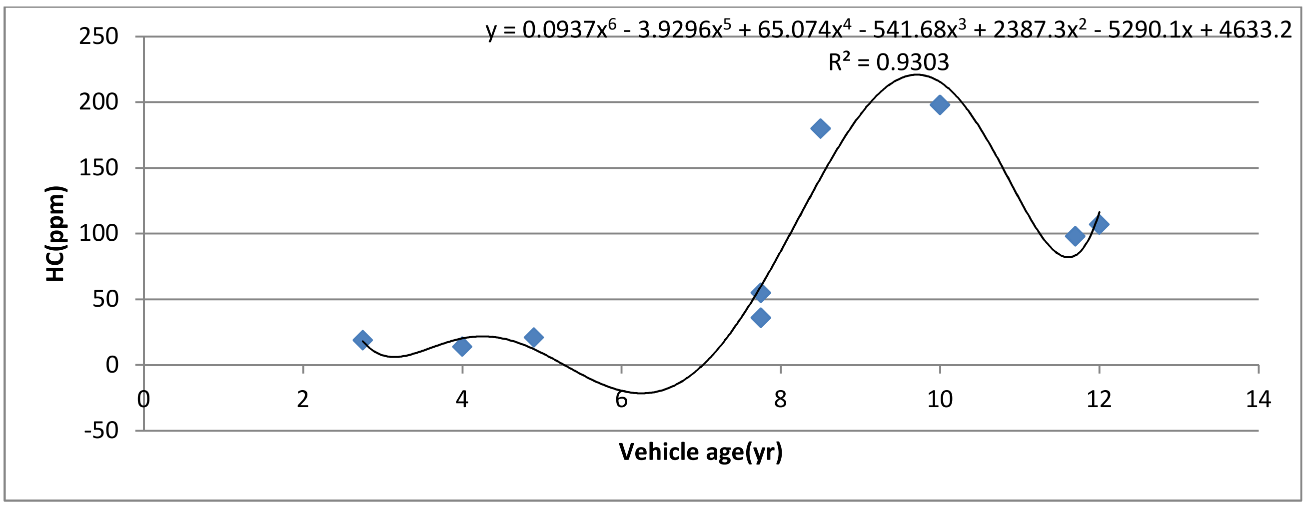

Fig.4.21 Vehicle age vs HC emission Alto (Idle)

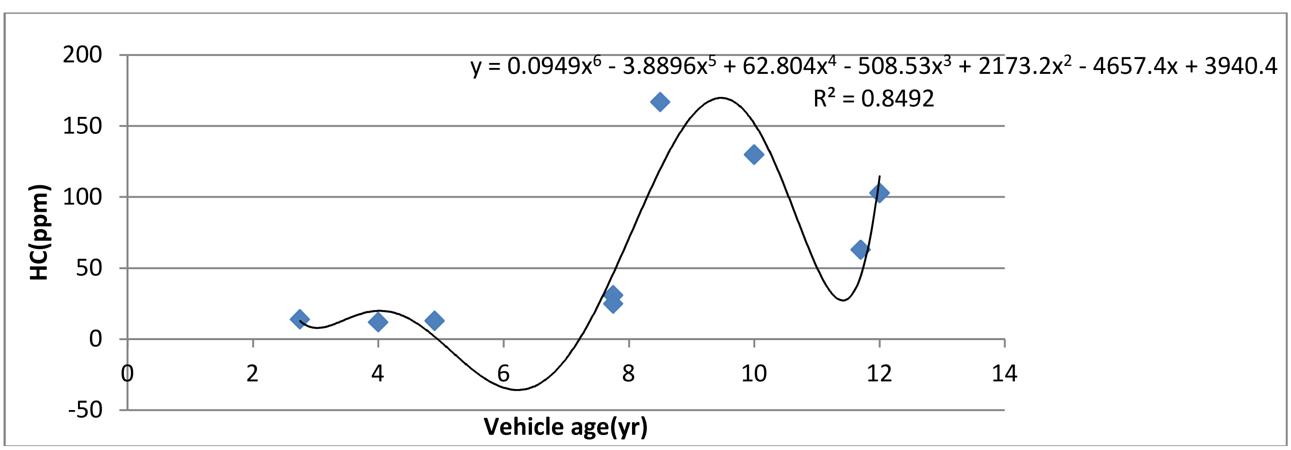

Fig.4.22 Vehicle age vs HC emission Alto (Fast Idle)

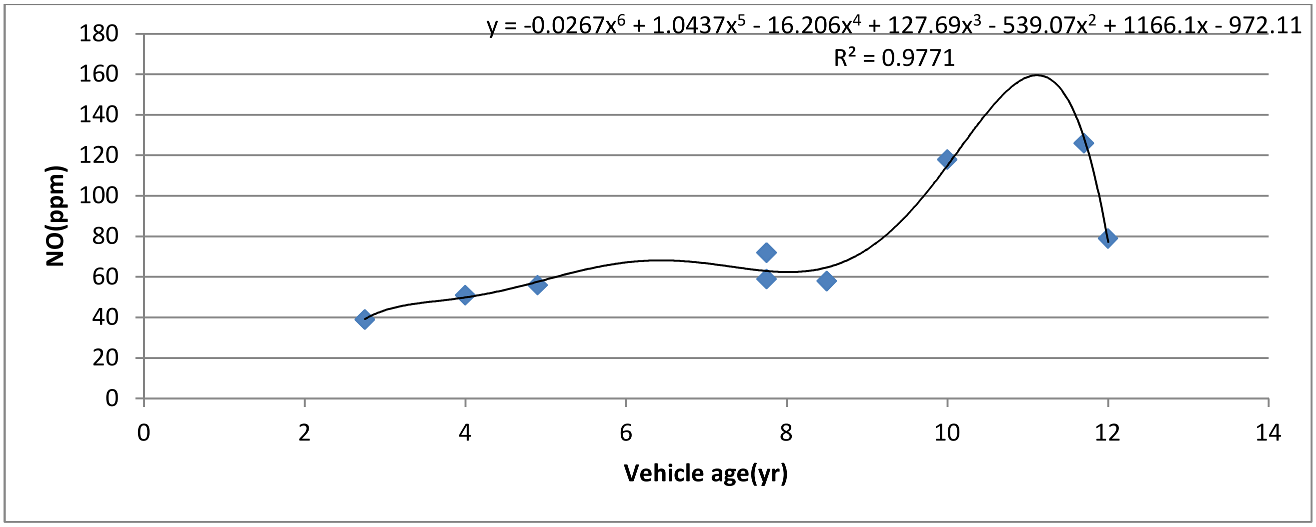

Fig.4.23 Vehicle age vs NO emission Alto (Idle)

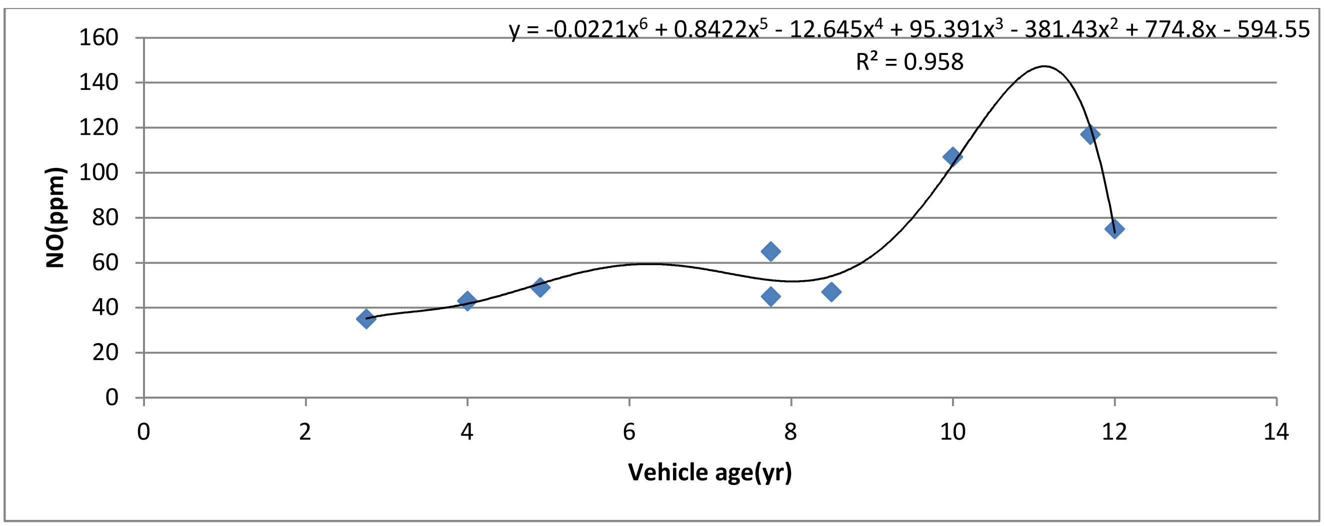

Fig.4.24 Vehicle age vs NO emission Alto (Fast Idle)

It is observed that the dependence of emission levels on vehicle age is polynomial in nature. The equations obtained for the best-fit polynomial trendlines in each case are given in Tables 4.1

Table 4.1 Equations relating CO, HC and NO emissions with vehicle age (model-wise)

S/N.	Model	EMISSION	Test mode	Equation (s)	R^2 values
1.	SWIFT	CO	Idle	$y = -0.0006x^6 + 0.0226x^5 - 0.3074x^4 + 1.9883x^3 - 6.1573x^2 + 7.7924x - 1.5733$	0.683
			Fast Idle	$y = 0.0004x^6 - 0.0181x^5 + 0.3204x^4 - 2.7409x^3 + 11.404x^2 - 19.108x + 4.1157$	0.5448
2.	SWIFT	HC	Idle	$y = -0.0684x^6 + 2.6655x^5 - 40.227x^4 + 294.81x^3 - 1058.8x^2 + 1568.9x - 312.51$	0.8301
			Fast Idle	$y = 0.0109x^6 - 0.4093x^5 + 6.0465x^4 - 44.056x^3 + 160.83x^2 - 241.76x + 64.033$	0.7052
3.	SWIFT	NO	Idle	$y = 0.0862x^6 - 3.3438x^5 + 50.422x^4 - 370.77x^3 + 1345.4x^2 - 2017.1x + 446.76$	0.5326
			Fast Idle	$y = 0.0386x^6 - 1.4878x^5 + 22.255x^4 - 162.08x^3 + 582.14x^2 - 862.04x + 199.56$	0.5266
4.	SANTRO	CO	Idle	$y = 0.0002x^6 - 0.0105x^5 + 0.289x^4 - 4.097x^3 + 31.232x^2 - 120.3x + 181.21$	0.7122
			Fast Idle	$y = 2E-05x^6 - 0.0012x^5 + 0.0344x^4 - 0.4926x^3 + 3.7869x^2 - 14.694x + 22.295$	0.4635
5.	SANTRO	HC	Idle	$y = 0.0245x^6 - 1.5999x^5 + 42.121x^4 - 569.04x^3 + 4140.3x^2 - 15285x + 22229$	0.65
			Fast Idle	$y = 0.0201x^6 - 1.3089x^5 + 34.411x^4 - 464.58x^3 + 3379.7x^2 - 12474x + 18132$	0.4845
6.	SANTRO	NO	Idle	$y = 0.0154x^6 - 1.004x^5 + 26.395x^4 - 356.12x^3 + 2585x^2 - 9500.7x + 13768$	0.8508
			Fast Idle	$y = 0.0152x^5 - 0.8302x^4 + 17.615x^3 - 179.68x^2 + 872.77x - 1514.7$	0.4583
7.	WAGNOR	CO	Idle	$y = 5E-05x^6 - 0.0027x^5 + 0.0562x^4 - 0.5714x^3 + 2.8236x^2 - 6.0708x + 4.9797$	0.6561
			Fast Idle	$y = 4E-05x^6 - 0.002x^5 + 0.0423x^4 - 0.4264x^3 + 2.0624x^2 - 4.1594x + 2.745$	0.5477
8.	WAGNOR	HC	Idle	$y = -0.0004x^6 - 0.0102x^5 + 0.9482x^4 - 17.147x^3 + 122.52x^2 - 349.1x + 394.56$	0.4019
			Fast Idle	$y = -0.0009x^6 + 0.0127x^5 + 0.5177x^4 - 13.283x^3 + 105.95x^2 - 319.81x + 364.45$	0.35
9.	WAGNOR	NO	Idle	$y = -0.0054x^6 + 0.3021x^5 - 6.558x^4 + 69.618x^3 - 367.91x^2 + 852.25x - 459.95$	0.7101
			Fast Idle	$y = -0.0061x^6 + 0.3362x^5 - 7.1751x^4 + 74.968x^3 - 391.77x^2 + 914.4x - 583.09$	0.6256
10.	ALTO	CO	Idle	$y = 0.0004x^6 - 0.018x^5 + 0.2865x^4 - 2.2791x^3 + 9.5537x^2 - 20.031x + 16.519$	0.7477
			Fast Idle	$y = 0.0004x^6 - 0.0155x^5 + 0.2497x^4 - 2.018x^3 + 8.6325x^2 - 18.551x + 15.706$	0.7812
11.	ALTO	HC	Idle	$y = 0.0937x^6 - 3.9296x^5 + 65.074x^4 - 541.68x^3 + 2387.3x^2 - 5290.1x + 4633.2$	0.9303
12.	ALTO	HC	Fast Idle	$y = 0.0949x^6 - 3.8896x^5 + 62.804x^4 - 508.53x^3 + 2173.2x^2 - 4657.4x + 3940.4$	0.8492
13.	ALTO	NO	Idle	$y = -0.0267x^6 + 1.0437x^5 - 16.206x^4 +$	0.9771

				$127.69x^3 - 539.07x^2 + 1166.1x - 972.11$	
			Fast Idle	$y = -0.0221x^6 + 0.8422x^5 - 12.645x^4 + 95.391x^3 - 381.43x^2 + 774.8x - 594.55$	0.958

A glance at emission equations having vehicle age as variable reveals that, the ageing of cars has a direct influence on the emission characteristics and it may render them to exceed the prescribed emission norms after certain age, which may further necessitate a thorough inspection and suitable maintenance, tuning of the cars as well.

4.2 Effect of vehicle mileage on CO , HC and NO emissions:

With respect to vehicle mileage, CO, HC and NO emissions in idle and fast idle test modes for different models of petrol-driven passeneger cars were also plotted and the results are depicted in Figures 4.25, 4.26, 4.27, 4.28, 4.29, 4.30, 4.31, 4.32, 4.33, 4.34, 4.35, 4.36, 4.37, 4.38, 4.39, 4.40, 4.41, 4.42, 4.43, 4.44, 4.45, 4.46, 4.47, 4.48, respectively.

