OPTIMIZATION OF THE VEHICULAR EMISSIONS OF PUBLIC TRANSPORTATION SYSTEM OF A METRO CITY: SOME STRATEGIES

A Thesis

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by

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CERTIFICATE

Certified that the thesis entitled **"Optimization of the Vehicular Emissions of Public Transportation System of a Metro City: Some Strategies"** being submitted by Mr. Amit Pal, to the University of Delhi, Faculty of Technology, in the Department of Mechanical Engineering at Delhi College of Engineering, Delhi, in the fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY**, is a record of bona-fide research work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirements for the submission of this work which has attained the standard required for a Ph. D. degree of the University of Delhi. The results presented in this thesis have not been submitted elsewhere for the award of any other degree or diploma.

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ABBREVATIONS

A/F	Air/Fuel
AAQS	Ambient Air Quality Standards
AFV	Alternative Fuel Vehicle
ARAI	Automobile Research Association of India
ASTM	American Society for Testing of Materials
BMEP	Brake Mean Effective Pressure
BPCL	Bharat Petroleum Corporation Limited
BRT	Bus Rapid Transit
BSEC	Brake Specific Energy Consumption
Bsec	Brake Specific Energy Consumption
BSFC	Brake Specific Fuel Consumption
Bsfc	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CFPP	Cold Filter Plugging Point
CI	Compression Ignition
CMVR	Central Motor Vehicle Rule
CNG	Compressed Natural Gas
CO	Carbon monoxide
CPCB	Central Pollution Board
CR	Compression Ratio
CRDi	Common Rail Diesel Injection
CRDI	Common Rail Diesel Injection
CRRI	Central Road Research Institution
DDF	Diesel Dual Fuel
DFE	Dual Fuel Engine
DISI	Direct-Injection Spark-Ignition
DMRC	Delhi Metro Rail Corporation
DRDO	Defense Research and Development Organization
DST	Department of Science and Technology
DTC	Delhi Transport Corporation
E-Diesel	Ethanol Diesel
EFC	Electronic Fuel Control
EGR	Exhaust Gas Recirculation
EPCA	Environment Pollution (Prevention & Control) Authority

Cont….

ABBREVATIONS

F/A	Fuel/Air
GDP	Gross Domestic Profit
GNCTD	Government of National Capital Territory of Delhi
GPS	Geographical Positioning System
GVW	Gross Vehicle Weight
HC	Hydrocarbons
HCV	Heavy Commercial Vehicle
HP	Horse Power
HR	Higher Range
IDC	Industrial Development Corporation
IGL	Indraprastha Gas Limited
IMEP	Indicated Mean Effective Pressure
IOCL	Indian Oil Corporation
IOF	Indian Oil Federation
IQR	Inter Quartile Range
ITO	Income Tax Office
LCV	Light Commercial Vehicle
LPG	Liquid Petroleum Gas
LR	Lower Range
Mfvcc	Constant for the specific type of Emissions and Vehicle Combination,
M_{f1}-	Growth factor as per historic trend for a particular type of vehicles
M_{f2}-	Change in growth for a type of vehicles, by proposed measures
M_{f3}-	Factor for the Impact of Fuel Quality Improvements
M_{f4}-	Factor for the Impact of Advanced Vehicle Technologies
MG	Mono Glycerides
MIDC	Maharashtra Industrial Development Corporation
MMt	Million Metric tons
MMT	Monorail Malaysia Technology
MoEF	Ministry of environment and Forests
MOP&NG	Ministry of Petroleum & Natural Gas ()
MPFi	Multi Point Fuel Injection
MRTS	Mass Rapid Transport System
MUV	Multi Utility Vehicle

Cont….

ABBREVATIONS

NAAQS	National Ambient Air Quality Standards
NCR	National Capital Region
NGO	Non Government Organization
NMHC	Non Methane Hydro Carbons
NO_x	Nitrogen Oxides
O_3	Ozone
OEM	Original Equipment Manufacturer
PAH	Polycyclic Aromatic Hydrocarbons
PCRA	Petroleum Conservation Research Association
PEC	Pure Energy Corporation
PFI	Port-Fuel-Injected
PIL	Public Interest Litigation
PM	Particulate Matter
PPM	Parts Per Million
PPME	Pongamia Pinnata Methyl Ester
PTS	Public Transportation System
PUC	Pollution Under Control Certificate
RBC	Red Blood Cells
RBF	Radial Basis Function
RON	Research Octane Number
RSPM	Respiarable Suspended Particulate Matter
S/V	Stroke/Volume
SAE	Society of Automobile Engineers
SI	Spark Ignition
SIAM	Society of Indian Automobile manufacturers
SO_2	Sulphur Dioxide
SPM	Suspended Particulate Matter
STA	State Transport Authority
STDV	Standard Deviation
TDC	Top Dead Centre
TEGDN	Tri-ethylene Glycol Di-nitrate
THC	Total Hydrocarbons
TPD	Tons Per Day
TSP	Total suspended particulates

Contd….

ABBREVATIONS

UHC	Unburnt Hydro Carbons
ULW	Unladen Weight
USA	United States of America
USD	United States Dollar
USSR	United States of Soviet Russia
VCR	Variable Compression Ratio
VOC	Volatile Organic Compounds
VVT	Variable Valve Timing
WBC	White Blood Cells
WHO	World Health Organization
YPR	Your Previous Rating
YRR	Your Revised Rating
ZET	Zero Emissions Technology
ZEV	Zero Emissions Vehicle

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CHAPTER 10. CONCLUSIONS AND RECOMMENDATIONS

ABSTRACT

Today, the capital city of India, Delhi is one of the most polluted cities in the world, which has been caused by phenomenal vehicular growth primarily during the past two-three decades. Incidentally, only a few decades earlier Delhi was acclaimed as one of the greenest capital in the world. In order to restore the air quality and refurbish its image, a number of plans have been prepared and implemented in Delhi during the past few years. The related externalities like traffic congestion, quality of available fuel quality, extent of overloading or over speeding, and maintenance, have a definite impact on the environmental degradation. Although the statistical data for the vehicular pollution of Delhi is available, a comprehensive planning and optimization strategy to overcome the above problem is yet to be formulated.

The present research highlights the severity of the issues related to vehicular exhaust emissions and suggests techniques for efficient planning and management of the Public Transportation System for the city of Delhi. In this study, a frame work of an optimization model for solving the transportation problems of the capital city of India, has been proposed. This study therefore, is an attempt to:

- ✓ Suggest a model to manage the complexities of the transport system of Delhi.
- ✓ To examine the compatibility and potential of the alternative fuels and improvement in the quality of fuel with a view to reduce the vehicular exhaust emissions.
- ✓ To incorporate feedback and expectations of the people in planning a Public Transportation System for the city of Delhi.
- ✓ To map what is the likely future scenario over a span of 20-22 years with different control action plans suggestive of mitigating the problem of pollution.
- ✓ To develop models to alter these future scenarios ensuring a clean and efficient transport system for Delhi.

In this work, a comprehensive experimental work has been performed on different single cylinder, twin cylinder and four cylinder Spark Ignition (S.I.) and Compression Ignition

(C.I.) engines to assess the impact of several alternative fuels like Ethanol, Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG) and Bio-Diesel on the vehicular exhaust emissions and to ascertain the viability of these alternative fuels for the internal combustion engines that are being used currently. The emission levels of these alternative fuels were found to be highly encouraging and these have been used in proposing the *emission modification factors* for several alternative fuels and advanced engine technologies.

A Delphi study was commissioned to obtain the feedback and suggestions of the experts, having technical backgrounds, such as industrial, scientific, transport administration, engineering academics and engineering studies. The questionnaire designed included a wide spectrum of different modes of transportation, beginning with bicycles and cycle rickshaws, encompassing all the prevalent modes of automobiles being used and including up to electric and solar powered vehicles. The data collected were analysed using the MATLAB software and the results have been used to estimate and then propose future *emission modification factors*.

An estimate of the current vehicular exhaust emissions in the metro city of Delhi has been worked out by considering different characteristics of vehicles, based on their age, engine technology, type of fuel used and average kilometers travelled. These estimated emissions were incorporated in the proposed *emission modification factors* to obtain the projected future emissions. These *emission modification factors* are based on our experimental results, literature review and survey analysis.

The projected future vehicle emission levels cater to various possibilities of the proposed control actions. Other than Business As Usual (BAU) scenario, eight different control scenarios have also been construed for the years 2010, 2020 and 2030. The vehicular emissions are observed to rise very rapidly- e.g. for BAU scenario the vehicular emissions in Delhi may rise approximately by 15%, 150%, and 400% respectively for the years 2010, 2020 and 2030, with reference to 2007 levels.

However by incorporating certain proposed strategies, it is anticipated that about 20% to 70% emissions of the BAU scenario projections can be reduced, depending upon which proposed integrated approach is implemented faithfully. Further, it is worth mentioning here that letting the BAU continue may be very disastrous to the overall health of our people, and its overall impact may prove to be an expensive affair taking into account of the expenses to be incurred on health services, fuel expenses on inefficient vehicles, unnecessary use of personal vehicles, wastage of valuable time in slow moving traffic etc.

Hence a sincere and wholehearted action to arrest the vehicular emission levels is the need of the hour. The strategies that have been contemplated include the following:

i. Improvement of public transport system, by making it cheaper, comfortable, reliable, efficient and available within walk-able distances.

ii. Optimization of traffic flow, improvement in traffic management (e.g., area traffic control system, no motorized-traffic zones, green corridors, removal of encroachment on roads, regulation of construction activities and digging of roads, etc.)

iii. Comprehensive inspection and certification system for I & M (Inspection and Maintenance) of on-road vehicles; emission warranty by manufacturers/authorized service providers, which should be for the entire legally usable life of the vehicle.

iv. Phasing out of grossly polluting units or mandatory technological up-gradation.

v. Improvements in quality of Fuels (e.g., reduction of benzene and aromatics in petrol, reformulated gasoline with oxygenates/additives, reduction of sulfur in diesel etc.)

vi. Accelerating the research on environment friendly alternative fuels such as ethanol, bio-diesel, hydrogen etc. and laying their quality standards and ensuring their availability in the market with satisfactory quality at affordable price and to suggest necessary subsidy wherever necessary.

vii. Tightening of emission norms regularly with the advancement of the technology for newer vehicles.

viii. Improvement in vehicle technology. (e.g., restriction on the two-stroke engines, provision for of on-board diagnostic system, commencement of the Gasoline Direct Injection Systems, Electric and Common Rail Diesel Injection, Hybrid vehicles, Fuel cell etc.)

ix. Checking adulteration of fuel and training the volunteers from the non government organizations (NGOs) /general public to do so and devising advanced technologies to check adulteration of fuels automatically.

x. Checking evaporative emissions from storage tanks and the fuel distribution systems.

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CHAPTER 1.

INTRODUCTION

In this work, an analysis of the vehicular emissions from the public transportation system of city of Delhi is presented. The report includes the history, present status and the suggested framework for the mitigation of the vehicular emissions in future.

1.1 GENERAL DESCRIPTION

This chapter gives an insight into the problem of the vehicular emissions, their main causes and present status in transportation system of Delhi. The population of the world is increasing at an alarming rate of nearly three percent per year. India is the world's seventh largest country as per its area, and in terms of population, it stands second only to China (Peterson, 1984). As the seventh most populous metropolis in the world, population of Delhi is 13.8 million, with an annual growth rate of 3.8 % per annum (Kathuria, 2006). By the end of 2050, the population of the India's second largest city (Delhi) is expected to touch a level of 1.9 times of what it is today, thus almost doubling the figure of the year 2006 (Srinivasachary and Bose, 2006). In recent years per-capita income in Delhi has grown at roughly 5 % per annum and at 3000 $ (USD), it is twice the national average (Economic Survey of Delhi, 2007).

As the economies grow, transportation activities also tend to expand. As such populations of megalopolis cities, motor vehicles, motor fuel consumption, and air pollution all have increased (Walsh, 1993). The global vehicle stock is expected to approximately double from about 640 million at present to about 1 billion vehicles by the year 2025 AD. It is estimated that the transportation sector will grow by about 7 % during the next decade. The air quality crisis in most of the cities is often attributed in large measures (40–80 %) to the vehicular emissions. The Urban India presents a picture of metamorphosis as most of the cities are growing rapidly. Today, existing cities are expanding, new cities are being created, and adjacent cities are merging. The feudal towns have changed to industrial cities, cities into metropolis and metros into megalopolis. Moreover, urban populations are growing at a faster rate than the national average (Ghose, 2000). This rapid growth of the urban population also brings with it increasing demands for energy-based goods and services. Owing to the expanding economic base, there is an influx of population migrating from the rural areas and urban fringe to the core city in search of better quality of life. This has overstretched infrastructure of the urban areas, which is unable to cater to the ever-growing needs of in-migrants. Transportation systems are expanding everywhere and, improved performance of technology alone is presently insufficient to counteract the growing demand of transportation. Projections, therefore, consistently show worsening air quality in the cities of India in future. This congruence has contributed to urban air pollution problem directly related to motor vehicle emissions of Carbon Monoxide (CO), Ozone (O_3), toxics and particulates (Davis, 1998). In India, outdoor air pollution is restricted mostly to the urban areas, where automobiles are the major contributors, and also to a few other areas having a concentration on industries and thermal power plants.