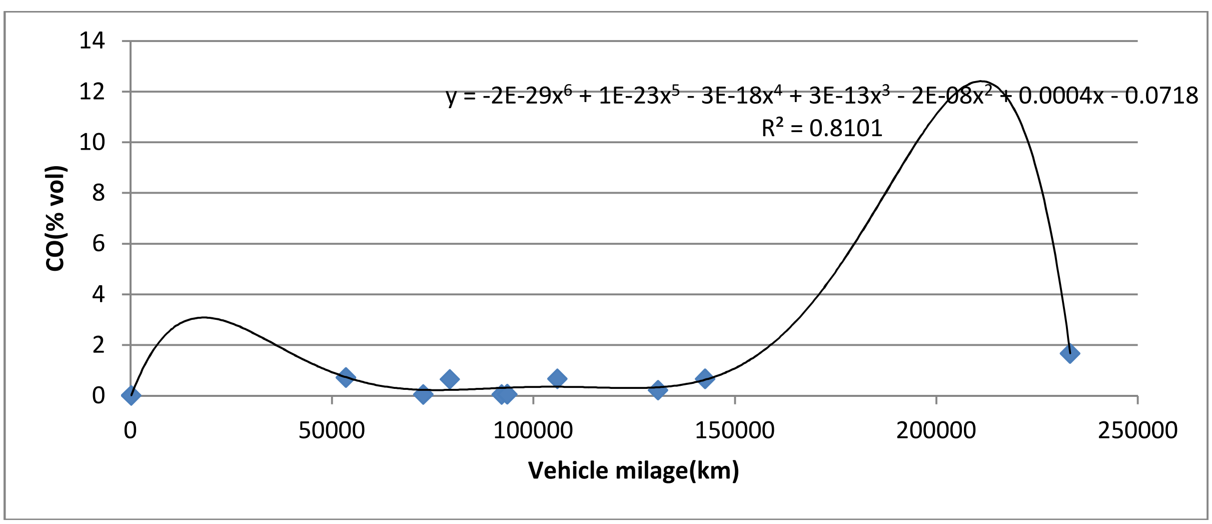

Fig.4.25 Vehicle mileage vs CO emission of swift (Idle)

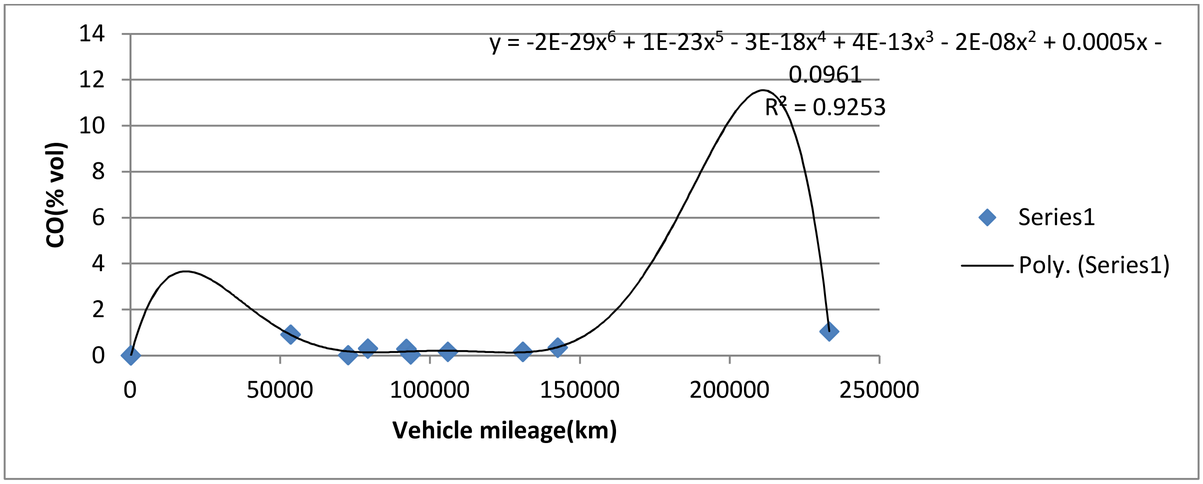

Fig.4.26 Vehicle mileage vs CO emission of swift (Fast Idle)

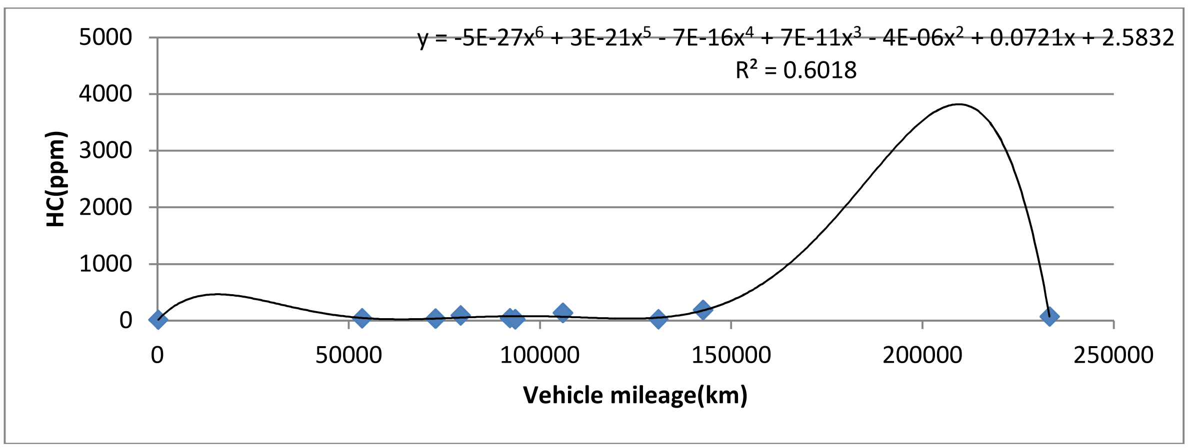

Fig.4.27 Vehicle mileage vs HC emission of swift (Idle)

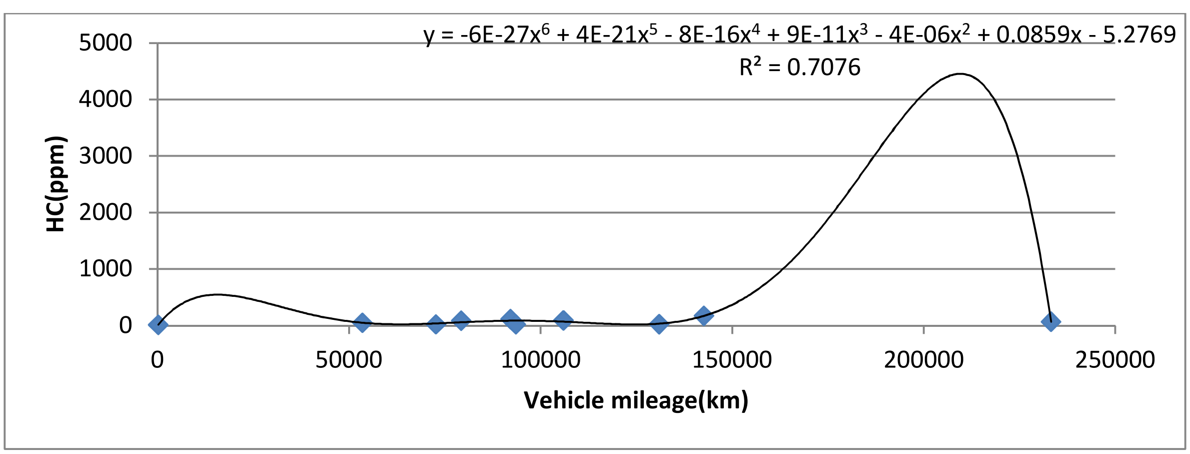

Fig.4.28 Vehicle mileage vs HC emission of swift (Fast Idle)

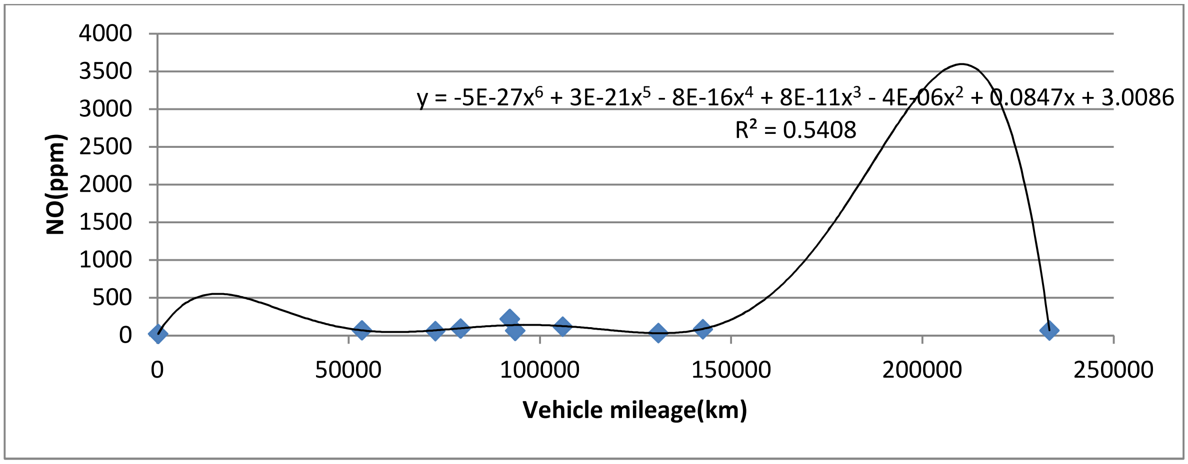

Fig.4.29 Vehicle mileage vs NO emission of swift (Idle)

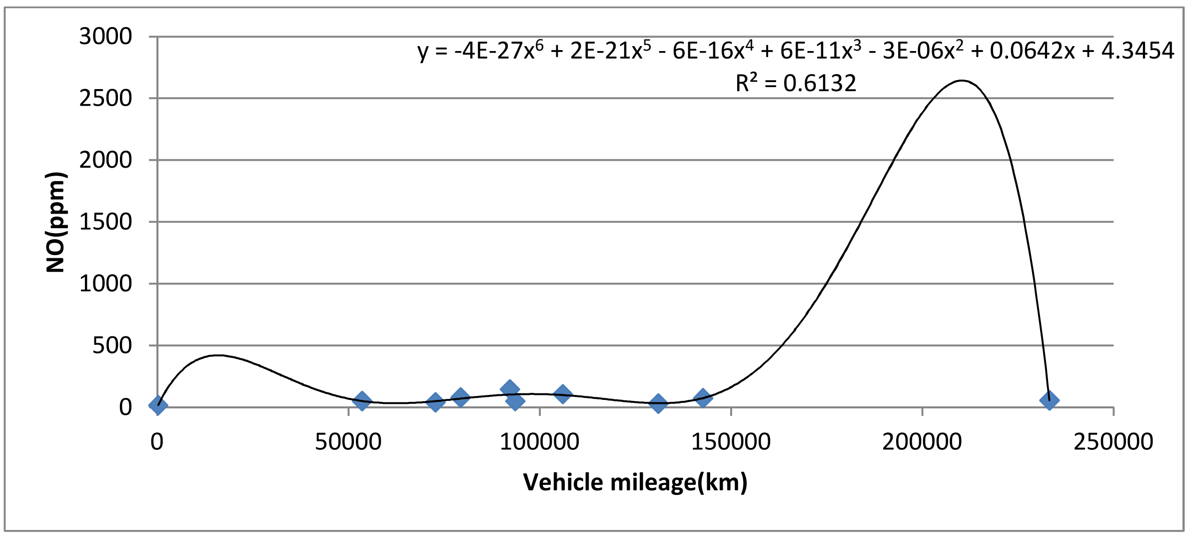

Fig.4.30 Vehicle mileage vs NO emission of swift (Fast Idle)

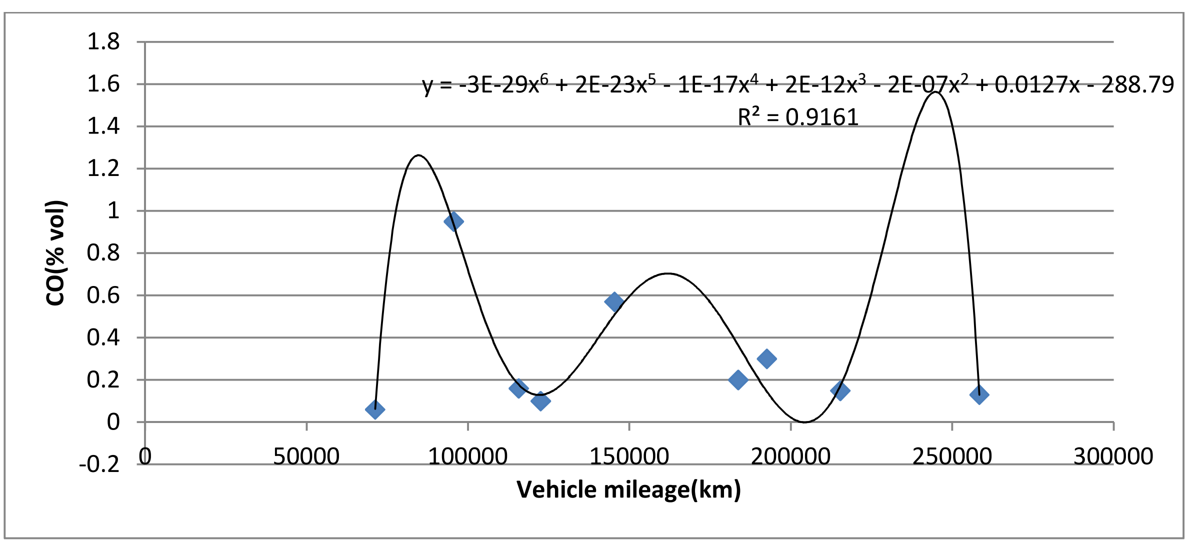

Fig.4.31 Vehicle mileage vs CO emission of Santro (Idle)

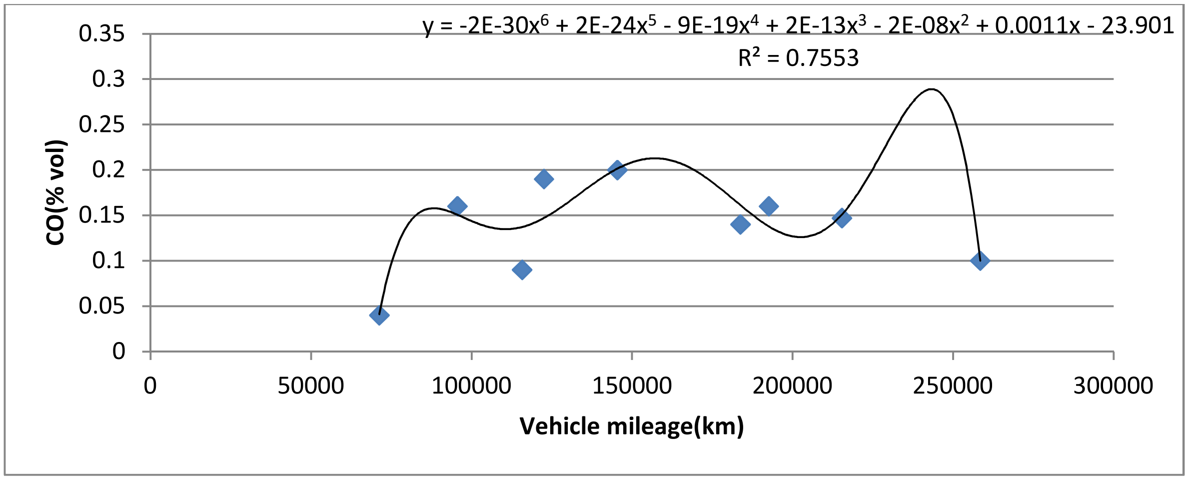

Fig.4.32 Vehicle mileage vs CO emission of Santro (Fast Idle)

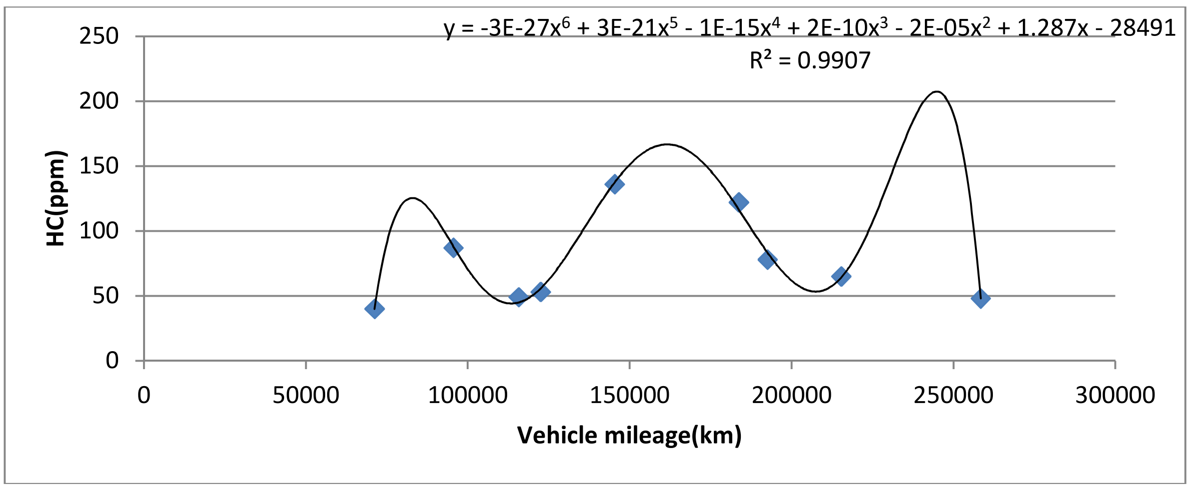

Fig.4.33 Vehicle mileage vs HC emission of Santro (Idle)

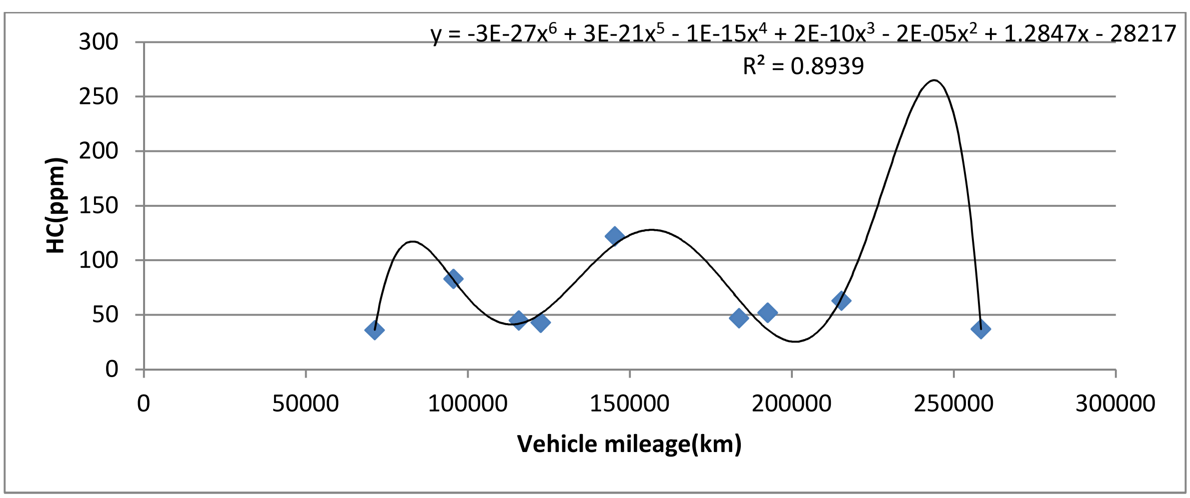

Fig.4.34 Vehicle mileage vs HC emission of Santro (Fast Idle)

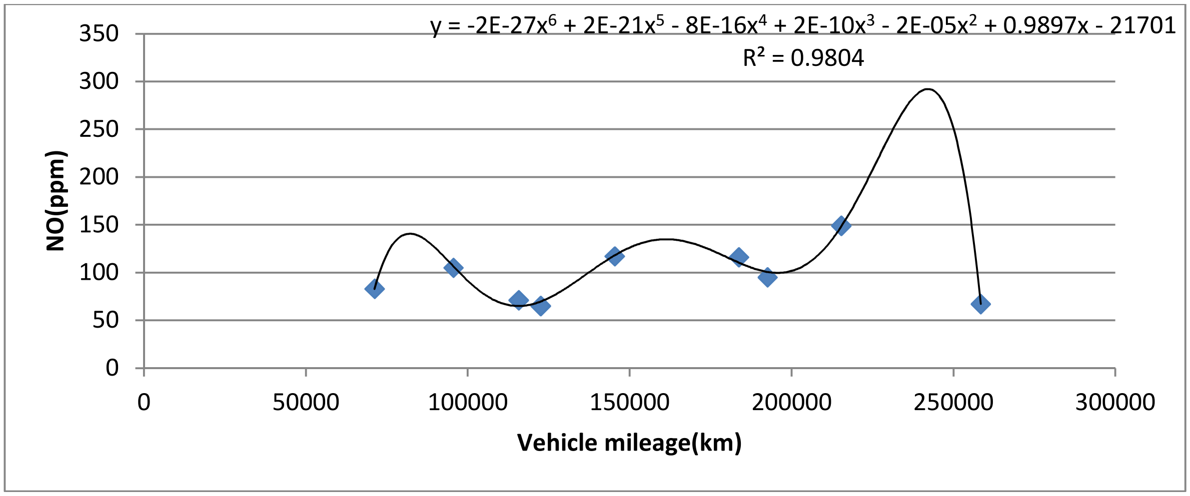

Fig.4.35 Vehicle mileage vs NO emission of Santro (Idle)

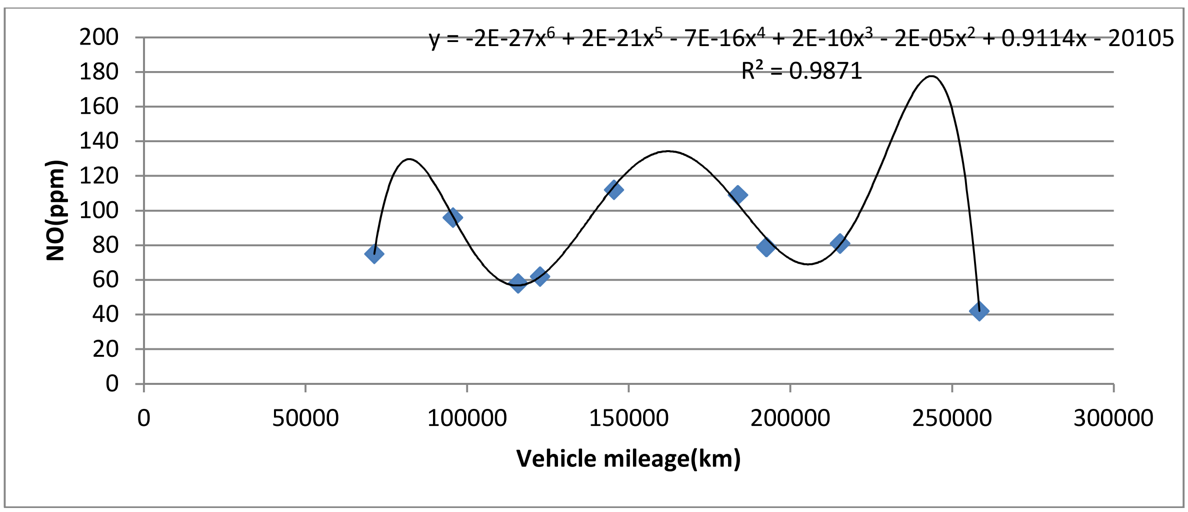

Fig.4.36 Vehicle mileage vs NO emission of Santro (Fast Idle)

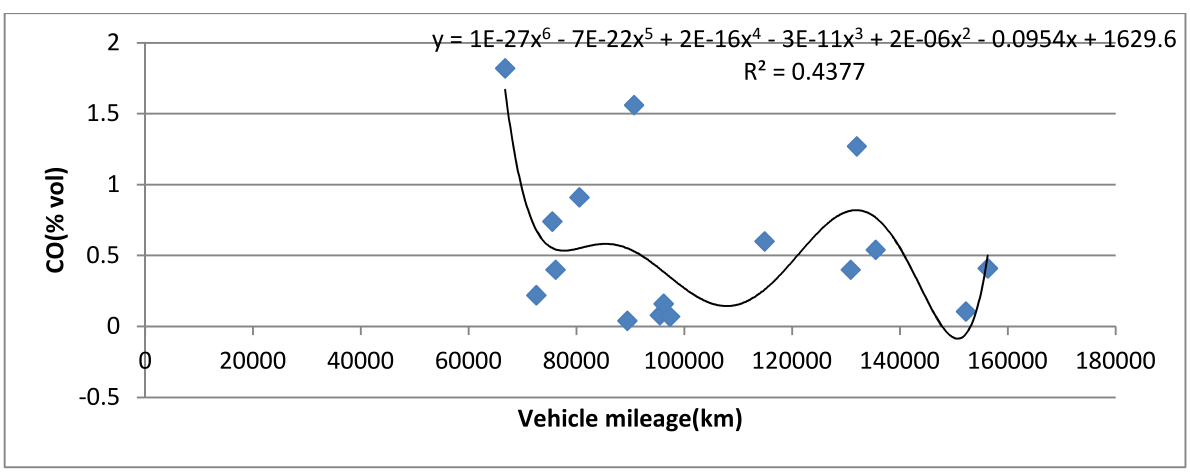

Fig.4.37 Vehicle mileage vs CO emission of Wagnor (Idle)

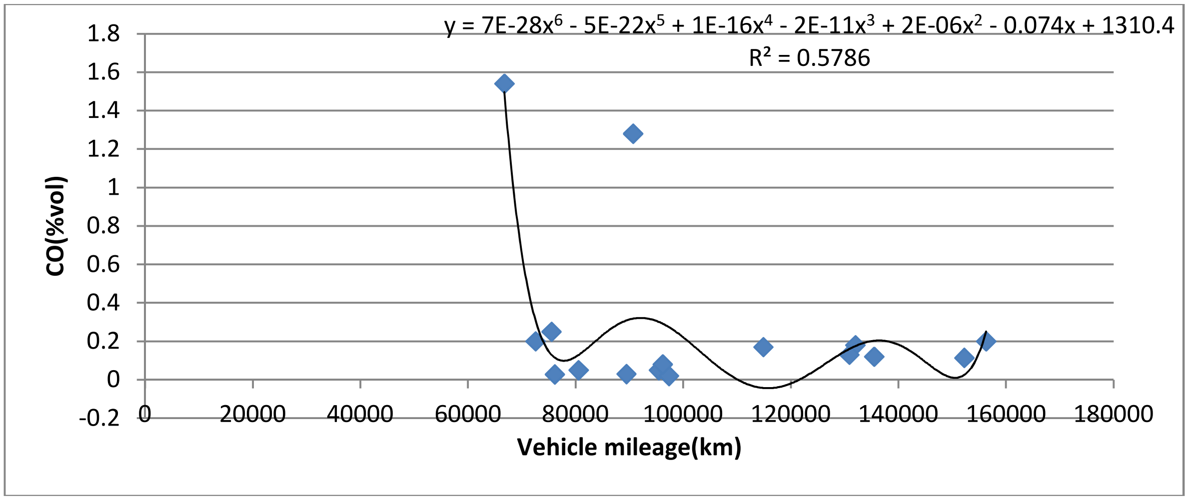

Fig.4.38 Vehicle mileage vs CO emission of Wagnor (Fast Idle)

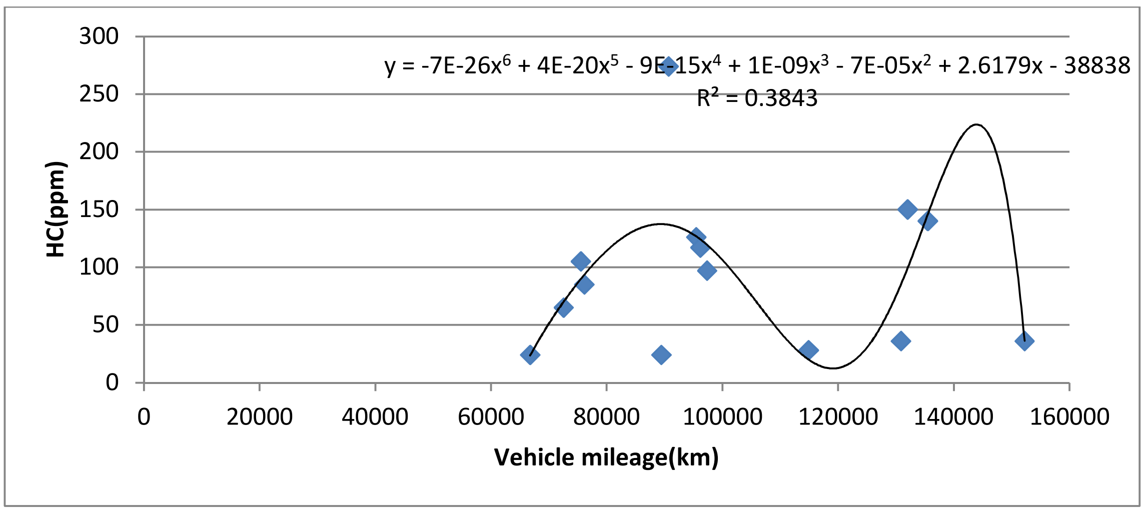

Fig.4.39 Vehicle mileage vs HC emission of Wagnor (Idle)

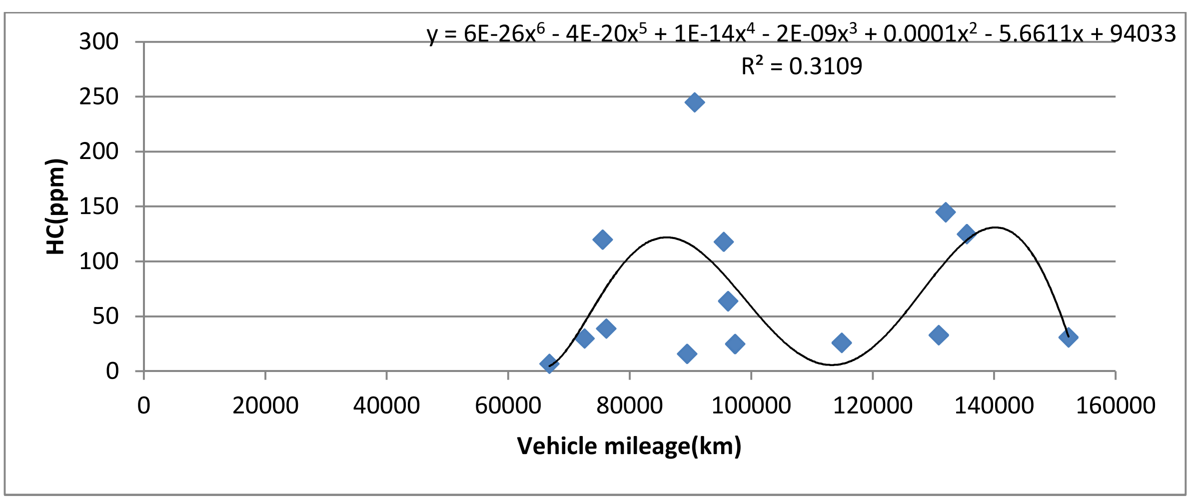

Fig.4.40 Vehicle mileage vs HC emission of Wagnor (Fast Idle)