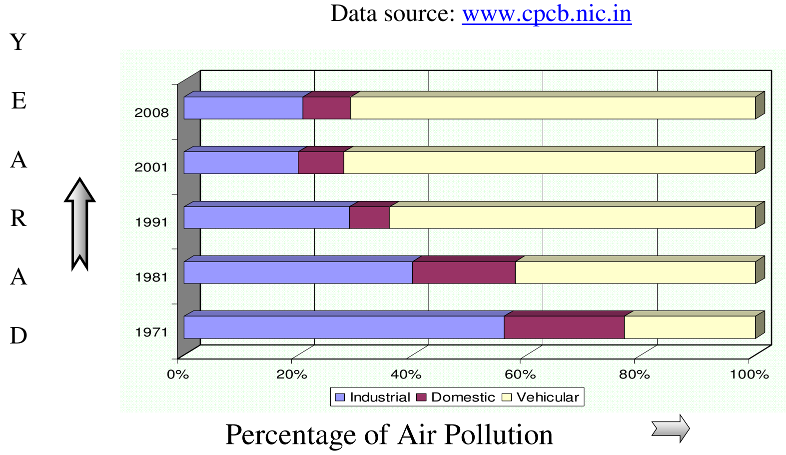
1.2 COMPONENTS OF AIR POLLUTION

Distribution of the different sources of air pollution for the capital city of Delhi is given in Table 1.1, represented graphically in Figure 1.1 which shows that the vehicular emissions component is continuously growing and it is a major contributor to the total air pollution in Delhi, having about 70 % share.

Table 1.1: Individual Stock of Various Sources of Air Pollution in Delhi

Period	Air Pollution Source		
Year	**Industrial**	**Vehicular**	**Domestic**
1970-71	56 %	23 %	21 %
1980-81	40 %	42 %	18 %
1990-91	29 %	64 %	07 %
2000-01	20 %	72 %	08 %
2007-08	22 %	70 %	08 %

Data source: www.cpcb.nic.in

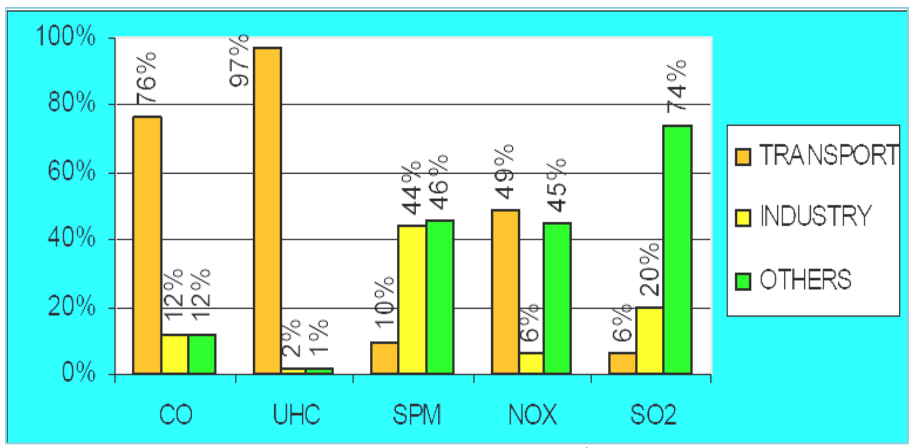


[Data source: Deptt. of Transport, Govt. of Delhi, India]

Figure 1.1: Components of Air Pollution Sources in Delhi

Distribution of the various components of vehicular emissions is shown in Figure 1.2, which shows that for UHC (Unbrunt Hydrocarbons) emissions vehicles are highest contributor with 97 % share and for the carbon monoxide contribution of vehicular sources is about 75 % and for nitrogen oxides also vehicles are the highest contributors i.e. about 49 %. It can be construed from this data that the vehicular sources are the main culprits for the deteriorating air quality in Delhi.

AIR POLLUTION %



Air Pollutants

Figure1.2: Pollution Components of Air Pollution Sources

Table 1.2: Trends of Vehicular Population Growth in Delhi (In thousands)

Year	Scooters and motorcycles	Cars/ jeeps	Auto rickshaws	Taxis	Buses	All motor Vehicles
1971	93	57	10	4	3	180
1980	334	117	20	6	8	521
1990	1077	327	45	5	11	1547
2000	1568	852	45	8	18	2584
2010	2958	1472	103	14	39	4809
2020	6849	2760	209	28	73	10336

Source: Transport department, Government of National Capital Territory of Delhi

The vehicular stock in Delhi as given in Table 1.2, is expected to almost quadruple by the year 2030, and may grow at an even faster rate. The domestic auto industry is predicting car sale increase of ten percent per year. The vehicular stock in Delhi is expected to almost quadruple by the year 2030 (Ramanathan, 2006). With an extensive network of roads and increasing income, this sharp upward trajectory in vehicle sales and use is plausible. Like most mega cities of the developing world, Delhi is not prepared to manage this pent up demand. If the present trend of vehicle population continues to grow, Delhi may have to face extreme economic and environmental consequences.

Air pollution increasingly threatens the human health, road traffic could worsen to the point of paralysis, large settlements of poor people on the urban periphery may become even more disfranchised, and the cost of doing business and providing transportation infrastructure will soar as will greenhouse gas emissions. Rampant vehicle growth in Delhi is overwhelming the capacity and resources of local government. The Central Pollution Control Board (CPCB) has been monitoring the ambient air quality regularly at various locations in Delhi, measuring sulphur dioxide, oxides of nitrogen and particulates etc. The monitoring stations are located at Ashok Vihar, Shahzadabagh, Siri Fort, Janakpuri, Nizamuddin, Shahdara.The atmospheric concentrations of air pollutants show a rising trend. The ambient air quality data indicates high values of suspended particulate matter at all the monitoring stations, namely, 367-452 microgrammes per cubic meter on annual average basis as against the prescribed standard of 140-360 microgrammes per cubic meter. Though the annual mean value of sulphur dioxide (SO_2) is 15-26 microgrammes per cubic meter and oxides of nitrogen are 28-46 micrograms per cubic meter, remain within the prescribed limits of 60-80 micrograms per cubic meter, but there is a rising trend.

1.3 VEHICULAR AIR POLLUTION–CAUSES OF EMISSIONS

As already discussed above, vehicular exhaust source is one of the major sources of air pollution in major cities. Air pollution due to vehicles can be attributed to the factors discussed in the following subsections:

1.3.1 Pollution from Two-Wheelers

Two-wheelers account for about two thirds of the total vehicular population in Delhi. Because of inherent drawbacks in the design of two- stroke engines, two-wheelers emit about 20-40 % of the fuel un-burnt/partially burnt. Presently, two-wheelers account for more than 70 % of the unbrunt hydrocarbons (UHC) and nearly 50 % of the carbon monoxide emission in Delhi. As these emissions are less visible, the general public is not aware of the role of two-wheelers in the deteriorating air quality. The two-stroke engine, inspite of R&D efforts towards improving its design, will continue to be a high emitter of hydrocarbons and carbon monoxide.

Now most of the manufacturers are producing only four stroke engines for two wheelers and over a span of next 10 years, most of the two wheelers will be of four stroke engines only. This will help in controlling the UHC emissions from two wheelers. But these benefits will be obtained only if the four stroke vehicles are regularly maintained, as their maintenance cost is little higher due to valves like reciprocating parts. Thus the best remedy is to discourage the people to use the two wheelers for general purposes like going to office for which an efficient public transportation system must be developed. Further for the persons very much in need of these personal vehicles, electric vehicles must be recommended and subsidized suitably.

1.3.2 Pollution from DTC and Other Privately Operated Buses

The regular fixed-route bus system now comprises of about 4,000 privately operated blue line buses, 5,760 Delhi Transport Corporation (DTC) operated buses and about 7,000 RTVs (Rural Transport Vehicles). It is complemented by 3,000 private charted buses which provide point-to-point service during peak hours to the subscribers who pay a monthly fee for a guaranteed seat. Charted bus users are mostly the upper middle class. Charges are ranging from rupees 20/- to 50 per day/ per trip depending on the distance and a/c or non a/c service. These buses are in many ways in direct competition with personal vehicles. Indeed, 43 percent of the charter bus commuters own two-wheelers and 11 percent own cars. Charter buses are in many cases replacing the use -and perhaps even purchase- of private vehicles.

About two thirds of the DTC fleet is beyond 4-5 years of the recommended age, some even beyond 8-10 years. Most of these buses require phasing out in a well planned manner as their condition is beyond normal maintenance measures. Their continued use has resulted in emissions of very high levels of smoke and particulates. The operators of these buses have given to understand that there is very little that can be done to improve the performance of their vehicles, including pollution control, if such vehicles continue to function beyond the recommended age and carry more than the permitted load of passengers.

1.3.3 Overloading of Vehicles

Due to insufficient buses in the system, all buses, particularly during peak hours, carry more than the designed load of passengers. This is also causing more pollution due to overloading of the bus engines, which results in higher smoke emissions and this is also compelling the people to use personal vehicles so as to have a comfortable journey. High capacity buses are being inducted for carrying more passengers. The worst polluters should be taken-off the heavy traffic corridors and high density areas. Similarly, for trucks, enforcement of laws related to overloading requires to be enforced vigorously. Most of the times, they are found heavily polluting, but it remains a mystery as to how do they get overlooked by the traffic police?

1.3.4 Lack of Inspection and Maintenance of Vehicles

Inadequate inspection and maintenance of the vehicles results in high exhaust emission of air pollutants from vehicles and higher fuel consumption. Emissions can be reduced by proper and regular inspection and maintenance of the vehicles. Present system of checking pollution once in three months is only eyewash; a more effective system can be established through setting up of automated testing stations (Roger John et al. 2002). The system can begin with testing of commercial vehicles and public transport vehicles to be linked with renewal of permits and registration etc. For better results, all vehicles registered must have a liability clause with the manufacturers or their authorized maintenance service providers to provide regular inspection and maintenance.

1.3.5 Inappropriate Emission Norms

Emission norms for all categories of petrol and diesel vehicles at the manufacturing stage were introduced for the first time in 1990, and made tighter in 1996. Stricter emission norms, already notified, have come into effect from 1st April, 2000 and thereafter. Presently Euro IV equivalent Bharat Stage IV emission norms are in practice.

1.3.6 Adulteration of Fuel and Fuel Products

Fuel quality standards for petrol and diesel fuel have been notified under the Environment (Protection) Act. The quality standards are being implemented by the Ministry of Petroleum & Natural Gas (MOP&NG) through the oil companies. They have introduced low-sulphur diesel (350 ppm) recently within the city limits which would be further extended to other areas. Considering the serious nature of problem due to air pollution and due to particulates which are emitted mainly from diesel vehicles, it is necessary that diesel with even ultra lower sulphur (50 ppm) content is introduced in Delhi. Adulteration of fuel and fuel products also equally affects the air quality and also that of specified fuel quality.

1.3.7 Improper Traffic Planning and Management

Improper traffic management system and unworthy road conditions also result in buildup of air pollutants near the roadways as the emissions are higher when the vehicles are idling. To relieve congestion on Delhi roads, there is an urgent need for constructing fast motorways to enable transit traffic to pass unhindered. The existing road capacity network can be better utilized by up-gradation of the traffic management. The network of synchronized signals must be expanded to cover other busy crossings. Conventional subways and foot over bridges are generally not liked by the general public, neither they are sufficient to fulfill all the requirements, hence in future escalators or ramp like stepless stairs for road crossing must be given preference; to reduce the traffic congestion on the road at traffic signal crossings.

1.3.8 Other Causes of Vehicular Emissions

- High vehicle density in the Indian urban centers results in air pollution build-up near roadways, railway stations and at traffic intersections.
- High population exodus to the urban centers has also resulted in increase in the number of vehicles, resulting in high levels of vehicular air pollution.
- Older vehicles are predominant in vehicle vintage. These older vehicles are grossly polluting, though in cities like Delhi, grossly polluting, vehicles have been phased out.
- Absence of an effective mass rapid transport system (MRTS) and intra-city railway networks have resulted in people using their own vehicles for commuting to work. This has resulted in uncontrolled growth of vehicles.

1.4 Composition of the Vehicular Engines Exhaust

For an ideal combustion of a hydrocarbon fuel, we would have got only carbon dioxide and water vapour in the exhaust. However, as we know, in a real application, the exhaust gas contains a number of other undesirable pollutant species. Concern over the negative environmental and health effects of these noxious cocktail of gases has prompted the introduction of strict emissions legislation all over the world.

At present, most of the regulated vehicle exhausts emission standards apply to the following:

- Total Hydrocarbons (THC)
- Carbon Monoxide (CO)
- Oxides of Nitrogen (NOx)
- Particulate Matter (PM)

Let us have a brief outlook on the source of these emissions in Internal Combustion engines, their potential impact, and principle methods for their control (Pundir,1994).

1.4.1 Oxides of Nitrogen (NO_x)

NOx is the collective term for nitric oxide (NO) and nitrogen dioxide (NO_2) which are extremely toxic gases for humans. Basically, NOx, as the name implies, are generated from reaction between nitrogen and oxygen under high temperature and pressure conditions during the combustion process in an engine cylinder. Normally it takes place at the pre-combustion, combustion and post-flame regions where sufficient concentrations of oxygen and nitrogen are present. The formation of NOx depends mainly on the temperature as the rate of dissociation of nitrogen is directly proportional to the temperature increase. Therefore, higher the combustion reaction temperature, the more NOx will be produced.

Effects of NOx towards the Environment

The environmental problems caused by NOx are now worldwide issues due to the seriousness of ozone reactivity and the amount of formation of smog. NOx combines with water vapour in clouds to produce acid rain which pollutes clean water sources and corrodes metals used in our daily life. Acid rain also harms the growth of organisms in the lake and disturbs the balance of the ecosystem both on land and at sea. Apart from that, acidified soil is also the result of acid rain and it causes damage to the root system of trees, disabling the nutrient absorption process and disrupting the natural process of photosynthesis. When NOx reacts chemically with other atmospheric gaseous compounds such as volatile organic compounds (VOCs) under the sunlight, it will form smog.

Greenhouse effect is a global-warming phenomenon when heat energy from the sunlight is trapped by gases such as NO_x. This increases the average temperature of our planet and acts as a great threat to the life of crops, humans and the environment. The increased temperature will speed up the melting rate of the icebergs in north and south poles and there will be an increased risk of flooding in lower-terrain countries. Ozone depletion is also related to the excessive emission of NO_x. Thus, Nitrogen oxides formed also allows more penetration of harmful ultraviolet solar radiation to the earth and leads to skin irritation in humans.