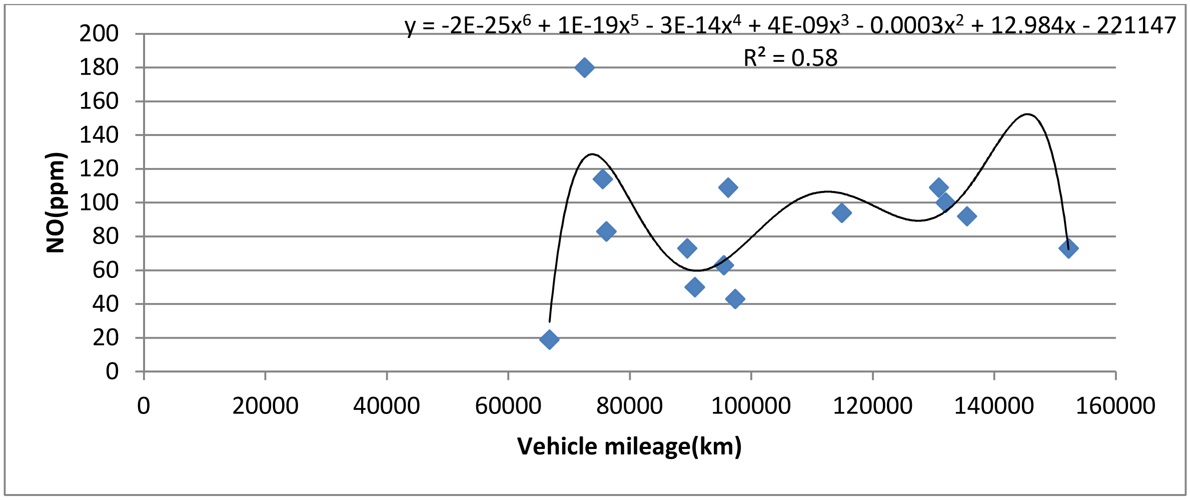

Fig.4.41 Vehicle mileage vs NO emission of Wagnor (Idle)

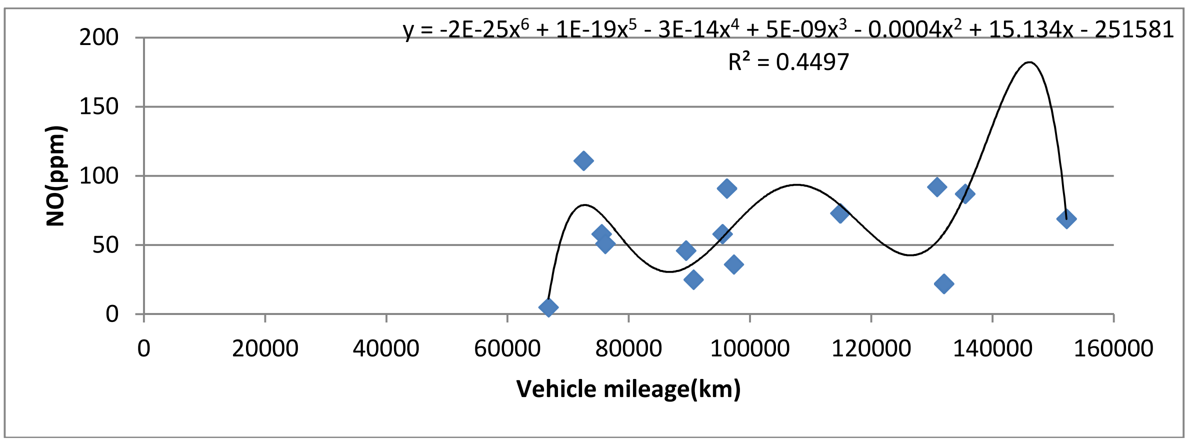

Fig.4.42 Vehicle mileage vs NO emission of Wagnor (Fast Idle)

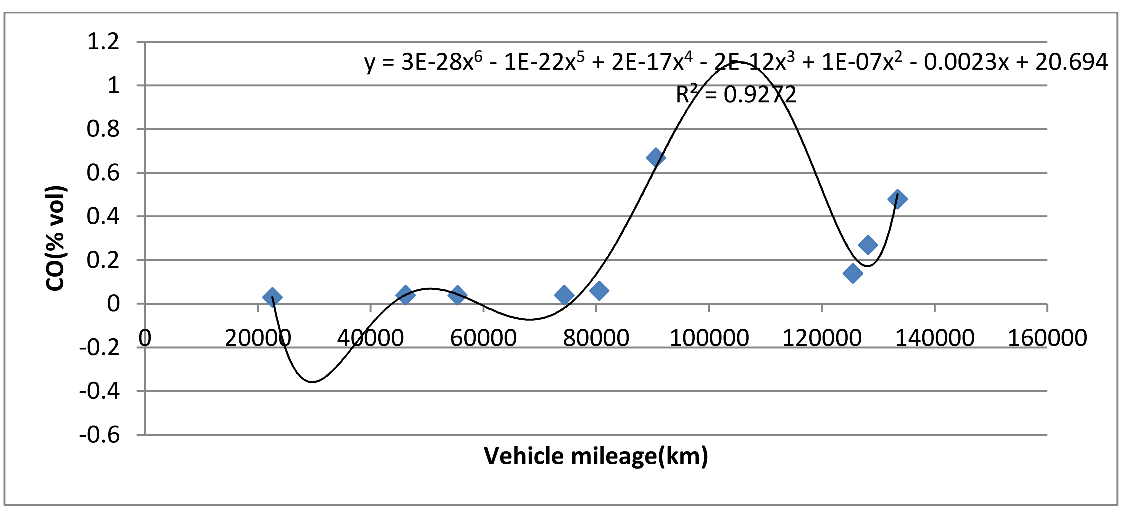

Fig.4.43 Vehicle mileage vs CO emission of Alto (Idle)

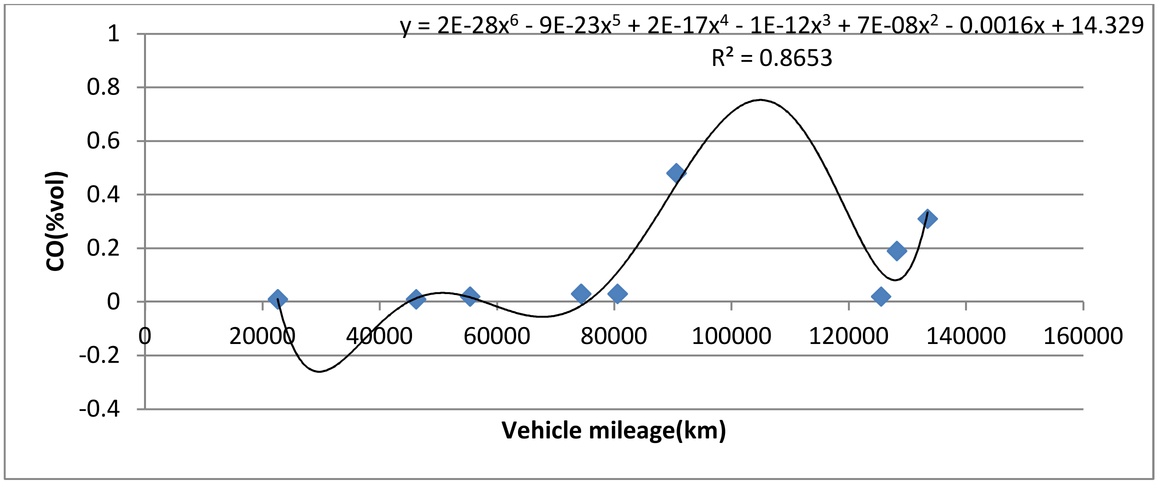

Fig.4.44 Vehicle age vs CO emission of Alto (Fast Idle)

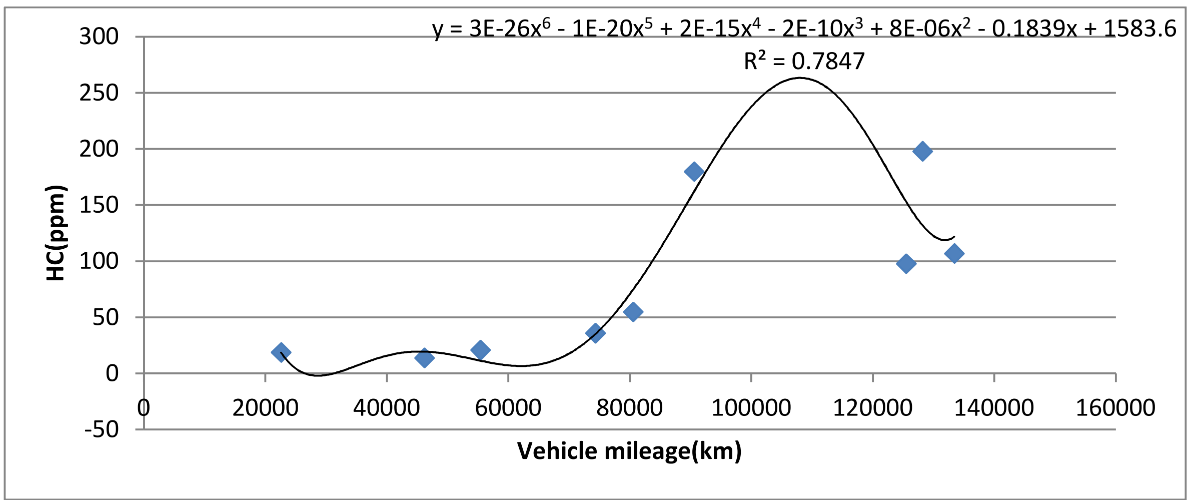

Fig.4.45 Vehicle mileage vs HC emission of Alto (Idle)

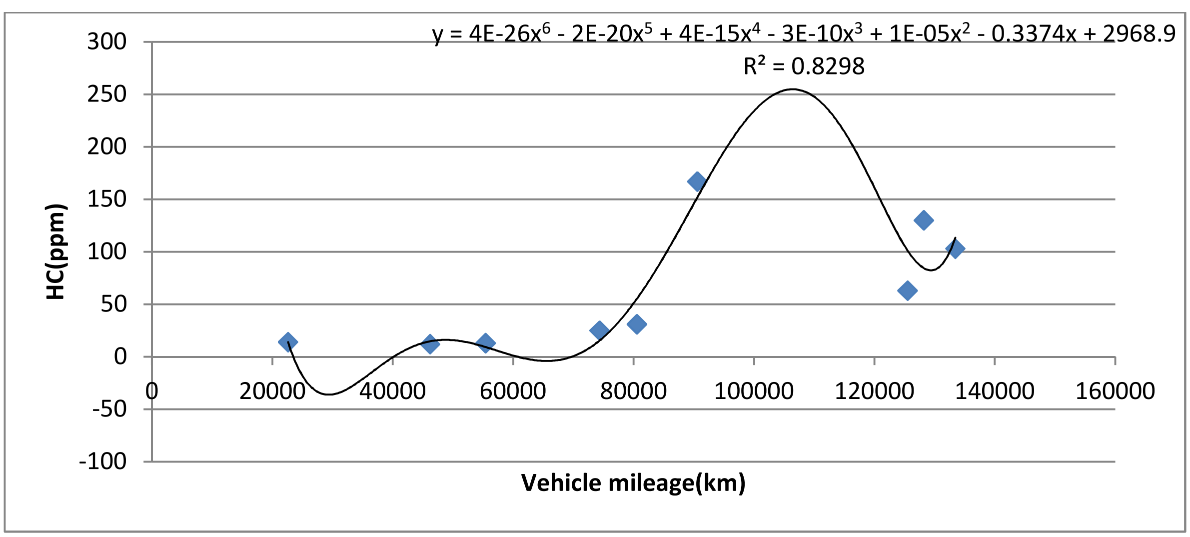

Fig.4.46 Vehicle mileage vs HC emission of Alto (Fast Idle)

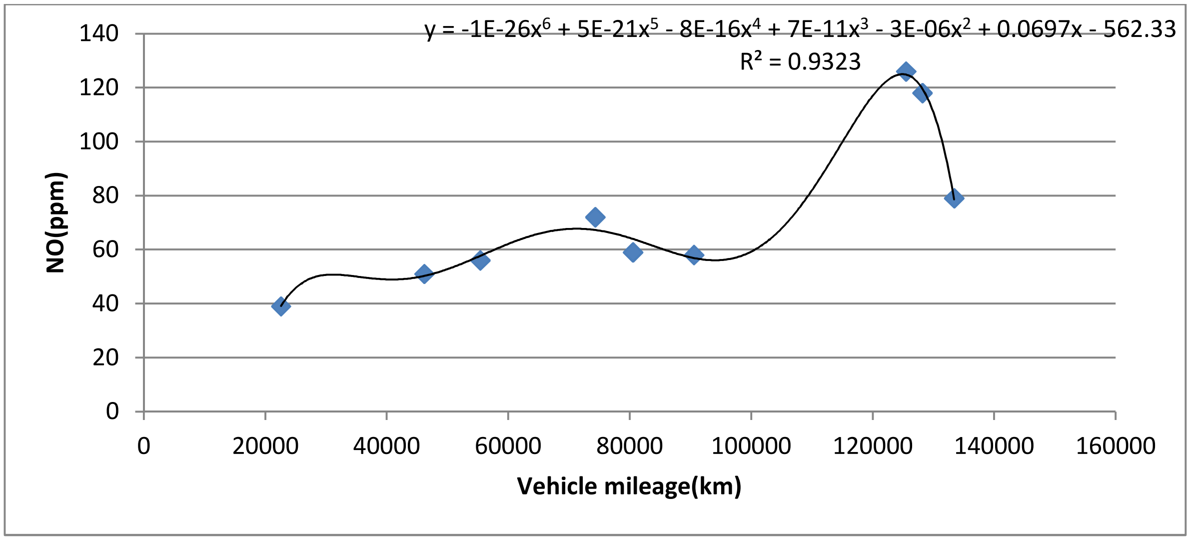

Fig.4.47 Vehicle mileage vs NO emission of Alto (Idle)

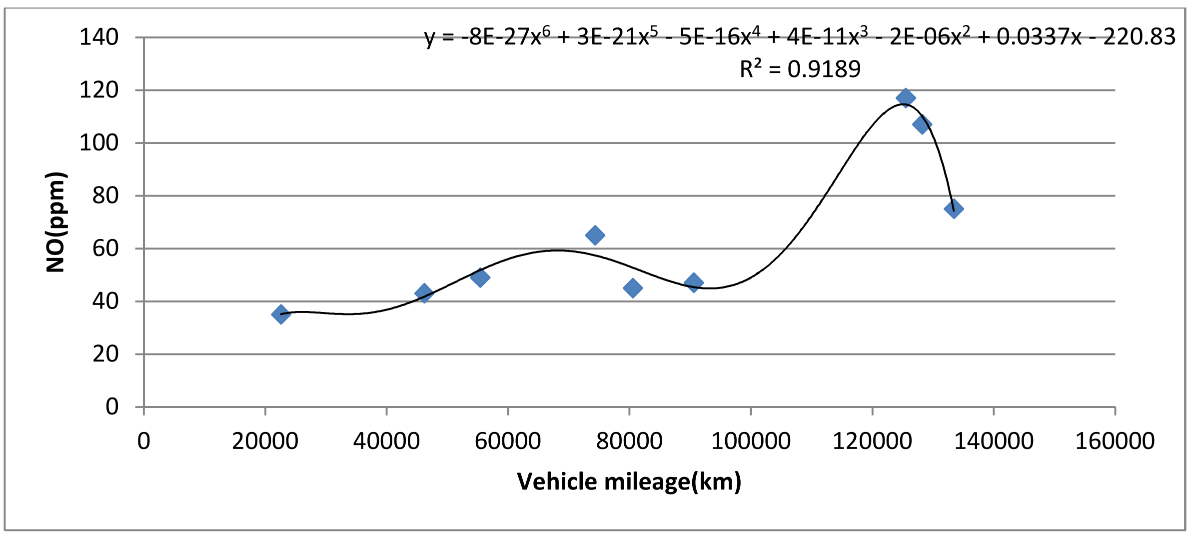

Fig.4.48 Vehicle mileage vs NO emission of Alto (Fast Idle)

It is revealed from the analysis that the nature of dependence of CO,HC and NO emissions on vehicle mileage is again polynomial and the equations obtained for the best-fit polynomial trendlines in each case are given in Tables 4.2.