Factors Affecting NOx Emissions

There are several factors which affect the formation of NOx in the engine and they are listed below:

(i) The air-fuel ratio plays a major role in determining the amount of emission of NOx as oxides of nitrogen are formed by the reaction of nitrogen with the oxygen in the combustion air. When the air to fuel ratio is greater than one which indicates that the combustion is in the lean condition, the fuel mixture has considerably less amount of fuel and excess amount of air. Engines designed for lean burning can achieve higher compression ratios and hence give better performance. However, it will generate high amount of NOx due to the excess oxygen present in the air.

(ii) Combustion temperature is also one of the primary factors that influence the formation of NOx. The formation of NOx is directly proportional to the peak combustion temperature, with higher temperatures producing higher NOx emissions from the exhaust.

(iii) The amount of nitrogen in the fuel determines the level of NOx emissions as fuels containing more nitrogen compounds result in higher levels of NOx emissions.

Choices of fuel type alter the formation of both the theoretical flame temperature reached and rate of radiative heat transfer.

(iv)The firing and quenching rates also influence the rate of NOx formation where a high firing rate is associated with the higher peak temperatures and thus increases the NOx emission. On the other hand, a high rate of thermal quenching results in lower peak temperatures and contributes to the reduction of NOx emission.

(v) Engine parameters such as load and speed of engine also influence the NOx emissions from the exhaust. When the engine is running under lean conditions, it emits less NOx.

However the nitric oxide (NO) emissions will consequently increase as the engine load increases. The effect of load becomes less significant when the engine is running close to stoichiometric air to fuel ratio. On the other hand, engine speed may increase or decrease the NO emissions as higher engine speed increases the burnt gas mass fraction and thus offsets the peak temperature, depending on the exact engine conditions.

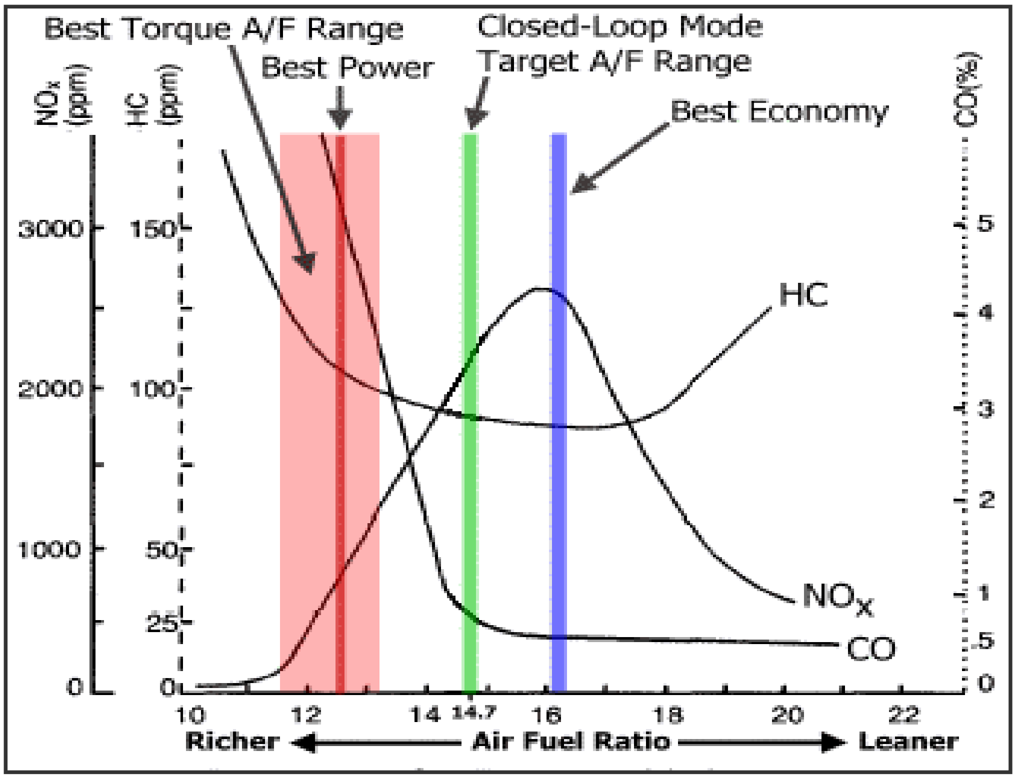
1.4.2 Unburnt Hydrocarbons (UHC) Emissions

Total hydrocarbon (THC) is used to measure the level of formation of unburnt hydrocarbons caused by incomplete combustion in the engine. The hydrocarbons emitted may be inert-such as methane gas-or reactive to the environment by playing a major role in the formation of smog. The types of hydrocarbons emitted from the exhaust greatly depend on the type and composition of fuel used. Fuels with a greater concentration of aromatics and olefins compounds will result in a higher percentage of reactive hydrocarbons. HC emissions rise rapidly as the mixture becomes substantially richer than stoichiometric. When combustion quality deteriorates - with very lean mixtures- HC emissions can rise rapidly due to incomplete combustion or misfire of the engines operating cycles. Figure 1.3 shows the variation of UHC emissions and other operating parameters for relative A/F ratios.

1.4.3 CO Emissions

Carbon Monoxide (CO) is a colorless, odorless, flammable and highly poisonous gas which is less dense than air. Inhalation of carbon monoxide can be fatal to humans since a small concentration (as little as 0.1 %) will cause toxicities in the blood due to its high affinity to oxygen-carrying heamoglobin. Exposure levels must be kept below 30 ppm to ensure safety. The, carbon monoxide also contributes in the formation of greenhouse gases and global warming by encouraging the formation of NO_x. Carbon monoxide forms in internal combustion engines as a result of incomplete combustion when a carbon based fuel undergoes combustion with insufficient air. The carbon fuel is not oxidized completely to form carbon dioxide and water. This effect is obvious in cold weathers or when an engine is first started since more fuel is needed. Carbon monoxide emission from internal combustion engines depend primarily on the fuel/air equivalence ratio.

Figure 1.3 shows the variation of CO, other emissions and other operating parameters for relative A/F ratios. It shows that CO emissions reduces with increasing A/F ratio, while HC emissions first reduces with increase in A/F ratio and further increases with A/F ratio, while NOx first increases with A/F ratio and then decreases. The optimum condition for minimization of all emissions is stoichiometric A/F ratio, i.e. 1:14.7



[Source: Toyota Motor Sales corporation literature]

Figure1.3: Variation of CO, UHC, NOx and Relative Air/Fuel Ratio

1.4.4 Particulate Matter Emissions

Although the emission of particulate matter (PM) is usually associated with the diesel engine, there is increasing evidence to suggest that PM emissions from SI engines pose a significant threat to health. In particular, PM emissions pose a significant problem for Stratified Charge Direct Injection Gasoline engines. In order to understand the reasons for this, we must first consider the formation and composition of PM. The WHO has identified SPM as the most sinister in terms of its effect on health. The SPM is not homogeneous; it has a number of constituents. As a result, it is measured and characterized in various ways such as: Total Suspended Particulates (TSP) with particle diameters range 50-100 µm, Particulate Matter-Inhalable particles having a diameter less than 10 µm- (PM_{10}), $PM_{2.5}$: Fine fraction, with a diameter less than 2.5 µm, Black smoke: a measure of the blackness of a particle sample gives a relative value for the soot content of the sample.

Due to their high health damaging potential, recent studies have started paying more attention to PM_{10} and $PM_{2.5}$ particles.

PM Formation in SI Engines

Particulates are principally soot which has absorbed other organic compounds, i.e., hydrocarbon compounds and soot is described as a carbonaceous material not just carbon, whereas PM is formed in fuel-rich regions of flames (both pre-mixed and diffusion flames). With respect to the Direct-Injection Spark-Ignition (DISI) engine, particularly in stratified charge mode, it is extremely difficult to achieve good charge homogeneity. Accordingly, there are proportionally a larger number of fuel-rich regions within the cylinder of a DISI engine, which provide potential sites for PM formation, than is the case for a similar Port-Fuel-Injected (PFI) engine. The literature suggests that PM emissions from DISI engines are of an order of magnitude greater than that of an equivalent PFI engine.

Respirable Suspended Particulate Matter (RSPM)

RSPM are the suspended particulates which are less than 10 microns in diameter (PM_{10}) and tend to pose a great health hazard as these particles can be easily inhaled. And they can get accumulated in the alveoli (Tiny air sacs in the lungs) this slows down the exchange of the Oxygen and Carbon Dioxide in the blood. The finer the particle, the higher is their propensity to remain air borne. The diverse sources of RSPM are fuel combustion in industries, power plants, industrial furnaces and boilers, diesel generating sets, and motor vehicles.

Soot formation in C. I. Engines

The evolution of liquid or vapour phase hydrocarbons to solid soot particles and possibly back to gas-phase products, involves six commonly identified processes: pyrolysis, nucleation, coalescence, surface growth, agglomeration, and oxidation. The sixth process oxidation converts hydrocarbons to CO, CO_2 and H_2O at any point in the process.

Pyrolysis

Pyrolysis is the process of organic compounds, such as fuels, altering their molecular structure in the presence of high temperature without significant oxidation even though oxygen species may be present. Fuel pyrolysis results in the production of some species which are precursors or building blocks for soot. Soot precursor formation is a competition between the rate of pure fuel pyrolysis and the rate of fuel and precursor oxidation by the hydroxyl radical, OH. Both pyrolysis and oxidation rates increase with temperature, but the oxidation rate increases faster. This explains why premixed flames (where some amount of oxygen is present) soot less and diffusion flames (no oxygen is present in the pyrolysis region) soot more as the temperature increases. All fuels undergo pyrolysis and produce essentially the same species i.e. unsaturated hydrocarbons, poly-acetylenes, polycyclic aromatic hydrocarbons (PAH) and, especially, acetylene.

Nucleation

Nucleation or soot particle inception is the formation of particles from gas-phase reactants. Reports on particle inception temperatures vary from 1300 to1600 K. These particle nuclei do not contribute significantly to the total soot mass, but do have a significant influence on the mass added later, because they provide sites for surface growth. Spatially, nucleation is restricted to a region near the primary reaction zone where the temperatures and radical and ion concentrations are the highest in both premixed and diffusion flames. According to Glassman, (1988), a general fuel independent soot formation mechanism exists, which has alternative routes to intermediate species. The routes are affected by temperature and initial fuel type. This implies that the propensity to soot is determined by the initial rate of formation of the first and second ring structures. Bruyce (1999) mentioned three soot nucleation routes viz:

(1) Cyclization of chain molecules into ring structures. An example of this is acetylene molecules combining to form a benzene ring.

(2) A direct path where aromatic rings dehydrogenate at low temperature and form polycyclics, and

(3) Breakup and recyclization of rings at higher temperatures.

Surface Growth

Surface growth is the process of adding mass to the surface of nucleated soot particle. There is no clear distinction between the end of nucleation and the beginning of surface growth and in reality, the two processes are concurrent.

During surface growth, hot reactive surface of the soot particles readily accepts gas-phase hydrocarbons which appear to be mostly acetylenes. This leads to an increase in soot mass while the number of particles remains constant. Surface growth continues as the particles move away from the primary reaction zone into cooler and less reactive regions, even where hydrocarbon concentrations are below the soot inception limit. A major portion of the soot mass is added during surface growth and thus, the residence time of the surface growth process has a large influence on the total soot mass or soot volume fraction. Surface growth rates are higher for small particles than that for larger particles because small particles have more reactive radical sites.

Coalescence and Agglomeration

Coalescence and agglomeration are both processes by which particles combine. Coalescence (sometimes called coagulation) occur when particles collide and coalesce, thereby decreasing the number of particles and holding the combined mass of the two soot particles constant. During coalescence, two roughly spherically shaped particles combine to form a single spherically shaped particle. Agglomeration occurs when individual or primary particles stick together to form large groups of primary particles. The primary particles maintain their shape. Typically, the combined soot particles form chain-like structures but in some cases clumping of particles has been observed.

Exhaust soot from diesel engines consist of primary particles which are spherical in shape which agglomerate to form long chain-like structures. Size of primary soot particle appear to vary depending on operating conditions, injector types, and injector conditions but most primary particle sizes have been reported to range from 20 to 70 nanometers(nm). Bruce, (1991) and Lee (2001) used a sampling probe and optical scattering technique respectively, and reported primary particles from 20 to 50 nm with an average diameter of about 30 nm and reported a range of 30–70 nm for the primary particle diameter. In-cylinder light-scattering measurements by (Tree and Foster, 1994) in diesel engines have produced estimates of 30–50 nm. After combustion ends, particles agglomerate further and are seen to be chain-like and typically range in size from 100 nm to 2 nm but may be larger.

Oxidation

Oxidation is the conversion of carbon or hydrocarbons to combustion products. Once carbon has been partially oxidized to CO, the carbon will no longer evolve into a soot particle even if entering a fuel-rich zone. Oxidation can take place at any time during the soot formation process from pyrolysis through agglomeration. The most active oxidation species depends on the process and state of the mixture at the time. Glassman (1988) states that soot particle oxidation occur when the temperature is higher than 1300 soot's graphite-like structure is thought to be responsible for its unusually high resistance to oxidation. Oxidation of small particles is considered a two stage process. First, chemical attachment of oxygen to the surface (absorption), and second, desorption of the oxygen with the attached fuel component from the surface as a product. OH is most likely to dominate soot oxidation under fuel-rich and stoichiometric conditions. While under lean conditions, soot is oxidized by both OH and O_2. Haynes, (1981), stated that about 10-20 % of all OH collisions with soot are effective at gasifying a carbon atom.

1.4.5 Volatile Organic Compounds

Volatile Organic Compounds (VOCs) includes variety of HC compounds that are generated due to incomplete combustion of fuels or formed during combustion process. Chemically, hydrocarbons are defined as compounds consisting of carbon and hydrogen (Keoleian, et al. 1997). In the urban air, most important VOCs are benzene, a series of aldehydes and the series of poly aromatic hydrocarbons (PAHs). About 55 % of HC emissions from gasoline fueled vehicles, with no emission controls, originate in the exhaust system; 13 % to 25 % come from the crankcase blow-by and 20 % to 32 % evapourate in the fuel lines, fuel tank and carburetor. Methane consists of 5 % to 15 % of HC emissions from vehicles not equipped with catalytic converters and up to 40 % of exhaust HC from catalyst equipped vehicles. This is because the catalysts are less effective in oxidising methane than other HCs (Gautam and Onursal 1982). Benzene is an aromatic HC present in gasoline. About 85 % to 90 % of benzene emissions come from exhaust and the remainder comes directly from gasoline evapouration and through distribution losses. Benzene in exhaust originates both from partial combustion of other aromatic HC compounds in gasoline, such as, toluene, and xylene and form the benzene already in gasoline. Benzene consists 63 % to 85 % of the toxic emissions in the exhaust from gasoline fueled cars equipped with fuel injected engines and 36 % to 65 % from older years model cars equipped with carburetor engines and catalytic converters. Aldehydes are not present in the vehicle exhaust emissions s and are secondary pollutants formed in atmosphere. These have high potential reactivity in ozone (O_3) formation. Controlled gasoline fueled cars have higher emissions of formaldehyde than acetaldehyde.

Uncontrolled diesel fuelled vehicles emit 1g~2g of aldehyde per liter. PAH are emitted at a higher rate in the exhaust of diesel fuelled vehicles than gasoline fuelled vehicles. In Delhi, motor vehicles forms about 85 % of total Volatile Organic Compounds (VOC) emissions (CRRI, 1998).

1.4.6 Carbon Dioxide (CO_2)

Carbon dioxide is considered as the major greenhouse gas and it can cause death by suffocation if inhaled in large amounts. CO_2 has a tendency to absorb heat radiation of the sun, thus creating a thermal radiation shield which reduces the amount of thermal radiation energy allowed to escape from the earth. As a result of this, the temperature of earth rises and accelerates the melting rate of polar ice caps and expansion of oceans into low lying areas .To reduce the emission of CO_2 efficiently, engines with higher thermal efficiency that are able to operate at the lowest level of excess air are used .

1.4.7 Lead oxides

Motor vehicles fueled with leaded gasoline are the main sources of lead (Pb) in air. Tetraethyl lead was earlier added to gasoline to increase the fuel's octane number, which improves the antiknock characteristics of the fuel in spark ignition engines. Now a day's its addition has been restricted. About 70 % to 75 % of this Pb is transformed into inorganic Pb in vehicle's engine upon combustion, and emitted to the atmosphere through the exhaust pipe along with 1 % of the organic Pb that passes through the engine unchanged (Gautam, and Onursal 1982). The rest of Pb remains trapped within the exhaust system. Organic Lead (Pb) emissions usually occur as vapour, while inorganic Pb is emitted as PM, often less than 1 mm in size. Although Pb in gasoline accounts for less than 10 % of all refined Pb production, about 80 % to 90 % of Pb in global ambient air originates from combustion of leaded gasoline. In recent years, Pb has been phased out in the major part of the industrial world, but is still used in many developing countries. In India, unleaded petrol is now being used everywhere (CPCB, 2005).

1.5 AIR POLLUTION AND ITS ADVERSE EFFECTS ON PUBLIC HEALTH

A recent study reports that in Delhi one out of every 10 school children suffers from asthma that is worsening due to vehicular pollution (Kathuria, 2002). Similarly, two of the three most important health related problems in Bangkok are caused by air pollution and lead contamination, both of which are contributed greatly by motor vehicles. Situation is same in a number of other mega-cities across the globe. The worst thing about vehicular pollution is that it cannot be avoided as the emissions are emitted at the near-ground level where we breathe. Pollution from vehicles gets reflected in terms of increased mortality and morbidity and is revealed through symptoms like cough, headache and nausea, irritation of eyes, various bronchial problems and visibility. According to the World Health Organization (WHO), 4 to 8 % of deaths that occur annually in the world are related to air pollution and its constituents.

Because of sources of these emissions the public health implications (Utell et al. 1998 and Anon 1996) are substantial. An improved understanding of the association of the particulates with mortality suggests the importance of sub-micron particles (PM_{10}) to which motor vehicles are major contributors, (Anon, 1995).Automobile exhausts and certain industrial pollutants contain NO_2, which by photochemical reaction produces O_3, and affects allergic asthmatics by augmenting allergic responses, (Steinberg et al. 1991).

Similarly SO_2, NO, particulate matter and acid aerosols affect pulmonary function and cause inflammation of bronchial mucous (Karen and Michak, 1991, Giuseppe and Francesco, 1993). It has been observed from several studies that air pollution plays an important role in the genesis and augmentation of allergic disorder and it is described as a disease of civilized society, (Dennis, 1996 and Bonai, 1994).As vehicular exhaust emissions are directly emitted to the atmospheric air; they are directly inhaled by the commuters or road users.

Following facts are worth-mentioning to grasp the health problems generated by vehicular exhaust air pollutants:

- A World Bank report underlines that more than 40,000 people die prematurely per year in India due to health problems caused by air pollution.

- Studies reveal that the cases of respiratory diseases and allergies have almost doubled since 1990.
- Nearly 80-90 percent lead in ambient air is attributed to the composition of leaded petrol. Unleaded petrol in India contains a very high level of benzene, which may cause lung cancer.
- It is estimated that almost 50 percent population in Mumbai has absorbed 30 microgram of lead in 100 milliliter of blood, while simply 50 microgram is sufficient to culminate in brain damage and muscular problems.
- The levels of air pollution in large cities have been increasing with such a tremendous magnitude that the World Health Organization has suggested the international tourists to limit their visits to the four mega cities of India- Kolkata, Mumbai, Delhi and Chennai.

1.5.1 Effects of Carbon Monoxide

The toxicity of CO is well known. It is mortal above one thousand ppm. It can also act in much lower concentrations, due to its affinity for blood hemoglobin that is 240 times greater than of oxygen. This blocking of hemoglobin reduces the oxygen supply to the tissues. This situation is aggravated when combined with cardiovascular problems.

Carbon Monoxide may also display long term toxicity such as headache, dizziness and nausea, which occurs when CO blocks 25 % of the hemoglobin. Loss of consciousness which is dangerous for drivers can occur if the CO rate reaches 50 % and death occurs when the rate reaches 70 %.

1.5.2 Effects of Nitrogen Oxides

The nitric oxide NO is by itself nontoxic. The suspected effects concern its fixation to hemoglobin. Nitrogen peroxide is insoluble and can penetrate deeply in to the pulmonary system. It acts on pulmonary alveoli and impairs their structures, inhibits the pulmonary defenses, and has a cytotoxic effect on the alveolar macrophages. It stimulates their activity in low doses and then weakens the defenses of the body, thus causing other complications. Nitrogen peroxide can thus cause the death of specific cells in the lungs and impair the regulation of the pulmonary function. The symptoms of the toxic action of NO_2 are insomnia, coughing, panting, and impairment of the mucous membranes. Japan recommends an environmental limit of 0.04 ppm for NO_2. NO_x is also responsible for the formation of smog. Smog is forefront to our environmental concerns as it reduces the visibility of surroundings and poses a health hazard to humans which includes irritation of eyes, respiratory and cardiovascular problems such as asthma and headaches.

1.5.3 Effects of Ozone

Ozone displays toxic effects similar to those of NO_2, but in much lower concentration. However, its lower stability and greater solubility limit its depth of penetration.The human body reacts by shrinkage of the respiratory passages as soon as the O_3 concentration exceeds 0.1 ppm. Physical activities also diminish tolerance to these pollutants. Other symptoms are irritation of the eyes and mucous membranes. Headaches, coughing and reflexive inhabitation of breathing, as well as reduced lung capacity can trigger attacks of asthma, followed by acute inflammation and pulmonary edema. Ozone causes oxidation of proteins and per-oxidation of fatty acids, especially unstructured fatty acids. Anti-oxidants like vitamins E can counteract its action. Ozone strongly affects the pulmonary functions of asthmatics. Its carcinogenic or mutagenic action hasn't been demonstrated.

1.5.4 Effects of Hydrocarbons

Human health is mainly affected by unsaturated hydrocarbons. The olefins are liable to undergo partial metabolic conversion, converting them to genotoxic epoxides. Benzene is well known haematotoxic and occupational exposure to it can cause Leukemia. However this Leukemia only occurs with concentrations over 40 ppm. They affect the bone marrow by inhibiting the formation of red blood corpuscles (RBC). The white blood corpuscles (WBC) are also destroyed as well as the blood platelets. Benzene is a suspect in other hematological disorders such hodkins disease and lymphoma, and may cause chromosomal anomalies. The metabolites of benzene responsible for these biological effects are still poorly known, although phenols and epoxides are often maintained as resulting from the enzymatic oxidation of benzene.

1.5.5 Effects of Particulate Matter

High SPM levels cause respiratory diseases and reduce visibility. While the human nostrils filter out 99 % of the inhaled large and medium sized particles, the rest may enter the wind pipe and lungs where some inhaled particles cling to the protective mucous. There are many evidences to suggest that aerodynamic size is a significant factor determining the health effects of particulate emissions from engines. The adverse health effects of very small (nano) particles are thought to be particularly severe. Sub-micron particles remain airborne for a substantially greater time than do larger particles. Nano particles are easily ingested and absorbed into the bloodstream etc. SI engines are prone to produce sub-micron PM prompting authorities to consider moving from existing mass-based PM emission regulations to size-based regulations for future standards.

1.5.6 Effects of Carbon Dioxide

Carbon dioxide is considered as the major greenhouse gas and it can cause death by suffocation if inhaled in large amounts. CO_2 has the tendency to absorb heat radiation of the sun, thus creating a thermal radiation shield which reduces the amount of thermal radiation energy escaping from the earth. As a result of this, the temperature of earth rises and accelerates the melting rate of polar ice caps and expansion of oceans into low lying areas. To reduce the emission of CO_2 efficiently, engines with higher thermal efficiency & operating with lowest excess air are required.

1.6 ORGANIZATION OF THE THESIS

Various chapters in the thesis are summarised here and arranged in the following order.

Chapter 1. This chapter discusses the preliminary characteristics of the problem of the metropolitan transportation system like growth of vehicles, general theory of vehicle emissions and their health effects, problems of the transportation system of the capital city of Delhi.

Chapter 2 discusses the details of the literature review carried out in this area of investigations which includes Studies on Transportation Systems, Studies on Vehicular emissions and Emission Norms, Studies on Quality of Fuels used, Studies on Alternative Fuels and finally the Gaps in the Literature Review and Motivation for this Work are presented.

The research methodology adopted is described in the **Chapter 3** and a schematic flowchart showing the steps followed in this research work is also presented.

Chapter 4 contains the detailed analysis of the present modes of transport being used in the capital city of Delhi, their main problems and the salient requirements of the Public Transportation System of Delhi.

A case study of efficacy of CNG as a fuel in the transportation system of Delhi is presented in the **Chapter 5,** in this the administrative and practical difficulties encountered in using CNG as fuel in the transport system of Delhi and the advantages gained through this change over are presented.

Chapter 6 presents the experimental set ups designed and fabricated to evaluate the emission of C. I. Engines and the emission reduction results are detailed out in this chapter.

The experimental study on S. I. engines are presented in **Chapter 7,** it discusses the experimental set ups designed and fabricated to evaluate the emission from S. I. engines with various alternative fuels like Ethanol, CNG and LPG.

Chapter 8, describes the need and details of the Delphi Investigations **-t**his chapter gives brief details of the Delphi Survey commissioned, including the statistical analysis with the feedback and suggestions of the experts.

Chapter 9 gives the analysis and synthesis of the Delphi Investigations -in this chapter vehicular emission load of the capital city of Delhi is estimated and the future emission load is also estimated for the proposed changes and the different possibilities of the proposed strategies are presented. For some of the results are comparisons with the available reported/published data is also given.

Chapter 10 presents Conclusions drawn from the study and the recommendations for the mitigations of the exhaust pollution from the transportation sector are described in this chapter. In this chapter the strategies that have been contemplated are summarized and their liabilities and future scopes for the present topic are discussed.

There are seven appendices to give the additional details, such as Appendix-I gives the Delphi Questionnaire used in Round-I, Appendix–II contains the Delphi Survey Feedback form used in Round-II, Appendix–III gives a summary of Emission Norms and Legislations, Appendix–IV discusses the brief chemistry, production techniques and the requirements of Biodiesel, Appendix V gives important details of Ethanol and Ethanol blends, Appendices-VI gives Calculation details of Future Emissions as used in chapter 9, List of Publications and Curriculum Vitae of the author is given in Appendix VII.

1.7 CONCLUDING REMARKS

It can be concluded from the initial study that the population and the number of vehicles and number of vehicles per person in the urban cities are growing at an alarming rate. The growth of vehicles is unplanned and due to many complex reasons contributing to high rise in air pollution load. Further it is causing spread of a number of health problems and proving economically much costlier. Thus there is an urgent need to thoroughly analyse the exact reasons of the growth of the vehicles and air pollution, so that a sustainable transport system can be planned. Next chapter presents the summary of the literature survey carried out and outlines the necessity for the present work.

CHAPTER 2.

THE LITERATURE REVIEW

This chapter gives the details of search of the literature review in the field of the transport systems, with regard to the past work done by various researchers and the organizations and the policies proposed and implemented by the concerned government departments.