Table 4.2 Equations relating CO, HC and NO emissions with vehicle mileage (model-wise)

S/N.	Model	EMISSION	Test mode	Equation (s)	R^2 values
1.	SWIFT	CO	Idle	$y = -2E-29x^6 + 1E-23x^5 - 3E-18x^4 + 3E-13x^3 - 2E-08x^2 + 0.0004x - 0.0718$	0.8101
			Fast Idle	$y = -2E-29x^6 + 1E-23x^5 - 3E-18x^4 + 4E-13x^3 - 2E-08x^2 + 0.0005x - 0.0961$	0.9253
2.	SWIFT	HC	Idle	$y = -5E-27x^6 + 3E-21x^5 - 7E-16x^4 + 7E-11x^3 - 4E-06x^2 + 0.0721x + 2.5832$	0.6018
			Fast Idle	$y = -6E-27x^6 + 4E-21x^5 - 8E-16x^4 + 9E-11x^3 - 4E-06x^2 + 0.0859x - 5.2769$	0.7076
3.	SWIFT	NO	Idle	$y = -5E-27x^6 + 3E-21x^5 - 8E-16x^4 + 8E-11x^3 - 4E-06x^2 + 0.0847x + 3.0086$	0.5408
			Fast Idle	$y = -4E-27x^6 + 2E-21x^5 - 6E-16x^4 + 6E-11x^3 - 3E-06x^2 + 0.0642x + 4.3454$	0.6132
4.	SANTRO	CO	Idle	$y = -3E-29x^6 + 2E-23x^5 - 1E-17x^4 + 2E-12x^3 - 2E-07x^2 + 0.0127x - 288.79$	0.9161
			Fast Idle	$y = -2E-30x^6 + 2E-24x^5 - 9E-19x^4 + 2E-13x^3 - 2E-08x^2 + 0.0011x - 23.901$	0.7553
5.	SANTRO	HC	Idle	$y = -3E-27x^6 + 3E-21x^5 - 1E-15x^4 + 2E-10x^3 - 2E-05x^2 + 1.287x - 28491$	0.9907
			Fast Idle	$y = -3E-27x^6 + 3E-21x^5 - 1E-15x^4 + 2E-10x^3 - 2E-05x^2 + 1.2847x - 28217$	0.8939
6.	SANTRO	NO	Idle	$y = -2E-27x^6 + 2E-21x^5 - 8E-16x^4 + 2E-10x^3 - 2E-05x^2 + 0.9897x - 21701$	0.9804
			Fast Idle	$y = -2E-27x^6 + 2E-21x^5 - 7E-16x^4 + 2E-10x^3 - 2E-05x^2 + 0.9114x - 20105$	0.9871
7.	WAGNOR	CO	Idle	$y = 1E-27x^6 - 7E-22x^5 + 2E-16x^4 - 3E-11x^3 + 2E-06x^2 - 0.0954x + 1629.6$	0.4377
			Fast Idle	$y = 7E-28x^6 - 5E-22x^5 + 1E-16x^4 - 2E-11x^3 + 2E-06x^2 - 0.074x + 1310.4$ $R^2 = 0.5786$	0.5786
8.	WAGNOR	HC	Idle	$y = -7E-26x^6 + 4E-20x^5 - 9E-15x^4 + 1E-09x^3 - 7E-05x^2 + 2.6179x - 38838$	0.3843
			Fast Idle	$y = 6E-26x^6 - 4E-20x^5 + 1E-14x^4 - 2E-09x^3 + 0.0001x^2 - 5.6611x + 94033$	0.3109
9.	WAGNOR	NO	Idle	$y = -2E-25x^6 + 1E-19x^5 - 3E-14x^4 + 4E-$	0.58

				$09x^3 - 0.0003x^2 + 12.984x - 221147$	
			Fast Idle	$y = -2E-25x^6 + 1E-19x^5 - 3E-14x^4 + 5E-09x^3 - 0.0004x^2 + 15.134x – 251581$	0.4497
10.	ALTO	CO	Idle	$y = 3E-28x^6 - 1E-22x^5 + 2E-17x^4 - 2E-12x^3 + 1E-07x^2 - 0.0023x + 20.694$	0.9272
			Fast Idle	$y = 2E-28x^6 - 9E-23x^5 + 2E-17x^4 - 1E-12x^3 + 7E-08x^2 - 0.0016x + 14.329$	0.8653
11.	ALTO	HC	Idle	$y = 3E-26x^6 - 1E-20x^5 + 2E-15x^4 - 2E-10x^3 + 8E-06x^2 - 0.1839x + 1583.6$	0.7847
		HC	Fast Idle	$y = 4E-26x^6 - 2E-20x^5 + 4E-15x^4 - 3E-10x^3 + 1E-05x^2 - 0.3374x + 2968.9$	0.8298
12.	ALTO	NO	Idle	$y = -1E-26x^6 + 5E-21x^5 - 8E-16x^4 + 7E-11x^3 - 3E-06x^2 + 0.0697x - 562.33$	0.9323
			Fast Idle	$y = -8E-27x^6 + 3E-21x^5 - 5E-16x^4 + 4E-11x^3 - 2E-06x^2 + 0.0337x - 220.83$	0.9189

As elucidated by the emission equations having vehicle mileage as variable, it is found that the accumulated kilometres has a direct effect on the emission,characteristics and owing to this accumulation the vehicles, after a certain mileage, becomes non-compliant to the relevant emission norms.

4.3 Effect of Time since last inspection (TSLI) on CO ,HC and NO emissions:

In the present work, the effect of time elapsed since last inspection on the tailpipe CO,HC and NO emissions was also evaluated. The elapsed time was recorded in units of month with respect to idle and fast idle CO,HC and NO mass concentration. The model-wise study of the different models of petrol-driven Maruti cars was done in order to evaluate the effect of TSLI on CO, HC and NO emissions characteristics for individual models and the results plotted have been shown in Figures 4.49, 4.50, 4.51, 4.52, 4.53, 4.54, 4.55, 4.56, 4.57, 4.58, 4.59, 4.60, 4.61, 4.62, 4.63, 4.64, 4.65, 4.66, 4.67, 4.68, 4.69, 4.70, 4.71, 4.72.

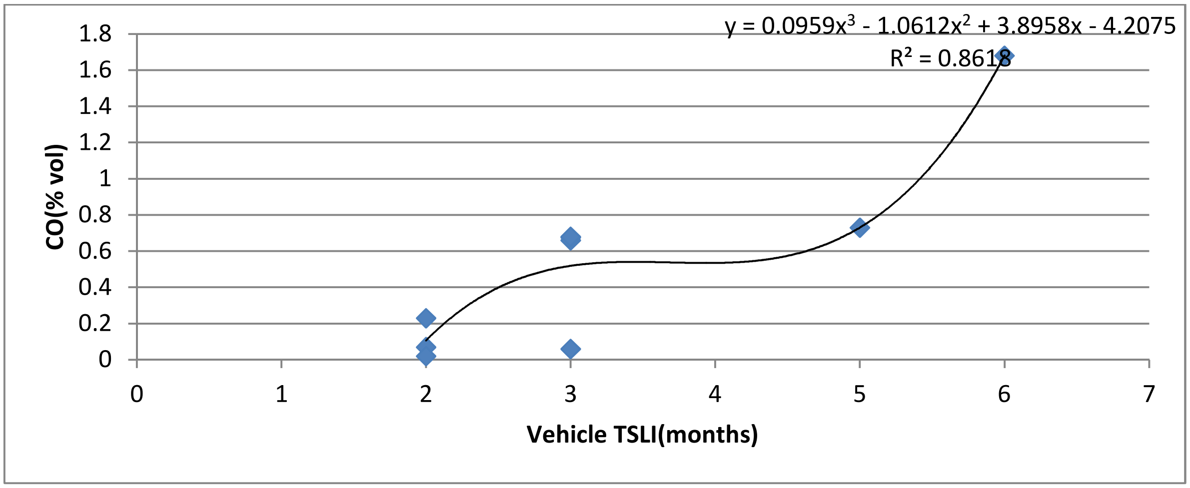

Fig.4.49 Vehicle TSLI vs CO emission of Swift (Idle)

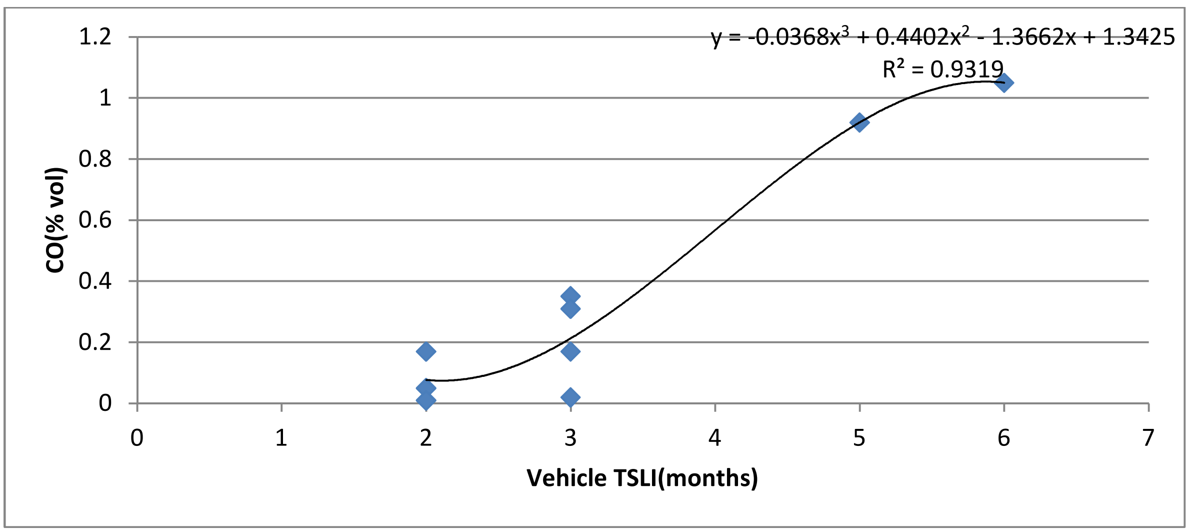

Fig.4.50 Vehicle TSLI vs CO emission of Swift (Fast Idle)

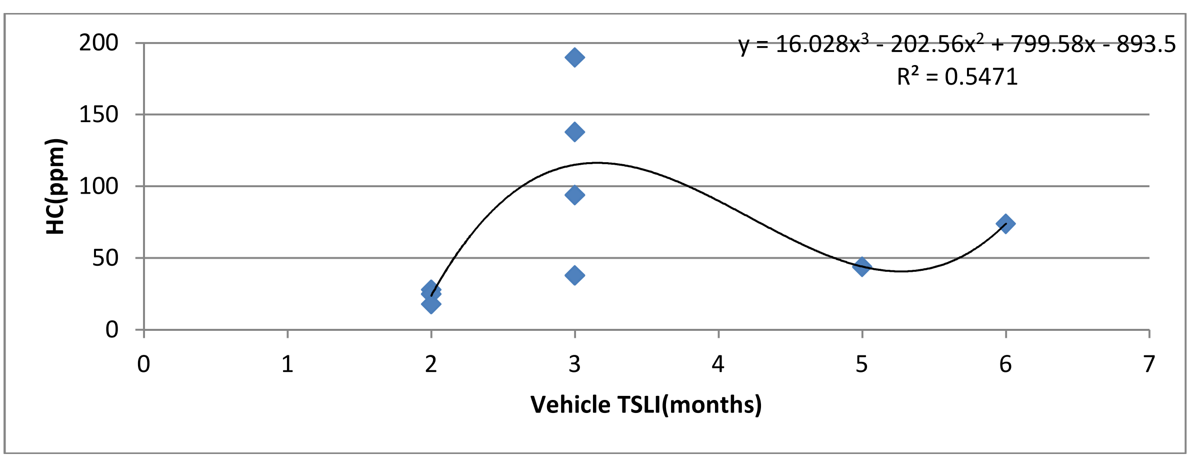

Fig.4.51 Vehicle TSLI vs HC emission of Swift (Idle)

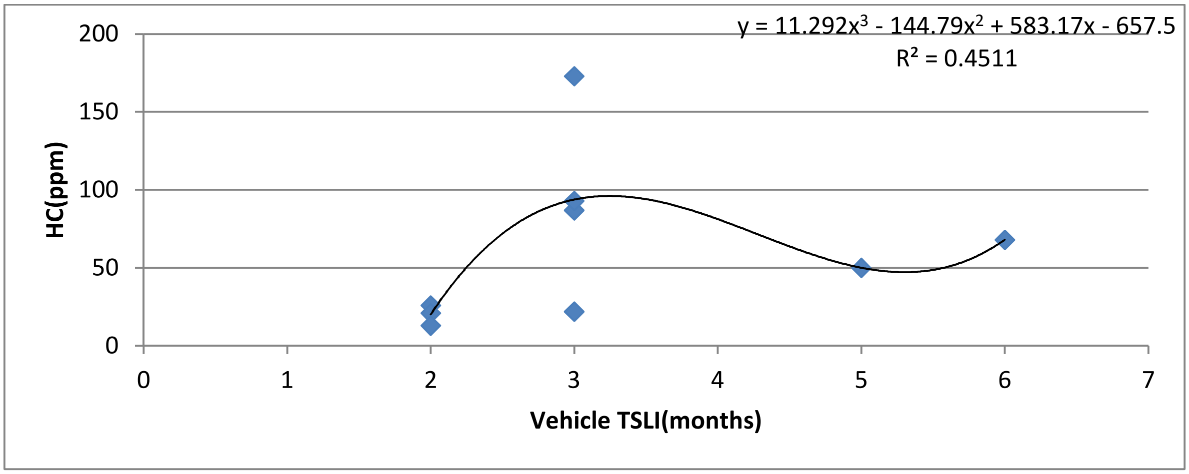

Fig.4.52 Vehicle TSLI vs HC emission of Swift (Fast Idle)

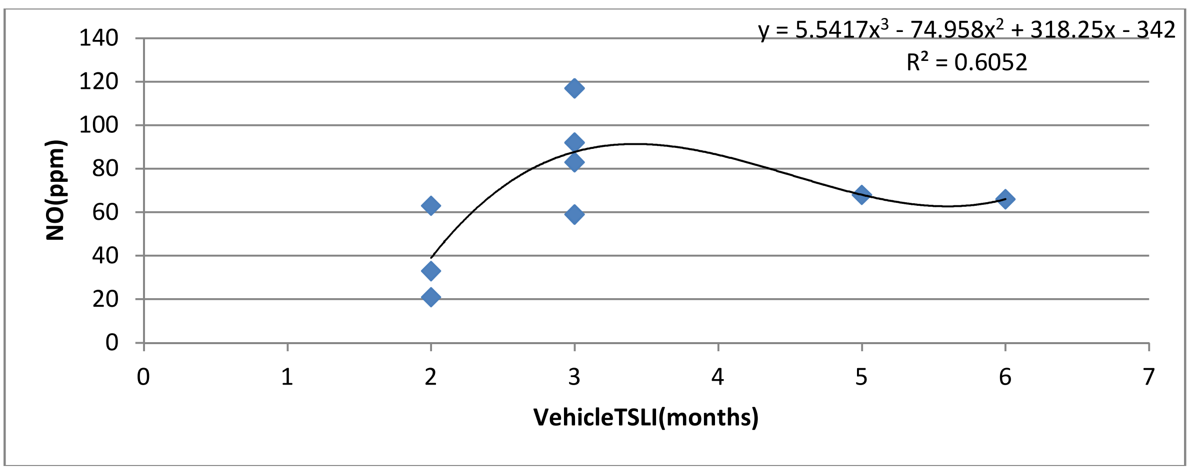

Fig.4.53 Vehicle TSLI vs NO emission of Swift (Idle)

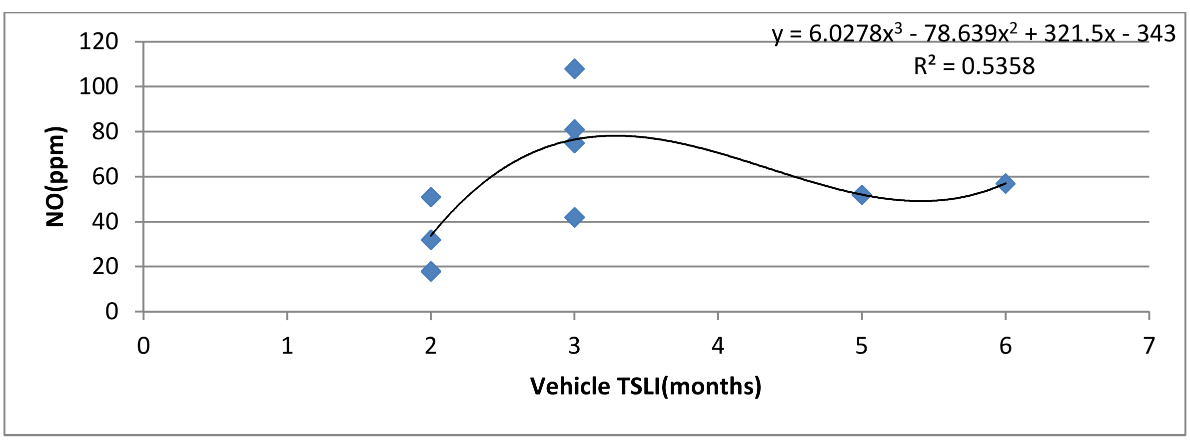

Fig.4.54 Vehicle TSLI vs NO emission of Swift (Fast Idle)

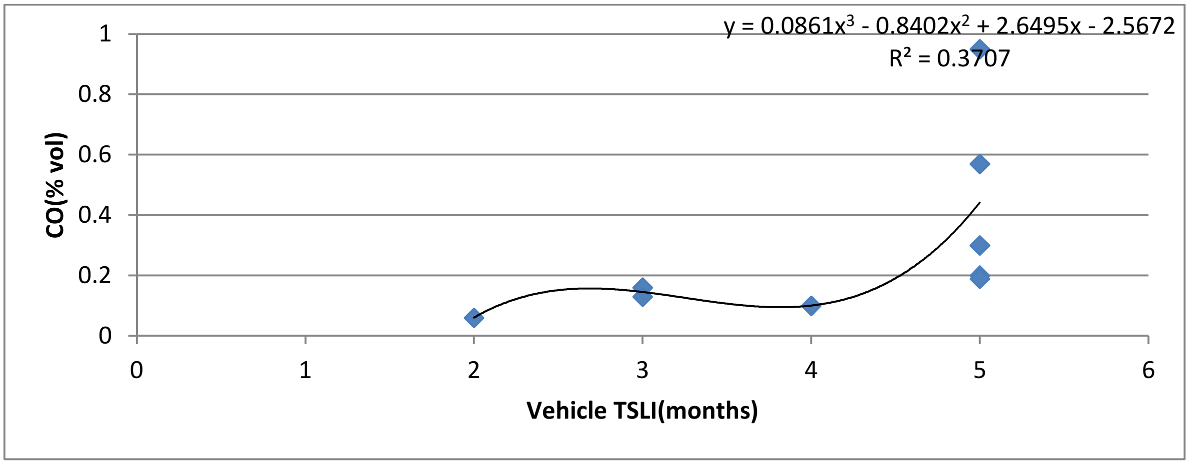

Fig.4.55 Vehicle TSLI vs CO emission of Santro (Idle)

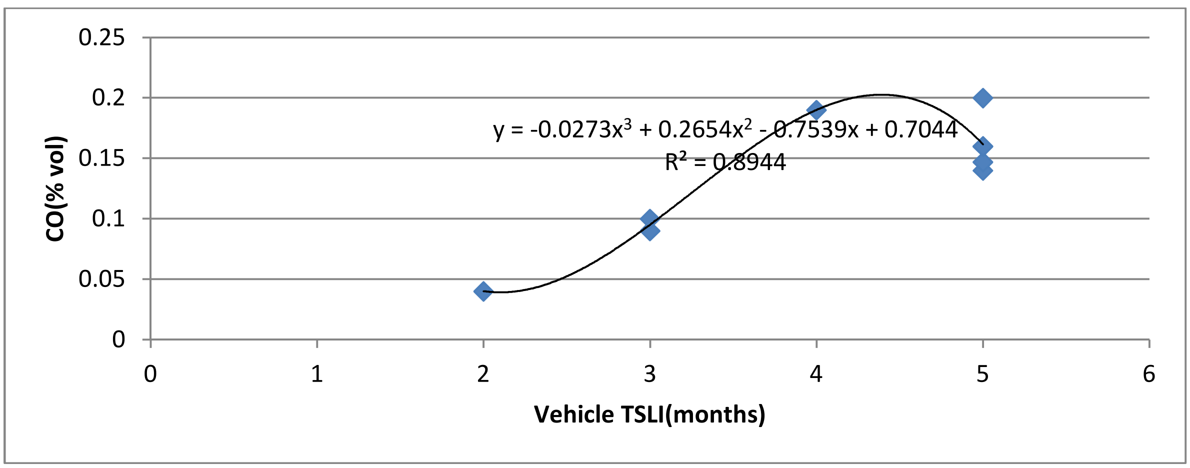

Fig.4.56 Vehicle TSLI vs CO emission of Santro (Fast Idle)

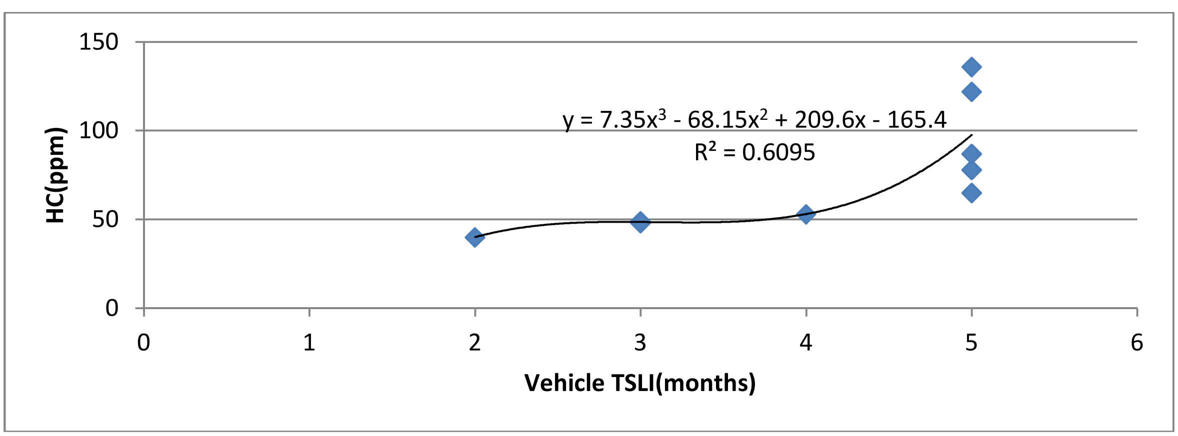

Fig.4.57 Vehicle TSLI vs HC emission of Santro (Idle)

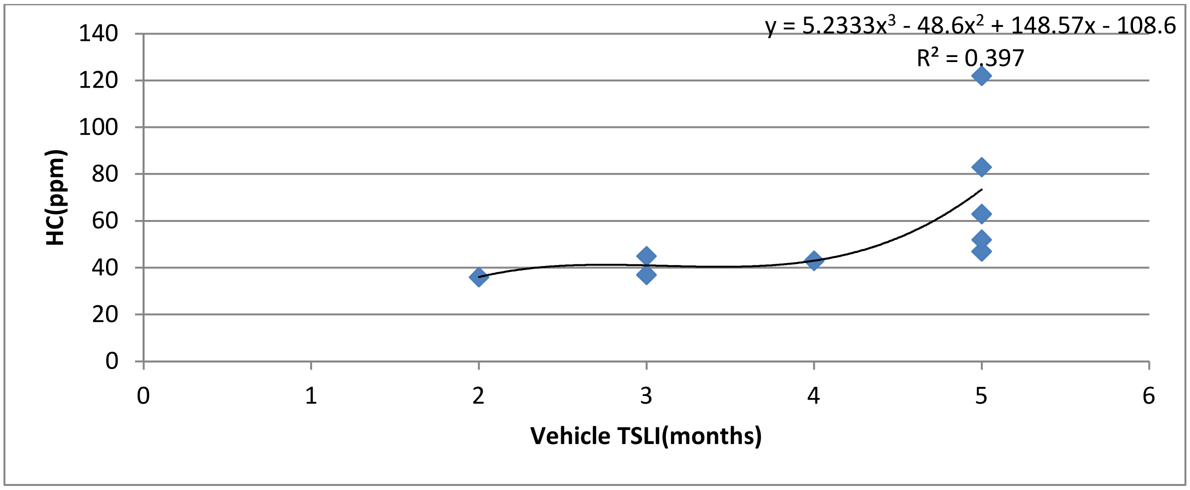

Fig.4.58 Vehicle TSLI vs HC emission of Santro (Fast Idle)

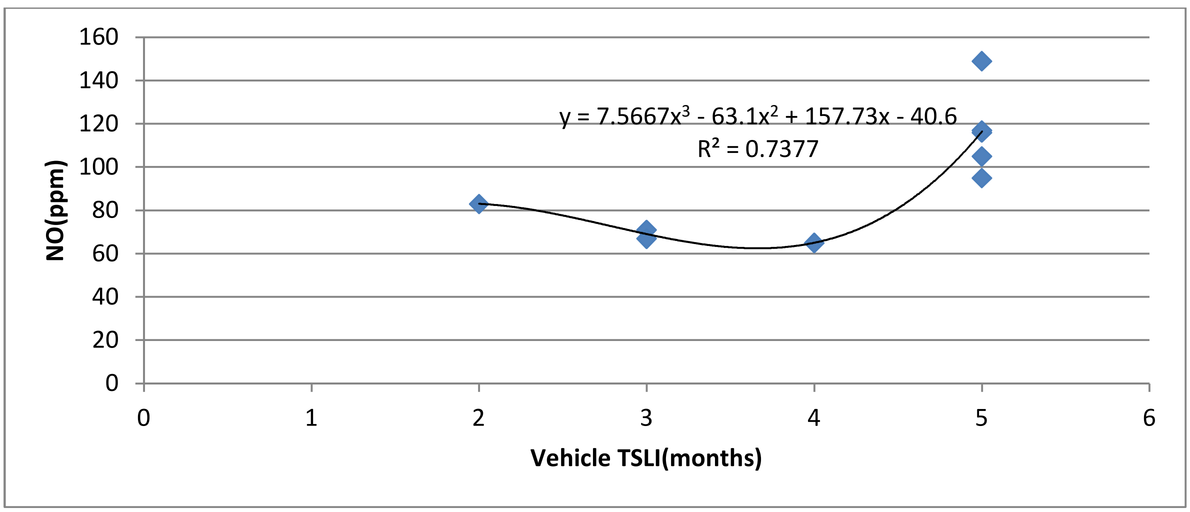

Fig.4.59 Vehicle TSLI vs NO emission of Santro (Idle)

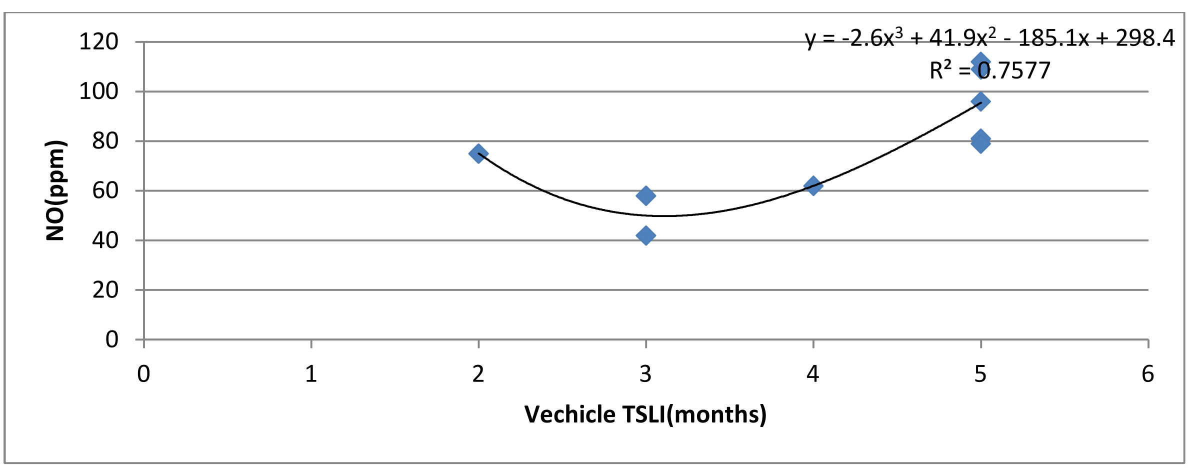

Fig.4.60 Vehicle TSLI vs NO emission of Santro (Fast Idle)

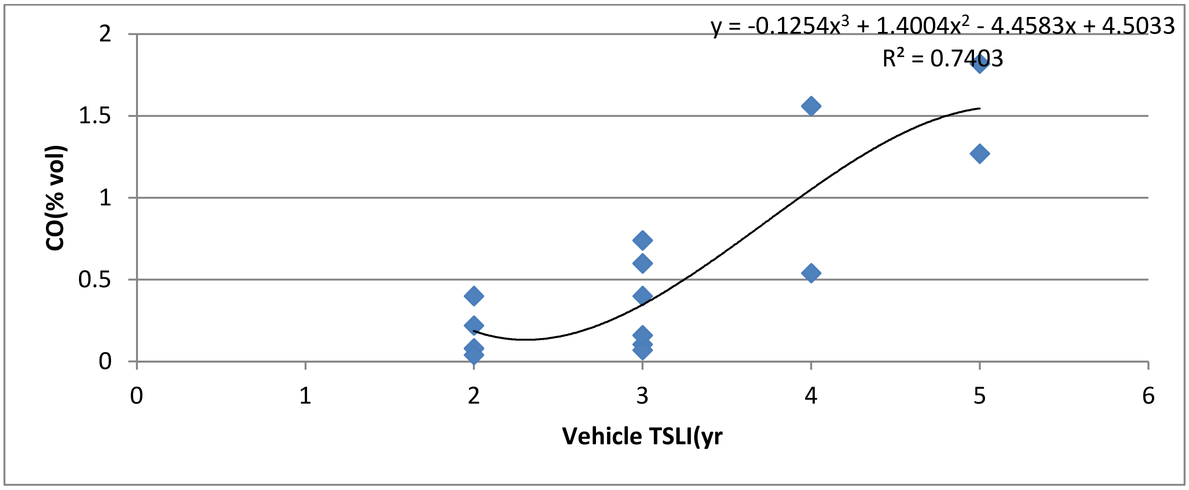

Fig.4.61 Vehicle TSLI vs CO emission of Wagnor (Idle)