2.1 INTRODUCTION

A comprehensive literature review was carried out to understand the level of activity and identify the issues unknown or little known in this area of investigation. This was necessary for thoroughly examining the problem of vehicular emissions, specifically in Delhi, the capital city of India. For a systematic study, the literature survey was briefly classified into the following sub-categories:

1. Studies on Transportation Systems of Delhi
2. Studies on Vehicle Emissions and Emission Norms
3. Studies on Quality of the Fuel for Transportation
4. Studies on Alternative Fuels
5. Identifying the Gaps in the Literature Review and Motivation for this Work

2.2 STUDIES ON TRANSPORTATION SYSTEMS

Many researchers have attempted to estimate or predict the present and future transportation requirements of the capital city of India. Goyal and Ramakrishna (1998) presented various methods of estimation of emission from vehicular traffic in urban cities. Bose and Sperling (2001) suggested restructuring land development patterns to reduce the demand for transport and accelerating the introduction of very efficient advanced vehicle technologies.

In one of the reports submitted to the Supreme Court of India, Environment Pollution (Prevention & Control) Authority (EPA, 2003) reported that the two wheelers are the most polluting mode of transport in the Asian cities- mainly in Delhi -and stressed the need for better public transportation system. The estimated passenger travel demand for Delhi were given by Bose and Nesamani (2000) for the year 2000 as 94.4 billion passenger kilometer while Mohan (2001) stressed the need for specifically reserved lines on the road for the bus transport in his proposed bus rapid transit (BRT) corridor model. Kathuria (2002) stressed on an integrated approach, with combined use of transport policies like improved public transport, road pricing, parking etc. and advanced vehicle technologies. In a study of public transport and car use in developing countries, Ruter (1997) reported potential annual savings for HC, CO, NO_2, SO_2 and PM as 98.6, 97.3, 85.1, 46.1 and 27.6 percent per person respectively in air pollution through using public transport instead of driving to attend work in car. Nagendra and Khare (2006) presented the analysis of the urban traffic with change in metrological conditions.

In a comparative study, Das and Parikh (2003) reported that despite similar population and higher per capita Gross Domestic Profit (GDP), the Mumbai transport system results in 60 % less energy consumption and reduced emissions compared to Delhi, mainly due to a higher share of public bus transport and suburban railway system of Mumbai. Lack of effective policy and investment, along with uncontrolled urbanization growth, has resulted in gross discrepancies between supply and demand of transport services. An inadequate public transport system has led to a tremendous rise in the number of personal vehicles. At the same time, road space has not grown proportionately, leading to more traffic congestions; longer travel time and more energy consumption, which leads to increased costs and pollution. Higher economic activities would lead to higher pollution from the transport system. Socio-Economic implications of Delhi Metro were discussed by Singh et al. (2002) and EPA (2004) reported the status of various public transport projects in Delhi. In a survey work Sibal (2002) simulated 148 % increase in the rider-ship of the Delhi metro if the feeder buses are provided at every 0.5 km walking distance.

Similar to energy demand, a strong relationship is observed between economic growth and pollution from the transport system. Ghose (2004) has shown that the improved vehicle technology alone is presently insufficient to counteract the growth of transportation systems and efforts must be made to improve the quality of fuel and management of transport. Vehicular emissions reduction through Common Rail Diesel Injection (CRDI) in Compression Ignition engines were reported by Vaitheeswaran and Krishnakumar (2005). Analysis of Vehicular Pollution in Delhi, and study of different initiatives for its control were discussed by Arora (2002). In a study of vehicles in Delhi, significant reduction in vehicle emissions due to substitution of carbureted engines gasoline vehicles by Multi Point Fuel Injection (MPFI) System were reported by Singoria (2004).

2.3 STUDIES ON VEHICLE EMISSIONS AND EMISSION NORMS

The Ambient Air Quality Standards (AAQS) are pre-requisites for developing the programs for effective management of air quality and reducing the damaging effects of air pollution. The objectives of Air Quality Standards are:

- To indicate the levels of air quality necessary with an adequate margin of safety to protect public health, vegetation and property.
- To assist in establishing priorities for abatement and control of pollutants. To provide uniform yardstick for assessing air quality at national level.
- To indicate the need and extent of monitoring programs. The Central Pollution Control Board (CPCB) adopted first Ambient Air Quality Standards on November 11, 1982 as per Section 16(2) (h) of the Air (Prevention and Control of Pollution) Act, 1981.
- The air quality standards are revised by the CPCB on April 11, 1994

Uniform norms and emission standards are required to control the growth and harmful effects of automotive exhaust pollutants. Vehicular pollution sources can be mainly classified into four categories:

(i) Exhaust emissions; (ii) Evaporative emissions; (iii) Refueling losses; and

(iv) Crankcase losses.

Out of the four categories, the exhaust emissions account for about 70 % of the vehicular pollution whereas, crankcase emissions account for about 20 % and evapouration from fuel tank and carburetor accounts for the remaining part of pollution percentage (CPCB, 1999). Air pollution from vehicles largely results from combustion of fossil fuel. Diesel, consisting of sulfur impurities, leads to sulphur Dioxide (SO_2) production. Particulate Matter (PM_{10}) is a major pollutant from diesel engines exhausts (Onursal and Gautam 1982). Additional pollution sources include evaporative emissions of HCs from engines and fuel systems when automobiles are not running.

Evaporative emissions from sources other than the tailpipe are referred as running loss emissions when the engine is in operation. Crankcase emissions of HCs, or blow-by losses, originate from disabled or disconnected hoses. The types of pollutants emitted by petrol engines and diesel engines are similar but vary in proportion due to difference in the mode of operation of engines Keoleian, et al. (1997). Based on the working principle of the vehicle engine, Indian motor vehicles are categorized into following three groups.

(i) Vehicles with spark ignition engines using petrol;

(ii) Vehicles with two stroke ignition engines using lubricating oil mixed petrol (two- or three-wheelers); and

(iii) Vehicles with compression ignition engines using diesel.

In first type of engine (spark ignition), complete combustion does not take place and pollutants are produced even at stoichiometric values of air/fuel ratio (A/F =14.7). This is due to the facts that spark induced reaction is not fully propagated inside the combustion chamber. In four-stroke cycle petrol engine, the A/F ratio and operating temperature are low. As a result, substantial quantities of unburnt HCs and CO are emitted with low quantities of NOx. Two and three wheelers, being petrol driven, emit large quantities of unburnt HCs, CO and PM. While in the diesel engines, due to high A/F ratio and operating temperature, the concentration of NO_x is higher in the exhaust emissions. Since, diesel has low vapour pressure; the emission of fine carbon soot particles is also considerably high. Probably, the first emission standards for different kind of Indian vehicles were proposed in a report by Pundir (1994). This report was submitted to the ministry of forest and environment Government of India and deals with the different aspects of Indian vehicle exhaust emissions and their control specific to two wheelers, passenger cars and diesel vehicles.

A brief history of the emission norms and past, present and future emission norms are detailed in appendix-III

As it is commonly perceived, a properly compiled emission inventory is the fundamental building block of any air quality management system in a country and two essential building blocks required for compiling emission inventory are the emission factors and the activity data. In a project the Automobile Research Association of India (ARAI, 2007) experimentally developed Emission Factors for all the vehicles categories based on their age, vintage, engine size and fuel used. This data has been used in this study for the estimation of the present and future vehicle exhaust emissions. In a Petroleum Conservation Research Association (PCRA) sponsored research (1998), Central Road Research Institution (CRRI) reported that, Delhi's vehicles waste approximately 12 million rupees in fuel daily, only due to the vehicles idling at traffic lights, if the vehicles are kept idling for more than 14 seconds and these were estimated up to 27.5 million rupees per day spread over about 600 major traffic intersections in Delhi (CRRI, 2008).

2.4 STUDIES ON QUALITY OF FUEL

Use of poor quality fuel is a major contributor to vehicle exhausts emissions. Improved fuel quality can assist in emission reduction of newly developed as well as from the old engine vehicles. A large number of studies on effects of fuel qualities on engine performance and emissions have been carried out. First future Fuel Quality specifications and roadmap for improvement of the Gasoline, Diesel and other fuels quality in India were laid out by a committee under the chairmanship of Dr. Mukhopadhyay in the year 2000. An expert committee of the Ministry of Petroleum and Natural Gas, government of India, under the chairmanship of Dr. Mashelkar (2003) gave recommendations on Auto Fuel Policy for the transportation system of the entire country and presented a road map for its implementation. This report formulated strategies for its control and also emphasized on the need for the stricter emission standards and norms rather than resorting to other methods to achieve them. The recommended diesel specifications (applicable for Delhi and other Metros since 2005) primarily related to the vehicular pollution are summarised in Table 2.1 and those for gasolinein Table 2.2 whereas Indian biodiesel specifications are given in Table 2.3. The composition control covering olefins, aromatics and benzene are brought into specifications keeping in view Indian air quality requirements, evolution of refinery technology and emerging international fuel quality and vehicle designs.

Table 2.1: Recommended Indian Diesel Specifications 2005

S. No	Characteristic	BSII	BSIII	BSIV
1	Density K/m^3 at15 ^{0} C	820-800	820-845	820-845
2	Sulphur Content mg/kg (max)	500	350	50
3(a) 3(b)	Cetane Number minimum and / or Cetane Index	48 or 46	51 and 46	51 and 46
4	Polycyclic Aromatic Hydrocarbon	-	11	11
5 5(a) 5(b) 5(c)	Distillation Reco. Min. At 350 ^{0} C Reco. Min. At 370 ^{0}C 95 %Vol Reco at 0^o C max	85 95 -	- - 360	- - 360

Source: Society of Indian Automotive Manufacturer (SIAM).

Table 2.2: Recommended Gasoline Specifications 2005.

Sl. No	Characteristics	Unit	Bharat Stage II	Bharat Stage III	Bharat Stage IV
1	Density 15 ^{0}C	Kg/m^3	710-770	720-775	720-775
2	a) Recovery up to 70 ^{0}C(E70) b) Recovery up to 100 ^{0}C (E100) c) Recovery up to 180 ^{0}C (E180) d) Recovery up to 150 ^{0}C (E150)	%Volume %Volume %Volume %Volume ^{0}C % Volume	10-45 40-70 90 - 210 2	10-45 40-70 - 75min 210 2	10-45 40-70 - 75min 210 2
4	Research Octane Number (RON), Min		88	91	91
5	Anti Knock Index (AKI)/ MON, Min		84 (AKI)	81 (MON)	81 (MON)
6	Sulphur, Total , Max	% mass	0.05	150 mg/Kg	50mg/Kg
7	Lead Content(as Pb), Max	g/l	0.013	0.005	0.005
8	Reid Vapour Pressure (RVP), Max	Kpa	35-60	60	60
9	Benzene, Content, Max a) For Metros b) For the rest	% Volume	- 3 5	1	1
10	Olefin content, Max	% Volume	-	21	21
11	Aromatic Content, Max	% Volume	-	42	35

Source: Society of Indian Automotive Manufacturer (SIAM).

Table 2.3: Recommended Biodiesel Specifications 2005.

S.No.	Characteristics	Requirement	Method of Test ,	Ref to
			Other Methods	[P:] of IS 1448
(1)	(2)	(3)	(4)	(5)
i.	Density at 15°C, kg/m^3	860-900	ISO 3675	P:16/
			ISO 12185	P:32
			ASTM	
ii.	Kinematic Viscosity at 40°C, cSt	2.5-6.0	ISO 3104	P:25
iii.	Flash point (PMCC) °C, min	120	P:21	
iv.	Sulphur, mg/kg max.	50.0	ASTM D	P:83
v	Carbon residue (Ramsbottom) *, % by mass,	0.05	ASTM D	-
vi.	Sulfated ash, % by mass, max	0.02	ISO 6245	P:4
vii.	Water content, mg/kg, max	500	ASTM D	P:40
			ISO 3733	
			ISO 6296	
viii	Total contamination, mg/kg, max	24	EN 12662	-
ix	Cu corrosion, 3 hrs at 50°C, max	1	ISO 2160	P:15
x	Cetane No., min	51	ISO 5156	P:9
xi	Acid value, mg KOH/g, max	0.50	-	P:1 / Sec
xii	Methanol @, % by mass, max	0.20	EN 14110	-
xiii	Ethanol, @@ % by mass, max	0.20	-	
xiv	Ester content, % by mass, min	96.5	EN 14103	-
xv	Free Glycerol, % by mass, max	0.02	ASTM D	-
xvi	Total Glycerol, % by mass, max	0.25	ASTM D	-
xvii	Phosphorous, mg/kg, max	10.0	ASTMD	-
xviii	Sodium & Potassium, mg/kg, max	To report	EN 14108 &	-
			EN 14109	-
xix	Calcium and Magnesium, mg/kg, max	To report	**	-
xx	Iodine value	To report	EN 14104	-
xxi	Oxidation stability, at 110°C hrs, min	6	EN 14112	-

* Carbon residue shall be run on 100 % sample.
** European method is under development
@ Applicable for Fatty Acid Methyl Ester
@@ Applicable for Fatty Acid Ethyl Ester

Source: Society of Indian Automotive Manufacturer (SIAM).

2.5 STUDIES ON ALTERNATIVE FUELS

Despite discovery of new areas sources of unconventional sources of energy and due to inadequacies in the supply of other forms of commercial energy relative to demand, petroleum remains the primary source in India and is preferred as automotive fuel. Its consumption has been increasing sharply from 3.5 Million Metric Tons (MMt) in the year 1950-51 to 84.3 MMt in 1997-98 to about 130 MMt in 2001 and it were about 175 MMt in 2006-07.

In a research study at Harvard University (2001), it was reported that every CNG vehicle for one mile travel emits 20 percent more greenhouse gases than driving a comparable diesel vehicle for one mile but it emits 80 percent less particulate matter, 25 percent less nitrogen oxides, and 35 percent less hydrocarbons (volatile organic compounds). However, the output of carbon monoxide is over five times greater than that for diesel. Fleming and Allsup (1971) investigated single cylinder and multi cylinder engines and showed that light-load lean-limit; misfire region of CNG begins at an air fuel ratio between 140-150 percent of stoichiometric value. They further asserted that changes in ignition timing significantly influenced emission of NOx and HC but had little effect on CO emissions.