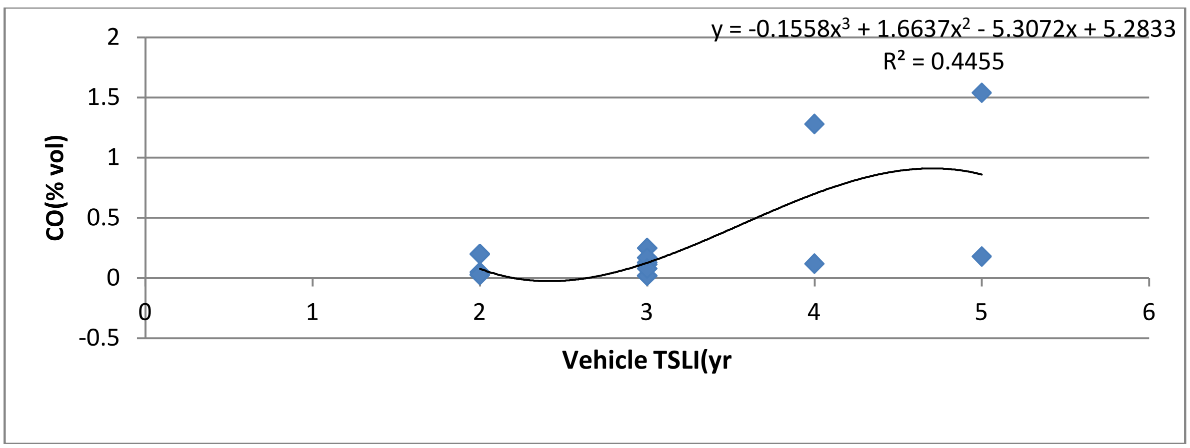

Fig.4.62 Vehicle TSLI vs CO emission of Wagnor (Fast Idle)

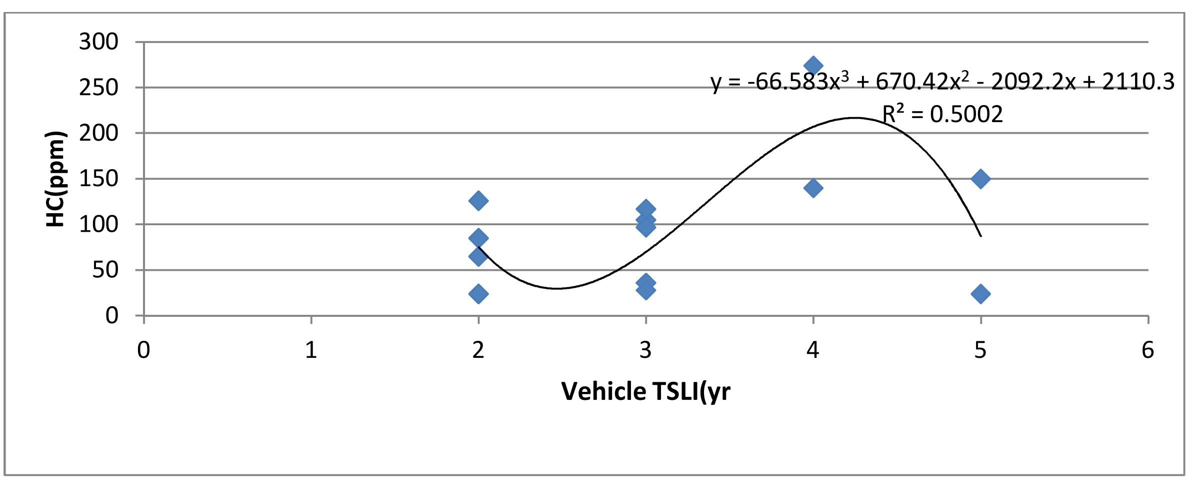

Fig.4.63 Vehicle TSLI vs HC emission of Wagnor (Idle)

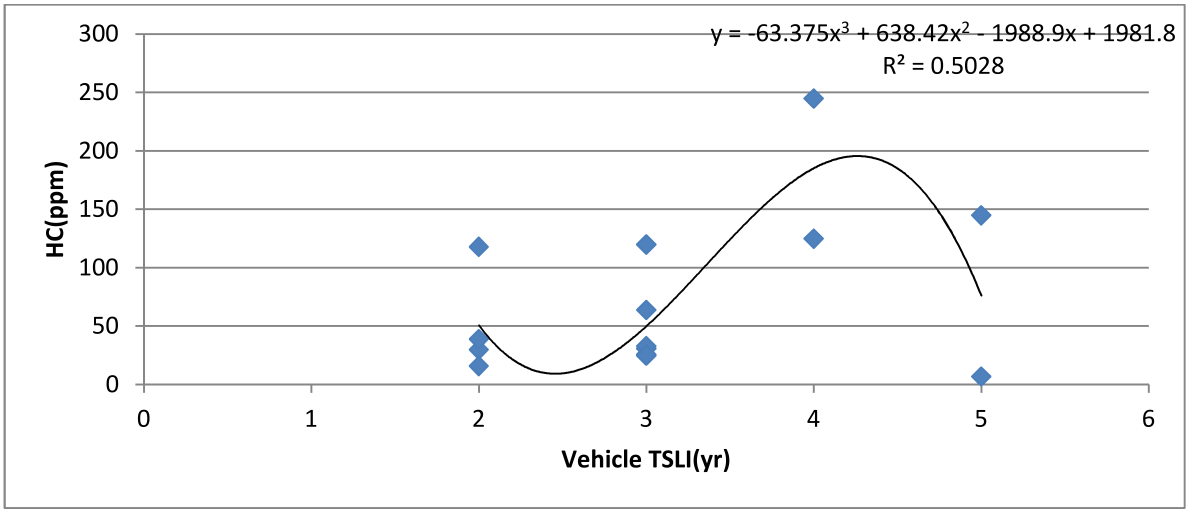

Fig.4.64 Vehicle TSLI vs HC emission of Wagnor (Fast Idle)

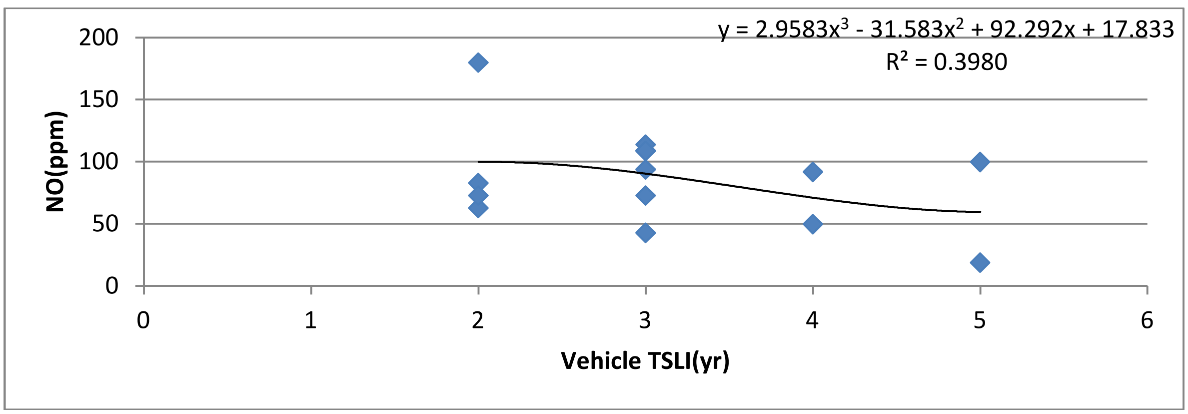

Fig.4.65 Vehicle TSLI vs NO emission of Wagnor (Idle)

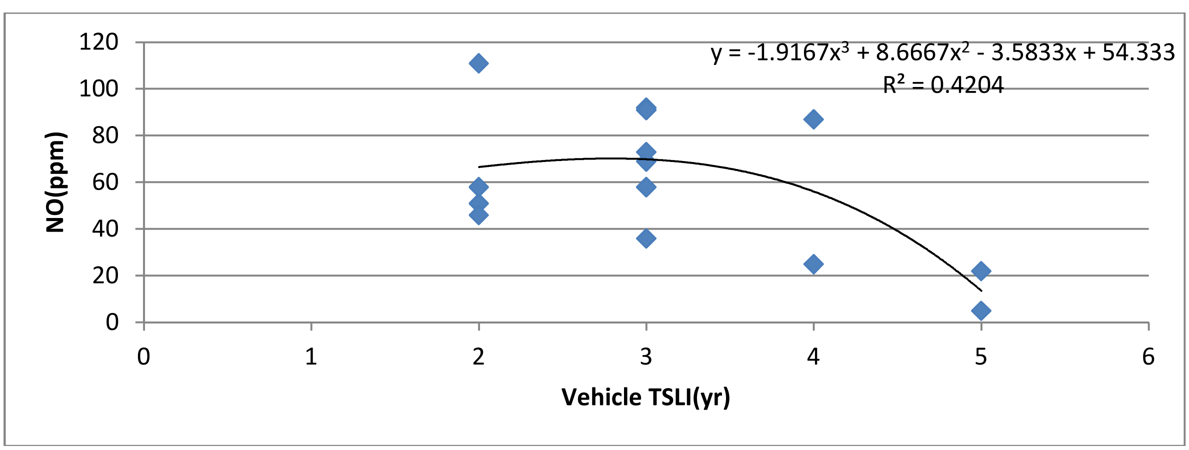

Fig.4.66 Vehicle TSLI vs NO emission of Wagnor (Fast Idle)

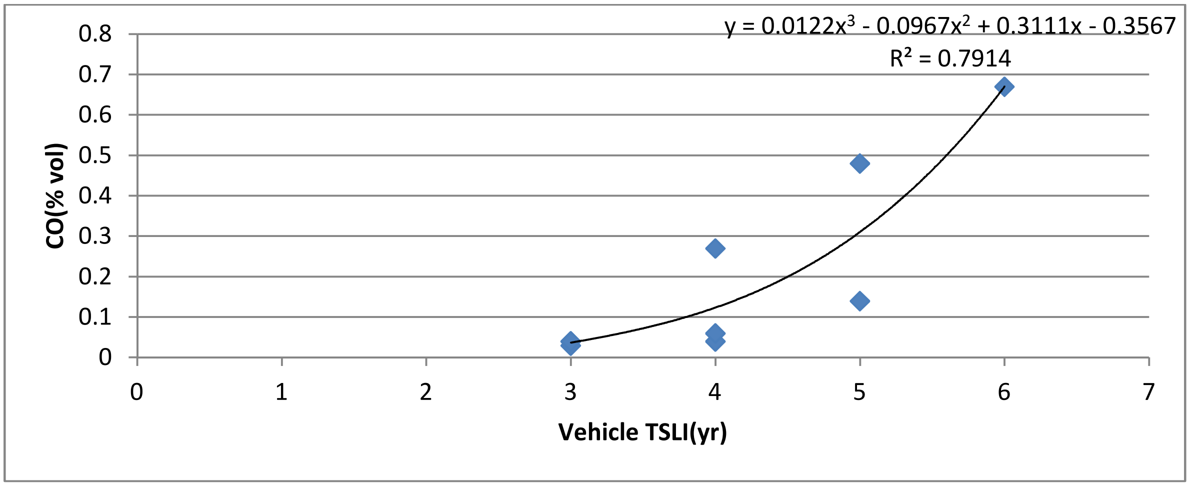

Fig.4.67 Vehicle TSLI vs CO emission of Alto (Idle)

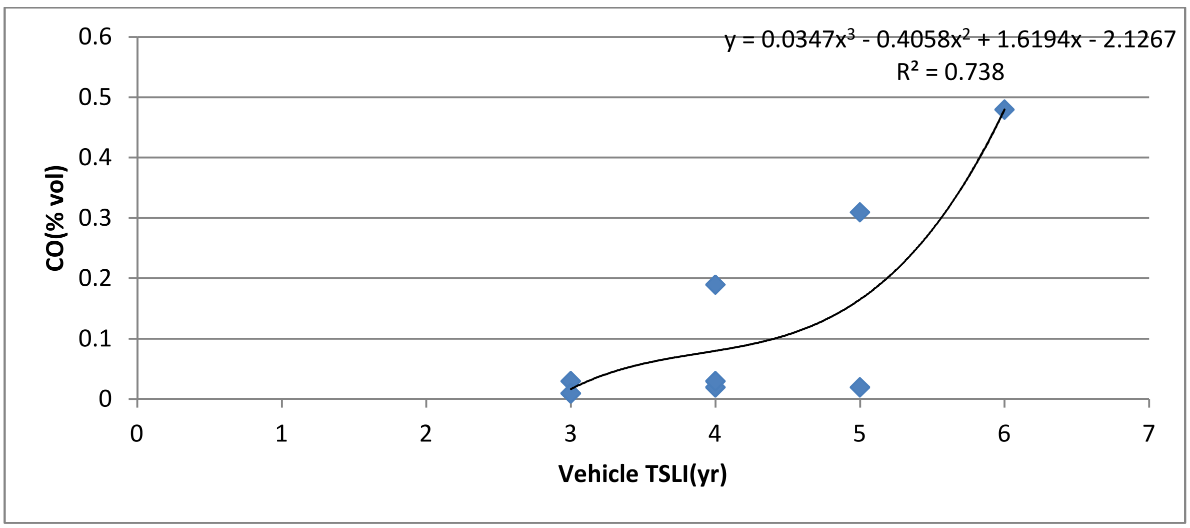

Fig.4.68 Vehicle TSLI vs CO emission of Alto (Fast Idle)

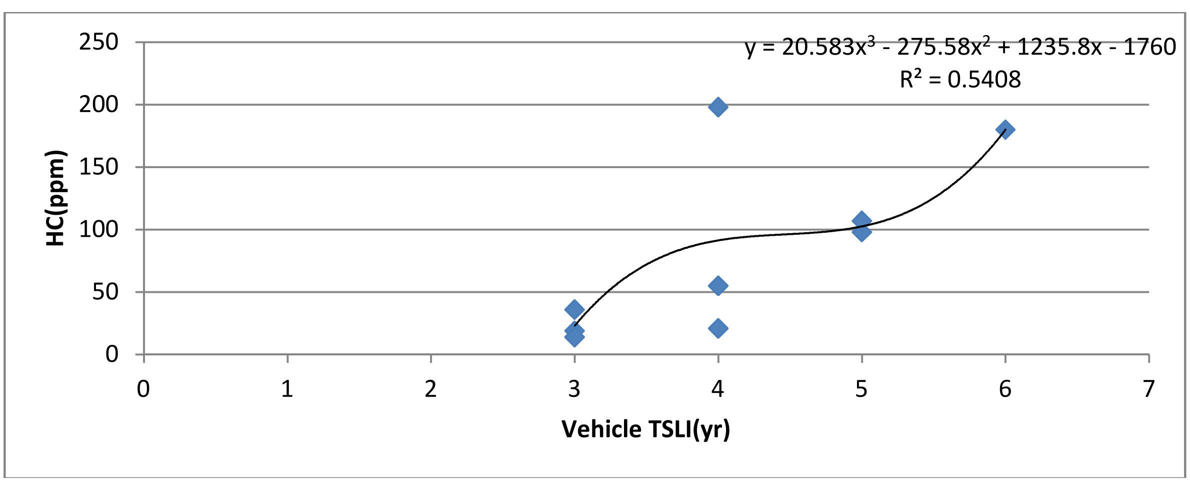

Fig.4.69 Vehicle TSLI vs HC emission of Alto (Idle)