Lower emissions can be achieved in engines of current design but with heavy penalty to engine performance. The CNG fueled engines showed improved efficiency (3-5 %) depending on the CR and air index and emitted less CO but slightly higher amount of NOx. Kumarappa and Prabhukumar (2008) found that two stroke spark ignition engines have high exhaust emissions and low brake thermal efficiency due to the short circuiting losses and incomplete combustion which occur during idling and at part load operating conditions. To eliminate the short circuiting losses, direct injection has been developed.

Electronic CNG injection system was developed for better fuel economy and reduced emissions. In the study of Bhandari (2005) a comprehensive review of various operating parameters have been prepared for better understanding of operating conditions (spark and compression ignited engines) for a natural gas fueled internal combustion engine. Experiments were carried out at a constant speed of 3500 rpm with a compression ratio of 12:1. This indicated an improvement in brake thermal efficiency from 15.2 % to 24.3 %. This is mainly due to significant reduction in short circuit loss of fresh charge and precise control of air fuel ratio. The pollution levels of HC and CO were reduced by 79 % and 94 % respectively compared to a conventional carbureted engine.

It was estimated that a CNG engine with range and power equivalent to that of the gasoline model would be 25 % less efficient. This trade-off between efficiency and performance is the reason that CNG is better suited for urban vehicles. The study finally concluded that CNG dual fuel retrofitted vehicle could provide very large CO reduction (80-95 %) compared to current gasoline vehicles. The Non Methane Hydrocarbons (NMHC) and NO_X emission impacts depended upon conversion techniques. Emission benefits in CNG engine would be greater in dedicated vehicles. The maximum level of CO emission was 0.325 percent in CNG operation. Results showed an improvement in the performance and emission characteristics of CNG fueled SI engines using specially designed Electro Mechanical Fuel system.

In an experimental work on a Ricardo engine, four stroke Variable Compression Ratio (VCR) engine with CNG, Maji S. et al. (2004) reported to 30-80 % reduction in CO emissions, to 14-20 % reduction in HC emissions and about 18 % reduction in NOx emissions. Estimates are that from CNG exhaust and evaporative greenhouse gas emissions are approximately 15 percent lower than that of LPG vehicles. Further it does not need lead or other additives to boost its octane rating. Comparisons of the levels of noxious gas emissions from LPG and petrol vehicles are inconclusive, with test results indicating both higher and lower levels compared to that of the petrol vehicles. An expert committee headed by Bhure Lal (2001) recommended that the CNG be made a mandatory fuel for Public Transport (mainly for the buses) in Delhi w.e.f. April 2001. This was fully implemented by the end of 2004 on the strong interventions of the Supreme Court of India. Centre for Science and Environment (2004) reported reduction in most of the pollutants, as a result of the use of CNG, but alerted over increase in particulate matter pollution below 10 micron resulting due to burning of fine particles of CNG.

In some other studies (Narain and Bell Ruth 2005; Narain and Krupnick 2007) the advantages gained through CNG based transportation system and also the difficulties encountered in its incorporation has been reported. This has made natural gas a promising fuel for reducing the emissions of oxides of nitrogen and predominantly particulate matter from heavy-duty transit buses. Recent research studies performed at West Virginia University (Kappanna, 2006) proved that natural gas engines emit lower PM emissions, on a mass basis, when compared to diesel engines without any exhaust-after-treatment devices. However, on a number basis, the emissions from natural gas-fuelled buses were of magnitude higher than that of their diesel counterparts. Semin (2009) investigated the engine cylinder combustion temperature effect when diesel engine is converted to CNG engine. This research was conducted to investigate the cylinder temperature of CNG engine compared to diesel engine. The combustion temperature was investigated on 7 engine speeds. The engine speed changed from 1000 rpm to 4000 rpm with variation in steps of 500 rpm.

Experimental results show that increasing speed of the diesel engine increased the maximum combustion temperature in the engine cylinder; contrary to this, increasing speed of CNG engine decreased the maximum combustion temperature in the engine cylinder. Decreasing of diesel engine will decrease the maximum combustion temperature in the engine cylinder. In the diesel engine, the highest maximum combustion temperature in the engine cylinder was found at 3500 rpm engine speed, because in this case, the combustion is better than that the other conditions and unburnt fuel is the lowest, hence the temperature produced from the combustion is the highest. Ismail (2009) developed a gaseous fuel injector for port injection CNG engine converted from diesel engine. In this work on diesel engine converted/ designed to run on natural gas with the port injection (sequential) or trans-intake valve-injection system, a high-speed gas jet was pulsed from the intake port through the open intake valve into the combustion chamber, where it caused effects of turbulence and charge stratification, particularly at part- load operations. The system was able to diminish the cyclic variations and to expand the limit of lean operation of the engine. It was reported that the flexibility of gas pulse timing offers the potential advantage of lower emissions and fuel consumption and that there are several advantages of port injection. To increase the power and decrease the exhaust gas emissions, the CNG engine needs some improvements such as conversion of diesel engine to port injection and improve the gaseous fuel injector nozzle holes geometries with variation in injection pressure and injection timing to give better performance and exhaust gas emissions.

Comparison of the performance results and optimization of the natural gas replacement in dual fuel mode were carried out by many researchers, Saraf et al.(2008), Papagiannakis (2003), Yusuf et al. (2001), Maji(2008) etc. . It has been found that CNG/diesel dual fuel engine (DFE) was one of the best solutions for the problems at present. In order to study and improve the emission performance of CNG/diesel DFE, an emission model for DFE based on radial basis function (RBF) neural network was developed, which was a black-box input-output training data model and does not require prior knowledge.

In comparison with diesel-powered buses, dual mode CNG powered buses show 50 % reduction of NOx emissions and a near-total absence of particles that could be improved using specific lubricant characteristics. To reduce CO and HC emissions it is necessary to use advanced engine technology injection systems rather than older technology using a carburetor. Fuel consumption depends very much on the use of technology conditions which shows fuel consumption varied between 20 to 45 per cent. Incidents occurring on vehicles concerned the ignition and gas-compression system. In the case of diesel-powered bus, the use of adapted after-exhaust-treatment devices can decrease exhaust emissions, pollutants level, especially for PM abatement. In that case, some trap technologies must be associated with adapted diesel-fuel formulations (for instance, ultra-low sulphur fuel). The first generation dual fuel conversion system is the open loop system with no computer control. Natural gas is fed into the airstreams at the intake of the engine. A pre-determined amount of natural gas was introduced to the system, which was totally independent of vehicle speed or load. These earlier systems had problems with knocking and significantly increased overall fuel consumption. For dual fuel engines the Electronic Fuel Control (EFC) generic electronic closed loop conversion systems were used. With these types of systems, the vehicle followed the original engine power, torque and required no engine modification. A targeted blend of 85 % natural gas and 15 % diesel fuel was reported in high load/high RPM conditions. Less wear on engines parts with reduced maintenance and oil charges were reported with these systems.

Among other alternative fuels, ethanol and bio-diesel are most viable in near future. The reasons for their preference in Indian scenario are following:

First, they can be produced from “cellulosic biomass”, such as trees and grasses or from different species of vegetable oils. Thus they represent really a zero emission technique as they eat up a lot of CO_2 in the process of their production.

Secondly, ethanol (CH_3CH_2OH) is made up of a group of chemical compounds whose molecules contain a hydroxyl group, OH, bonded to a carbon atom; so, the oxygen content of this fuel favours further combustion of gasoline. And most importantly these are home grown; therefore they not only reduce the burden of arranging the foreign currency but they generate a massive opportunity of employment generation.

The addition of ethanol to diesel fuel simultaneously decreases cetane number, high heating value, aromatic fractions and kinematic viscosity of ethanol blended diesel fuels and changes distillation temperatures. An additive used to keep the blends homogenous and , and suitable an ignition improver, which can enhance cetane number of the blends, have suitable effects on the physicochemical properties related to ignition and combustion of the blends with 10 % to 30 % ethanol by volume. Nowadays, there are many attempts being made for using ethanol in compression ignition (CI) engine.

Some past studies have considered numerous methods of introducing ethanol into CI engines, some work focused on the development of blends of diesel fuel and ethanol are considered here. Hoang et al. (2008) carried out an experimental investigation on the application of the blends of ethanol with diesel to a diesel engine. First, the solubility test of ethanol and diesel was conducted with and without the additive of normal butanol (n-butanol). Furthermore, experimental tests were carried out to study the performance and emissions of the engine fuelled with the ethanol blends compared with those fuelled by diesel. The test results show that it is feasible and applicable for the blends with n-butanol to replace pure diesel as the fuel for diesel engine; the thermal efficiencies of the engine fuelled by the blends were comparable with that fuelled by diesel, with some increase in fuel consumptions, which is due to the lower heating value of ethanol.

Bhattacharya and Mishra (2004) carried out tests to evaluate the feasibility of preparing diesel-ethanol blends using 200° (anhydrous ethanol) and ethanol lower proof having 190°, 180°, 170°, 160° and 150°. The observation on phase separation revealed that 150° and 160° proof ethanol were not suitable for blending with diesel. The relative density, dynamic and kinematic viscosity and gross heat of combustion of blends containing 200° to 170° proof ethanol were found to be close to that of diesel. The performance of a 10 hp constant speed C I engine on diesel-ethanol blends containing 20 % and 15 % ethanol by volume indicated power producing capability of the engine on blends similar to that of diesel.

Hansen et al. (2005) found that the properties of ethanol-diesel blends have a significant effect on safety, engine performance and durability, emissions. An increase in fuel consumption approximately equivalent to the reduction in energy content of the fuel can be expected when using ethanol-diesel blends. With ethanol percentages of 10 % or less, operators have reported no noticeable differences in performance compared to running on diesel fuel. Wang et al. (1999) showed that the most noteworthy benefits of E-diesel use lies with petroleum reductions and reductions in urban PM_{10} and CO emissions by urban bus operations.

The overall effect of farming tractors and urban buses on the nation's petroleum use is tiny, and that urban CO emissions are increasingly becoming a non-issue for major cities. However, specifically with respect to pollution abatement, E-diesel could be a non-trivial asset of fuel portfolios for urban buses needing to reduce their PM_{10} emissions. Ajav and Akingbehin (2002) experimentally determined some fuel properties of local ethanol blended with diesel to establish their suitability for use in compression ignition engines. Based on the findings of this study, blends with 5, 10, 15 and 20percent ethanol content were found to have appreciable fuel properties for use as supplementary fuel in farm engines.

Eckland et al. (1984) presents a "State-of-the-Art Report on the Use of Alcohols in Diesel Engines". Techniques that have been evaluated for concurrent use of diesel and alcohols in a compression-ignition engine include (1) Alcohol fumigation, (2) Dual injection (3) Alcohol/diesel fuel emulsions, and (4) Alcohol/diesel fuel solutions. Of these four options, fumigation and dual injection require additional and separate fuel handling systems including additional injectors for either manifold injection (for fumigation) or direct injection. Accordingly, these alternatives represent both a significant incremental cost for vehicle production and increased operational inconvenience related to refilling two fuel tanks rather than one.

In case of fumigation, Heisey and Lestz (1981) reported significant reductions in particulate generation; however, NOx generation increases. The incremental vehicular costs and increased NOx associated with fumigation have limited its acceptance. By definition, alcohol/diesel fuel emulsions are fuels with two liquid phases in equilibrium where a substantial portion of the ethanol is in a hydrophilic phase that is entrained in a continuous diesel phase. To maintain stable fuel emulsions of alcohol and diesel, large amounts of costly emulsifiers are typically required. Emulsifiers are always needed with methanol to maintain the entrainment of the methanol phase. They are needed with ethanol when the water content of ethanol is greater than 0.1 %. Baker (1981) reported that 9:10 and 3:2 parts by volume of alcohol to emulsifier were required by methanol and ethanol, respectively, to create stable emulsions.

Irshad Ahmad (2001) founds diesel engines are major contributors of various types of air polluting exhaust gasses such as Particulate Matter (PM), Carbon monoxide (CO), Oxides of Nitrogen (NOx), Sulfur, and other harmful compounds. It has been shown that formation of these air pollutants can be significantly reduced by blending oxygenates into the base diesel. Ethanol blended diesel (e-diesel) is a cleaner burning alternative to regular diesel for both heavy-duty (HD) and light-duty (LD) compression ignition (CI) engines used in buses, trucks, off-road equipment, and passenger cars. Although ethanol has been used as fuels oxygenate to reduce tail-pipe emissions in gasoline, its use in diesel has not been possible due to technical limitations (i.e., blending). Likos et al. (1982) reports increased NOx and hydrocarbon emissions for diesel-ethanol emulsions.

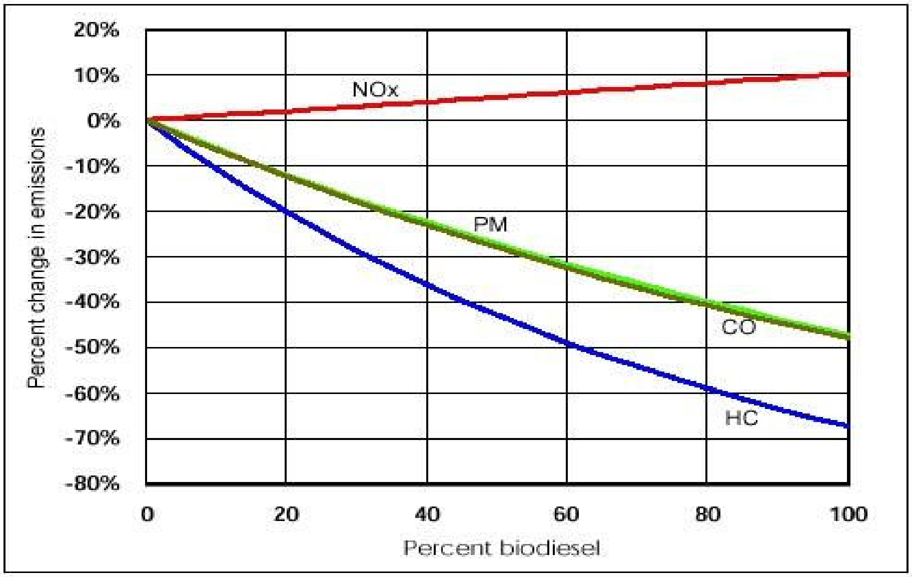
Alcohol-diesel fuel solutions form a homogenous phase rather than two liquid phases. Methanol is substantially insoluble in diesel, and so, most solution work has been performed with ethanol. A disadvantage of solutions is that two liquid phases form when the alcohol-diesel mixture is contacted with water. Although this can manifest into operating difficulties, similar problems occur when straight diesel is contacted with water.

Shaik et al. (2007) experimentally determined VCR engine has great potential for improving part-load thermal efficiency and reducing greenhouse gas emissions. As VCR is a geometric approach to improve all existing engine strategies, it is potentially one of the basic sources to investigate for the automotive industry. Variable compression, VCR promises more efficient operation, the ability to down-size the engine, multi-fuel flexibility, and the potential to revise emission characteristics. The full potential of variable compression can only be realized when it is used in combination with reduced engine displacement and high supercharging pressure. The biggest challenge in adoptation of the VCR is incompatibility with major components in current production. In short, VCR feature will permit SI engines significantly to reduce fuel consumption and emissions. Purchasing fuel efficient, clean vehicles would be greatly encouraged by tax breaks and that of existing SI engines subsidies by government.

Rao et al. (2008) carried out experiment in order to found out optimum compression ratio, experiments were carried out on a single cylinder four stroke variable compression ratio diesel engine. Results showed a significant improved performance and emission characteristics at a compression ratio 14.8. Agarwal and Das (2001) found ethanol diesel blends up to 20 % can very well be used in present day constant speed CI engines without any hardware modification. Exhaust gas temperatures and lubricating oil temperatures were lower for ethanol diesel blends than mineral diesel. The engine could be started normally both hot and cold. Significant reduction in CO and NOx emission was observed while using ethanol diesel blends. Snethil et al. (2006) reported that emulsification of animal fat with ethanol and water can be a promising technique for using animal fat efficiently in diesel engines without any modifications in the engine. Simultaneous reduction in nitric oxide and smoke can be achieved with the use of animal fat emulsions. However, poor part load performance needs attention.

The performance tests of methanol and bio-diesel fuels were conducted on a diesel engine by Snethil et al. (2003) at high loads, the blends reduce smoke significantly with a small penalty on CO, besides, and ethanol is most commonly used to increase gasoline's octane number. As a result, studying the effect of ethanol fuel on the pollutant emissions and performance of an engine holds interest of many researchers [Bata and Raon (1989), Gautam and Martin (2000), Szwarc and Branco (1985), Austin and Rubenstein (1980), Buttsworth et al. (2009)]. Results show that with increasing the ethanol content, the heating value of the blended fuel is decreased, while the octane number of the blended fuel increases. At the same time, the effect of the above ethanol–containing fuels on the exhaust emissions from a S. I. engine was studied too [Maji et al. (2002) and Hasan (2003) and Hakan Bayraktar (2005)]. The engine test indicated that CO and total hydrocarbon (THC) emissions decrease dramatically as a result of the leaning effect caused by the addition of ethanol. The fuel containing 30 % ethanol by volume can drastically reduce engine-out THC, CO and NO_X emissions at idle speed, but unburned ethanol and acetaldehyde emissions increase. In the study of Yüksel and Ceviz (2005), a new carburetor is designed by which the phase separation problem in gasoline–ethanol mixtures can be solved.

Biodiesel is considered as clean fuel since it has almost no sulphur, no aromatics and has about 10 % built in oxygen, which helps it to burn fully. Figure 2.1 shows the representative emissions reductions through the use of Bio-diesel. Its higher cetane number improves the combustion quality. Hebbal et al. (2006) have presented the investigation on deccan hemp, a non-edible vegetable oil in a diesel engine for its suitability as an alternate fuel.



Source: US Environmental Protection Agency (2002)

Figure 2.1: Emissions Reduction through the Use of Bio-diesel

Agarwal and Agarwal (2007) conducted experiments using various blends of Jatropha oil with mineral diesel to study the effect of reduced blend viscosity on emissions and performance of diesel engine. The acquired data were analyzed for various parameters such as thermal efficiency, brake specific fuel consumption (BSFC), smoke opacity, CO_2, CO and HC emissions. While operating the engine on Jatropha oil (preheated and blends), performance and emission parameters were found to be very close to mineral diesel for lower blend concentrations. However, for higher blend concentrations, performance and emissions were observed to be marginally inferior. Purushothaman and Nagarajan (2009) presented work on the performance, emission and combustion characteristics of a single cylinder, constant speed, direct injection diesel engine using orange oil as an alternate fuel and the results are compared with the standard diesel fuel operation. Results indicated that the brake thermal efficiency was higher compared to diesel throughout the load spectra. Carbon monoxide (CO) and hydrocarbon (HC) emissions were lower and oxides of nitrogen (NOx) were higher compared to diesel operation. Peak pressure and heat release rate were found to be higher for orange oil compared to diesel fuel operation.

Labeckas and Slavinskas (2006) reported the comparative bench testing results of a four stroke Diesel engine when operating on neat rapeseed oil methyl ester and it's 5 %, 10 %, 20 % and 35 % blends with Diesel fuel. They examined the effects of rapeseed oil inclusion in Diesel fuel on the brake specific fuel consumption of a high speed Diesel engine, its brake thermal efficiency, emission composition changes and smoke opacity of the exhausts. The brake specific fuel consumption at maximum torque and rated power found to be higher for rapseed oil by 18.7 % and 23.2 % relative to Diesel fuel. The maximum brake thermal efficiency is higher for rapseed oil at higher load. The maximum NOx emissions increase proportionally with the mass percent of oxygen in the bio-fuel and engine speed. The carbon monoxide emissions and visible smoke emerging from the biodiesel over all load and speed ranges are lower by up to 51.6 % and 13.5 % to 60.3 %, respectively. The carbon dioxide (CO_2) is slightly higher in case of biodiesel. The emissions of unburned hydrocarbons for all bio-fuels are low.

In the study of Altuna et al. (2008) a blend of 50 % sesame oil and 50 % diesel fuel was used as an alternative fuel in a direct injection diesel engine. The experimental results show that the engine power and torque of the mixture of sesame oil–diesel fuel are close to the values obtained from diesel fuel and the amounts of exhaust emissions are lower than those of diesel fuel. Sureshkumar et al. (2008) presented the results of performance and emission analyses of an unmodified diesel engine fuelled with Pongamia Pinnata Methyl Ester (PPME) and its blends with diesel. Engine tests were conducted to get the comparative measures of brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC) and emissions such as CO, CO_2, HC and NOx to evaluate the behaviour of PPME and diesel in varying proportions. BSFC and BSEC for all the fuel blends and diesel tested decrease with increase in load. This is due to higher percentage increase in brake power with load as compared to increase in the fuel Consumption. For the blends B20 and B40, the BSFC is lower than and equal to that of diesel respectively and the BSEC is less than that of diesel at all loads. This could be due to the presence of dissolved oxygen in the PPME that enables complete combustion engine emits more CO for diesel as compared to PPME blends under all loading conditions.The CO_2 emission increased with increase in load for all blends. The lower percentage of PPME blends emits less amount of CO_2 in comparison with diesel. Blends B40 and B60 emit very low emissions. This is due to the fact that biodiesel in general is a low carbon fuel and has a lower elemental carbon to hydrogen ratio than diesel fuel. HC emission decreases with increase in load for diesel and it is almost nil for all PPME blends except for B20 where some traces are seen at no load and full load. The NOx emission for all the fuels tested followed an increasing trend with respect to load.

The reason could be the higher average gas temperature, residence time at higher load conditions.In an experiment on a kirloskar single cylinder diesel engine with 10-20 % palm oil bio-diesel, Naveen and Dhuwe (2004) reported significant reduction in smoke level. Lapuerta et al. (2007) analyzed diesel engine emissions when using biodiesel fuels as opposed to conventional diesel fuels. The basis for comparison is engine power, fuel consumption and thermal efficiency. The engine emissions from biodiesel and diesel fuels are compared, paying special attention to the most concerning emissions: nitric oxides and particulate matter. Some of the important outcomes are: at part load operation, no differences in power output, since an increase in fuel consumption in the case of biodiesel would compensate its reduced heating value. At full-load conditions, a certain decrease in power has been found with biodiesel, an increase in bsfc has been found when using biodiesel. Such an increase is generally in proportion to the reduction in heating value (9 % in volume basis, 14 % in mass basis). Consequently, the thermal efficiency of diesel engines is not appreciably affected when substituting diesel by biodiesel fuel either pure or blended. There is slight increase of NO_X with biodiesel because of more oxygen content of biodiesel and at higher temperature it leads to increase $NO_{x.}$ There is a sharp reduction in particulate emissions with biodiesel as compared to diesel fuel. This reduction is mainly caused by reduced soot formation and enhanced soot oxidation. The oxygen content and the absence of aromatic content in biodiesel have been pointed out as the main reasons.CO is usually found to significantly decrease with biodiesel. A more complete combustion caused by the increased oxygen content in the flame coming from the biodiesel molecules has been pointed out as the main reason.

Some researchers worked to find the effect of viscosity on emissions and performance of diesel engine Agarwal et al. (2001), Gangwar et al. (2008) and Choudhary et al. 2008). Emission parameters such as smoke NOx and CO_2 were found to have increased with increasing proportion of Jatropha oil in the blends compared to diesel. They found Jatropha oil to be a promising alternative fuel for compression ignition engines. It can be directly used as straight vegetable oil as a replacement of diesel fuel and do not require any major modification in the engine. Thermal efficiency was lower for unheated

Jatropha oil compared to heated Jatropha oil and diesel. CO_2, CO, HC, and smoke opacity were slightly higher for neat Jatropha oil compared to that of diesel, but it were significantly less with Jatropha and other specie's bio-diesel. These emissions were found to be close to diesel for preheated Jatropha oil.

Hydrogen is, in fact, the technology and fuel of tomorrow and is the long term solution to pollution, energy security & CO_2 emission related concerns. Hydrogen is a renewable source of energy with near zero emissions of CO, HC, CO_2 and PM. It is clean and lean burning resulting in better fuel efficiency, avoids engine de-carbonizing and does not emit any greenhouse gases. Faster dispersion also implies that it is safe for the health and the environment. Hydrogen is recognized as an attractive solution in order to reduce greenhouse gases emissions and urban pollution.

The transport vehicles are one of the main sectors responsible for primary fossil energy consumption and CO_2 emission. Thus in this field, hydrogen may have a great potential as "friendly environmental" fuel, especially when hydrogen is produced from renewable primary resources (like wind power or biomass) providing then maximum CO_2 savings. Cost is the most significant barrier to widespread hydrogen use. To improve the economics, the cost of hydrogen must be reduced relative to the cost of other fuels or the value of hydrogen must be increased in the alternative fuels marketplace.

A neat hydrogen-operated engine gives out water as its main combustion product (Das 1991). It does not produce significant amounts of CO, HCs, SOx, smoke, lead or other toxic metals, sulfuric acid deposition, ozone and other oxidants, benzene and other carcinogenic compounds, formaldehydes, CO_2 and other greenhouse gases. While the depletion of non-renewable oil and gas resources will inevitably cause the costs of these fuels to increase, most agree that this will be a long, slow process. Most would also agree that hydrogen is likely to be the most significant renewable energy carrier at some time in the future; the point of contention is just how far in the future this will occur?

In the near term, accelerating the infrastructure and transition to the use of hydrogen for common vehicular applications can be achieved by taking advantage of leveraged benefits. The main benefit sought by including hydrogen in the alternative fuels mix is emissions reduction – eventually by 100 %. Imagine a fleet of 100 natural gas buses. The fleet owner wants to reduce emissions by buying hydrogen-powered buses but cannot afford to convert the entire fleet. What is the best way to reduce emissions using the least hydrogen? In the simplest example, a few of the buses are replaced with hydrogen internal-combustion engines with the same fuel economy as natural gas. These hydrogen-powered buses can have near-zero exhaust emissions, so if 7 of the 100 total buses run on hydrogen, there will be a 7 % reduction in emissions. By taking advantage of the unique properties of hydrogen, it is possible to improve the typical one-to-one relationship between emissions reduction and hydrogen use. Suppose he uses Hythane but now with 7 % hydrogen by energy blended with natural gas and used over the whole fleet. Both laboratory and real-world experience shows that a natural gas engine with a calibration optimized to reduce NOx emissions with 7 % hydrogen in natural gas will cut emissions by about 50 %, for every bus in the fleet. In this example, Hythane reduces emissions 50 % with 7 % hydrogen by energy, so the hydrogen utilization leverage factor is 50 % /7 % = 7.1, or more than 2.5 times better than the most generous fuel cell bus scenario. There are only minimal costs associated with changing the natural gas engine calibration and pre-blending the Hythane fuel. The natural gas refueling compressors, storage tanks, and fuel dispensers can be utilized, and the vehicle engine and fuel system does not require any hardware changes, Fanhua et al. (2009)

Many years of research have proven that only 5 % to 7 % hydrogen by energy is all that is necessary to minimize emissions and significantly stabilize the combustion of natural gas. Hythane is the next step on the path to an ultimate hydrogen economy.The only practical way immediately possible to utilize hydrogen in vehicles with present technology is through the use of Hythane, which provides leveraged benefits to justify infrastructure investment even before hydrogen vehicle technology becomes economically feasible.