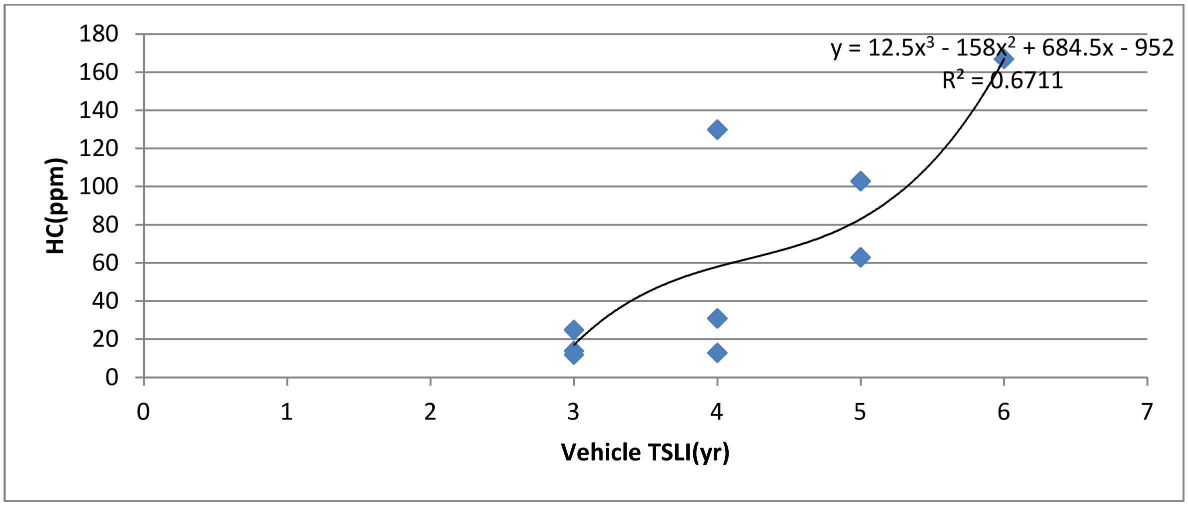

Fig.4.70 Vehicle TSLI vs HC emission of Alto (Fast Idle)

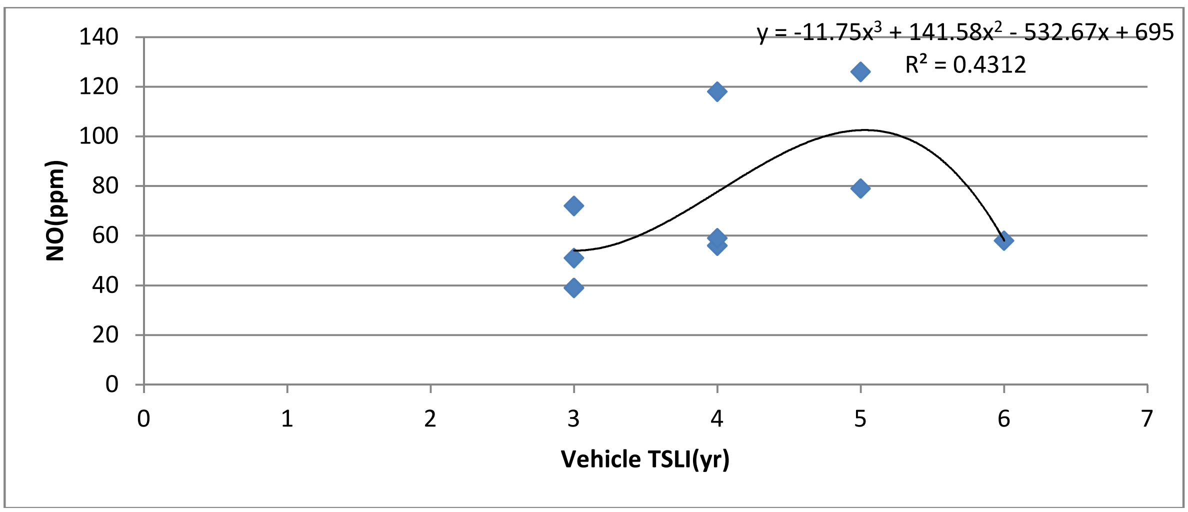

Fig.4.71 Vehicle TSLI vs NO emission of Alto (Idle)

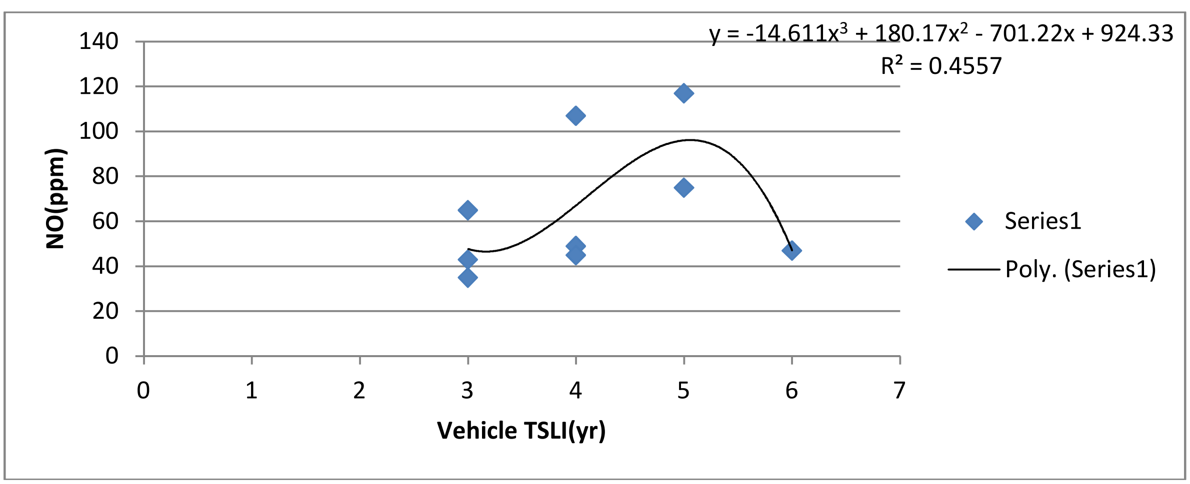

Fig.4.72 Vehicle TSLI vs NO emission of Alto (Fast Idle)

It is evident from the analysis that the correlation between CO,HC and NO emissions and vehicle TSLI is of polynomial in nature and the equations obtained there by for the best-fit polynomial trendlines in each case are given in Table 4.3.

Table 4.3 Equations relating CO,HC and NO emissions with vehicle TSLI (model-wise)

S/N.	**Model**	**EMISSION**	**Test mode**	**Equation (s)**	**R^2 values**
1.	SWIFT	CO	Idle	$y = 0.0959x^3 - 1.0612x^2 + 3.8958x - 4.2075$	0.8618
			Fast Idle	$y = -0.0368x^3 + 0.4402x^2 - 1.3662x +1.3425$	0.9319
2.	SWIFT	HC	Idle	$y = 16.028x^3 - 202.56x^2 + 799.58x - 893.5$	0.5471
			Fast Idle	$y = 11.292x^3 - 144.79x^2 + 583.17x - 657.5$	0.4511
3.	SWIFT	NO	Idle	$y = 5.5417x^3 - 74.958x^2 + 318.25x - 342$	0.6052
			Fast Idle	$y = 6.0278x^3 - 78.639x^2 + 321.5x - 343$	0.5358
4.	SANTRO	CO	Idle	$y = -0.1254x^3 + 1.4004x^2 - 4.4583x +4.5033$	0.7403
			Fast Idle	$y = -0.1558x^3 + 1.6637x^2 - 5.3072x +5.2833$	0.4455
5.	SANTRO	HC	Idle	$y = -66.583x^3 + 670.42x^2 - 2092.2x +2110.3$	0.5002
			Fast Idle	$y = -63.375x^3 + 638.42x^2 - 1988.9x +1981.8$	0.5028
6.	SANTRO	NO	Idle	$y = 2.9583x^3 - 31.583x^2 + 92.292x + 17.833$	0.3980
			Fast Idle	$y = -1.9167x^3 + 8.6667x^2 - 3.5833x +54.333$	0.4204
7.	WAGNOR	CO	Idle	$y = -0.1254x^3 + 1.4004x^2 - 4.4583x +4.5033$	0.7403
			Fast Idle	$y = -0.1558x^3 + 1.6637x^2 - 5.3072x +5.2833$	0.4455
8.	WAGNOR	HC	Idle	$y = -66.583x^3 + 670.42x^2 - 2092.2x +2110.3$	0.5002
			Fast Idle	$y = -63.375x^3 + 638.42x^2 - 1988.9x +1981.8$	0.5028
9.	WAGNOR	NO	Idle	$y = 2.9583x^3 - 31.583x^2 + 92.292x + 17.833$	0.3980
			Fast Idle	$y = -1.9167x^3 + 8.6667x^2 - 3.5833x +54.333$	0.4204
10.	ALTO	CO	Idle	$y = 0.0122x^3 - 0.0967x^2 + 0.3111x - 0.3567$	0.7914
			Fast Idle	$y = 0.0347x^3 - 0.4058x^2 + 1.6194x - 2.1267$	0.738

11.	ALTO	HC	Idle	$y = 20.583x^3 - 275.58x^2 + 1235.8x - 1760$	0.5408
		HC	Fast Idle	$y = 12.5x^3 - 158x^2 + 684.5x – 952$	0.6711
12.	ALTO	NO	Idle	$y = -11.75x^3 + 141.58x^2 - 532.67x + 695$	0.4312
			Fast Idle	$y = -14.611x^3 + 180.17x^2 - 701.22x +924.33$	0.4557

The emission equations having vehicle TSLI as variable show that the time elapsed since last inspection has a direct influence on the CO,HC and NO emission characteristics and the CO,HC and NO emissions are shown to increase with increase in time that has passed since the previous inspection/maintenance. This increase, as evidenced by the analysis, is of polynomial nature and it is also shown that CO,HC and NO emissions may even exceed the existing emission norms for in-use vehicles after a certain time since previous inspection.

4.4 Effect of level of inspection/maintenance on CO, HC and NO emissions:

The level of inspection/maintenance (to be expressed as I/M level here from) was categorized as excellent,good, satisfactory or poor on the basis of criteria adopted in this study. For this purpose, the frequency of inspection/maintenance got carried out in the workshop was chosen as the indicator. The criteria for classifying the I/M level is given in Table 4.4.

Table 4.4 Criteria for classification of I/M level

S. Number	Number of visits during a year	I/M level
1.	1-3	Poor
2.	4-6	Satisfactory
3.	7-9	Good
4.	10-12	Excellent

The I/M level is found to have a positive effect towards the reduction in CO,HC and NO emissions, it is revealed that CO emission is the most crucial factor being influenced by I/M level of the cars and should be taken care of suitably during the maintenance schedule through the proper tuning of engine.(Pandey, Pandey, & Mishra, 2016)

4.5 Relative standing of idle and fast idle test conditions for monitoring CO, HC and NO emissions with respect to vehicle age and mileage:

A glance at the trendlines relating to the two test conditions reveals that the fast idle test condition yields lower values of CO and HC emissions than those for the idle test condition. It, therefore, reflects that, if the fast idle test condition is also permitted in the country, the standardization procedure must look into the lowering of the values suitably than those prescribed for idle test conditions. (Abhinav Pandey et al., 2016)

The analysis of data, results and discussion have resulted in certain useful conclusions and important recommendations, which have been dealt with in the forthcoming chapter.

CHAPTER 5

RECOMMENDATIONS AND CONCLUSION

The effect of the various vehicles-related parameters on CO, HC and NO emissions of the petrol-driven passenger cars of Maruti and Hyundai has been systematically studied and based upon the analysis of data, results and discussion,It is revealed that the emission characteristics of petrol-driven passenger cars of Swift, Santro, Wagnor and Alto for CO, HC and NO emissions with respect to vehicle age are fairly described by a polynomial curve and the equations given in Table 4.1 these equation can be used for predicting the CO, HC and NO emissions with respect to the vehicle age of different models.

It has been observed that the effect of vehicle mileage on CO, HC and NO emissions of petrol-driven passenger cars of Swift, Santro, Wagnor and Alto is also fairly described by a polynomial curve and the equations given in Table 4.2 these equation can be used for predicting the CO, HC and NO emissions with respect to the vehicle mileage of different models. It is also seen that the time since last inspection (TSLI) is quite important from the point of view of CO, HC and NO emissions from different petrol-driven passenger cars of Swift, Santro, Wagnor and Alto. It is revealed that the CO, HC and NO emissions can be correlated with TSLI through polynomial trendlines which are given in Tables 4.3.

Inspection/maintenance (I/M) level is found to have a positive effect towards the reduction in CO, HC and NO emissions and it is revealed that CO emission is the most crucial factor being influenced by the I/M level of cars and should be taken care of suitably during the maintenance schedule through proper tuning of vehicles.

A comparison of idle and fast idle test conditions for monitoring CO,HC and NO emissions with respect to vehicle age and vehicle mileage reveals that fast idle test conditions yield lower values of CO, HC and NO emissions than those for the idle test mode. This necessitates suitable lowering of the values in case of the fast idle mode being proposed to be taken up for standardization in the future.

The outcome of the study relating to the effect of vehicle age, mileage and TSLI on CO, HC and NO emissions of petrol-driven passenger cars has led to the useful inferences, which can be used for the prediction of vehicular emission and helpful to develope the long-lasting compliance of pollution control systems with respect to vehicle age, mileage and regular monitoring as well as maintenance of pollution control systems, so the vehicular pollution from petrol-driven passenger cars can be reduced in the country.

Scope for future work:

1. With the limited data having been used for developing the emission equations in this study, there is a scope to further refine the predictive equations with a larger data set.
2. The study can be carried out for other makes and models of petrol-driven vehicles of different kinds and a synthesis of analysis can be taken up for like situations, which may eventually lead to the development of a generalized approach.
3. Suitable initiatives and steps should be taken up by the automobile sector to improve the compliance status of pollution control systems to be fitted in petrol-driven passenger cars for a long-lasting duration.

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APPENDIX-A

FORMAT OF DATA COLLECTION SHEET

DEPARTMENT OF ENVIRONMENTAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
DELHI – 110 042

"EXHAUST EMISSION FROM PETROL-DRIVEN PASSENGER CARS: A CASE STUDY"

- **Vehicle Characteristics**

1. Vehicle registration no. ....
2. Vehicle make/manufacturer
3. Vehicle model and model year
4. Vehicle age
5. Engine capacity (cc. or bhp.)
6. Fuel distribution system .... Carburetor / MPFI / other.....
7. Compression ratio
8. No. of cylinders / Bore X stroke (mm X mm)
9. Working status of Odometer Continuous / Intermittent / Non-working
10. Odometer reading (km) / V. M. T. ....
11. Previous inspection/maintenance record (S=Servicing, E= Engine–related maintenance) (I) .... (II).......... (III)................
12. Level of inspection/maintenance Excellent / Good / Satisfactory / Poor
13. Emission standard compliance system EURO-I / II / III/IV or BHARAT Stage-I /II/III/IV
14. Whether provided with Catalytic Converter .... (Yes / No).................
15. Time since last inspection (T. S.L.I., months)
16. Remarks, if any

- **Emission Characteristics**

Conditions	CO (%)	NO(ppm)	HC (ppm)
IDLING			
FAST IDLING (@ 2,500 rpm)			

Venue: SANJAY MOTORS,ROHINI SEC-17,NEW DELHI

Date: - -2017

Time: hrs. **Signature**