Some years ago, the blend of CNG and 20 % of H_2 in volume with the brand name Hythane® was extensively assessed and demonstrated in Montreal (Canada) in the field of the Euro-Quebec project. Two buses from NOVABUS ran in the city for a period of nine months. The 20 % H_2 portion (i.e. 7 % in terms of energy) was identified in that case of operation as the optimum in terms of efficiency, pollutant emission, and costs. The CO_2 emissions were reduced by 7, 5 % by an increase of the efficiency, the NOx were cut by 40 % without any increase of unburned hydrocarbons in the exhaust fumes. These buses were operated afterwards by SUNLINE in Palm Springs (California, USA) where they are still commercially in operation with new Cummins-Westport engines. No incident has been reported up to now.

The hydrogen fuel cell was first developed in the 1800's; however, it is only recently that further developments have made it a viable source of power for transportation. In a review paper (Thomas and Zalbowiz ,1999) states since 1960's fuel cells started to be used as a power source during space flights; today, environmental, economic, and resource issues are driving the hydrogen fuel cell rapidly into the mainstream transport market.

With diminishing oil reserves around the world, increasing prices, and increasing environmental concern surrounding the use of fossil fuels, hydrogen fuel cells hold the potential of a clean and virtually unlimited power source. Hydrogen is the most abundant element in the universe and can be produced locally through renewable means, thus helping to provide energy security in most regions of the world. Hydrogen fuel cells also hold the potential of providing remote communities with a reliable, cost-efficient power supply.

The main trouble with hydrogen is that it takes energy to get hydrogen in pure, usable form. That's why it's really not considered a fuel at all, but rather an energy carrier, a method of storing power generated any number of ways. It's not that hydrogen is so hard to find. It's the most abundant element in the universe, the H in H_2O - ordinary water - and the "hydro" in "hydrocarbon" - as in natural gas or other fossil fuels. Hydrogen today, in fact, is produced almost entirely from natural gas or from water electrolysis, both are presently not economical.

2.6 GAPS IN THE LITERATURE REVIEW

On the basis of literature review, it is observed that there is an urgent need for comprehensive study on the public transportation system requirements exclusively for the city like Delhi owing to the reasons given below:

- No literature listing the opinion of general public and or that of the experts in this area of research has been found.
- It appears that no comprehensive study on a holistic analysis of different modes of the public transportation system in Delhi has ever been carried out.

- There is a lack of substantial/meaningful data to access and predict the effects of the current transportation policies in practice have been found.
- A few studies/reports/data inter-relating the use of alternate fuels and advanced engine technologies have been noticed.
- Limited studies appears to have been carried out suggesting rationalized and simultaneous use of various modes in public transportation system of Delhi
- Very few studies have been carried out future impact on the quality of air and other pollution in Delhi over the next 10 to 20 years time span.
- Limited comprehensive data is available on the efficacy of the Bio-fuels as an alternative and economically viable source of energy.

Being declared as the fourth most polluted city in the world, Delhi is urgently in need for a research study, covering these gaps. Incessant and exponentially increasing cost of petroleum fuels and limited stock of our fossil fuels are other compelling reasons to use our transportation resources in a most efficient manner. Bio-Fuels can improve our environment as well as they may create enough employment opportunities for the millions of people, and make a large waste land into usable one.

2.8 NEED FOR THE PRESENT WORK

Both intensive and extensive studies are required for the better planning of the quantity of plantation required for the use of Bio-fuels. Further, being a democratic country, our transportation systems need to be based on the expectations, choices, preferences, and paying capacity of our people. Thus an extensive research study is required to incorporate the people in planning a proper future transportation system for the capital city of Delhi.

Present study is also aimed at developing a frame work for optimization leading to economical use of fuels, least air pollution, and adequate avenues of mobility for the general public. In brief this study is an attempt to:

i) To investigate the present status of Delhi's transportation system

(ii) To suggest a futuristic model to resolve the complexities of Delhi transport sector

(iii) To explore what is the likely future scenario over a span of next 10 to 20 years

(iv) And to Know-how to alter this future to ensure a clean and efficient transport system for Delhi?

2.8 CONCLUDING REMARKS

In this chapter the literature review part was discussed. The works of various researchers in the transport systems and connected areas were thoroughly examined and gaps in the literature review were sorted out. Thus at the end, the various potential areas of the problem which can be altered suitably were identified which are and the research constraints and possible techniques for the present problem were finalised. Next chapter presents the need for a systematic research methodology and the details about the research methodology adopted for this work.

CHAPTER 3.

THE RESEARCH METHODOLOGY

3.1 INTRODUCTION

Literature on research methodology abounds, as a problem of volumes normatively silhouetting various stage and steps of the research process is readily available. `However, there is a common drawback of treating the quantitative as well as qualitative issues in a dilapidated manner in this dilemma of the written text and papers. For instance the binary format of responses to the questionnaire ('yes' or 'no' type of answer) more often than not, fails to portray the reality. Moreover, these prescribed methods often results in a mismatch between the selection of research aids and attributes of the problems being investigated, rendering the research design defective. This match is mostly due to dynamic slides and changes in the attributes of the research topic during the process of its investigation.

It is therefore necessary to eliminate this gray area of research methodology by way of devising unexplored and newer techniques and / or suitably modifying the existing methods.

3.2 THE IDEAL RESEARCH DESIGN

According to Kerlingrr (1983), research design is the plan, structure and strategy of investigations conceived so as to obtain the answer to research question and to control variance. Young (1988) defines it as the logic and symmetric planning and directing a piece of research. The design results for translating a general scientific model into varied research procedures.

Babbie (1989) proposes that research design addresses the planning of scientific inquiry – designing a strategy for finding out something – two major aspect of research design are:

First, specify precisely what you want to find out? and

Second, you must determine the best way to achieve that.

To design is to plan, since design is the process of making decision regarding a situation before the situation actually arrives for which the decision has to be taken. It is a process of deliberate anticipation directed towards bringing an expected situation under control (Ackoff, 1953).

However, the research design can be described as overall schematic map of research, listing various paths to be traversed right from writing the hypothesis and its operational formulations, to the ultimate analysis of data. Though perceived as overview or outline, it indeed acts as a reference frame for the execution of the entire research plan. It can also be remarked that a research design is prepared as a research plan with explicitly signpost of the problem analysis, its scope and strategies to consummate the set objective.

3.3 PITFALLS OF THE EXISTING RSEARCH DESIGNS

Although it may not be feasible to evolve an ideal and impeccable research plan, attempts can be made to make it best by extenuating the following identifiable limitations:

- The research process is perceived as an agglomerate of discrete parts rather than as a whole one.
- A subliminal association with often tried and deconstructed ranges of techniques of research methods to the exclusion of more appropriate and newer techniques for example system dynamics, which is based on the systems methodology.
- The available literature on research methodology tends to be normative in nature, elaborating various steps for conducting the research study but providing very little guidance on the process of research design *per se*.
- An explicitly recognizable pattern of compartmentalized standard techniques suggested for discrete phases of the research design but none with a holistic view of the process of research.
- No significant attempts made to a very significant aspect of acquiring lucidity in setting forth the problem attributes in research design.
- Furthermore, any research effort originates generally as hazy and tentative, gaining deeper insights and translucency during its course of advancement and bringing about

several alterations and modifications in the originally envisaged framework of action plan. Essentially speaking a research design can never be a very specifically laid out course of action type be perused without digressions; it rather has to be consisting of an outlined sequence of pointers to keep the researcher always headed in the intended direction. But as the study surges ahead, envisaged facets, conditions, boundaries environments and inter linking ties in the data come to the fore .This may lead to a change / modification in, or deviation from, the earlier charted course of action, acquiescent to the changed circumstances. It therefore is apparent that an 'exactitude complex' and rigid pursuit of a research effort can decimate the very purpose and utility of the research project (Young,1988), Ferman and Levin (1975) supported the same view when they opined that research design is a tentative, flexible plan for research actually proceeds and unforeseen problems or insights come to the light. Sushil (1994) has proposed a flexible systems methodology for research design process based on a synthetic as well as analytic consideration.

3.4 SELECTION OF THE METHODOLOGY

According to glesne and peshkin(1992) , the use of multiple data collection methods contribute to the trustworthiness of the data and increases confidence in the research findings (denzin,1988). The identified 'high possibility value' techniques are critically appraised and analyzed before making them a candidate for the problem and situation. The criteria for selection comprise of traits like: the degree to which a technique can unravel the obscure issues of the problem, its competence to provide answers to the research problems and the succor to provide to the data collection and analysis. However, the best research design is the one that uses more than one research method, exploiting their strengths (Babbie, 1989). Out of several techniques identified, five are selected as relevant to this research problem.

The techniques selected finally in the context of this research problem are:

- Empirical Study (Questionnaire and Interview)
- Delphi
- System Dynamics
- Idea Generation Techniques
- Case Study

Consequent upon the selection of the techniques, the following queries arise: to which segment of the problem attributes and to which phase of the research design, should each of these selected techniques be applied?

Delphi is one of the most widely used techniques for creative exploration of ideas for the production of suitable information for the decision making or future planning applications. Delphi may be characterized as a method for structuring a group communication process, so that the process is effective in allowing a group of individuals as a whole, to deal with a complex problem. The Delphi study or technique was used to determine if there are emerging patterns or consensus on leadership practices and information technologies used in leading virtual teams.

The purpose of the Delphi technique is to elicit information and judgments from participants to facilitate problem-solving, planning, and decision-making. It does so without physically assembling the contributors. Instead, information can be exchanged via personal contact, mail (post), FAX, or email. This technique is designed to take advantage of participant’s creativity as well as facilitating the effects of group involvement and interaction. It is structured to capitalize on the merits of group problem-solving and minimize the liabilities of group problem-solving. Table 3.1, gives a comparison of the matching attributes of the problem and the suitable research techniques considered.

Table 3.1 Matching Attributes of the Problem and Research Techniques

Sr. No	Problem attributes	Empirical study	Delphi	System dynamics	Idea generation techniques	Case study
1.	**Complexities of PTS**	Limited problems can be handled	Various future plans can be ranked for their different potentials	A learning model for complex interplay of issues is feasible	Brainstorming for the problem solution is possible	It can handle both, simple and complex problems
2.	**The related issues from the system of PTS are dynamically changing**	Futuristic options remarking and indicators capture dynamics	Questionnaires and interview technique give snapshot of related issues	Issues assume rate and level variable and thus dynamically simulated	Snapshot of ideas on PTS representing future effect	The case study method takes care of dynamics if it is a historical case only

Sr. No	Problem attributes	Empirical study	Delphi	System dynamics	Idea generation techniques	Case study
3.	**The commuters requirements and financial and technical constraints**	Generalization and consensus building of pluralistic views by sampling	By repeated group of exercised people involved in PTS consensus is achieved	Building SD model required unitary views on PTS	Pluralistic nature of opinion of people involved are transformed into consensus	Many factors and their effects can be included in development of the PTS
4.	**Interaction with the people involved are not structured**	Organizational managers are used to unravel the unstructured issues	Questionnaires and interviews may be used to structure the problem	Rate and level variables are used for structuring	Structuring is not supported	It can also deal with ill-structured system and their imprecise relationships

Sr. No	Problem attributes	Empirical study	Delphi	System dynamics	Idea generation techniques	Case study
5.	**The attributes involved are qualitative**	Interviews held to gather qualitative data	Qualitative option of expert is gathered via individual contact	Qualitative variables used with dimensional consistency	Qualitative perceptions are generated by idea engineering	Can cover both qualitative and quantitative variables
6.	**The possible impact of the future policies on the PTS**	Limited results	Experts opinions are taken interactively with aggregation of group responses.	Analysis may be carried out in the flow model for assessing the impact	Limited results	By taking opinion of public the case study, to a limited extent, provide outputs for future

Sr. No	Problem attributes	Empirical study	Delphi	System dynamics	Idea generation techniques	Case study
7.	**Data on the execution of future plans of PTS not available**	Not used as a data collecting instrument	Primary data can be assessed in future after the implementation of PTS future plans	Simulated data on possible impact of PTS future plans can be generated	Not suitable	The case is developed both on concrete facts as well as opinion of the public
8.	**Critical appraisal**	Assessment of the present potential, awareness and practices related to future	Forecasting of the PTS is required, in Delphi it can be carried by a questionnaire/survey and interviews	Casual relationship of the key variable of PTS are logically included in the dynamic flow model	Idea generation on measure of flexibility plans of PTS, organizational & socioeconomic factors can be done	The understanding of implementing new PTS can be effectively generated by the case study method

In present work, it has been planned to carry out this work in three main parts. In first part of the study collection of the complete data on the public transportation system e.g. vehicle numbers, type, technology, engine capacities, vehicle usage emission factors etc. were carried out. Simultaneously the design, development and experimental testing on the use of alternative fuels on various I C Engines were carried out in the I.C. Engines Laboratory at Delhi College of Engineering, to obtain the emission data precisely.

3.5 DESIGN OF THE DELPHI'S QUESTIONNAIRE

In second part a Delphi Survey were conducted to acquire the general public and selected expert's opinion on present public transportation system of the metro city of Delhi and their desires and necessities. Keeping the limitation of the human resources and time available, it was decided to involve about 300 experts from different profiles, assuming about fifty percent successful responses to be achieved. The questionnaire for the survey was designed scientifically to obtain the feedback of the experts on various issues, which were subdivided into two main categories. Category 'A' was mainly containing questions related to the opinion of the experts on the present public transportation system. While Category 'B' were subdivided in five different sections containing questions related to the judgment of the experts on the level of experts awareness about the transportation system and alternative fuels and various suggested measures in the questionnaire to optimize the vehicle emissions.

Finally the responses of the experts were analyzed with the MATLAB software and various statistical parameters were computed for proper interpretation of the expert's responses. Those having opinion in wider difference were contacted again with the feedback on the responses of the first round and they were requested either to modify their earlier responses or to give the reasons for their specific responses. Then all the responses were again analyzed and on finding the differences within the statistically acceptable range survey activity were closed. In brief the research methodology for this study can be understood with the help of the flowchart shown in Figure 3.1

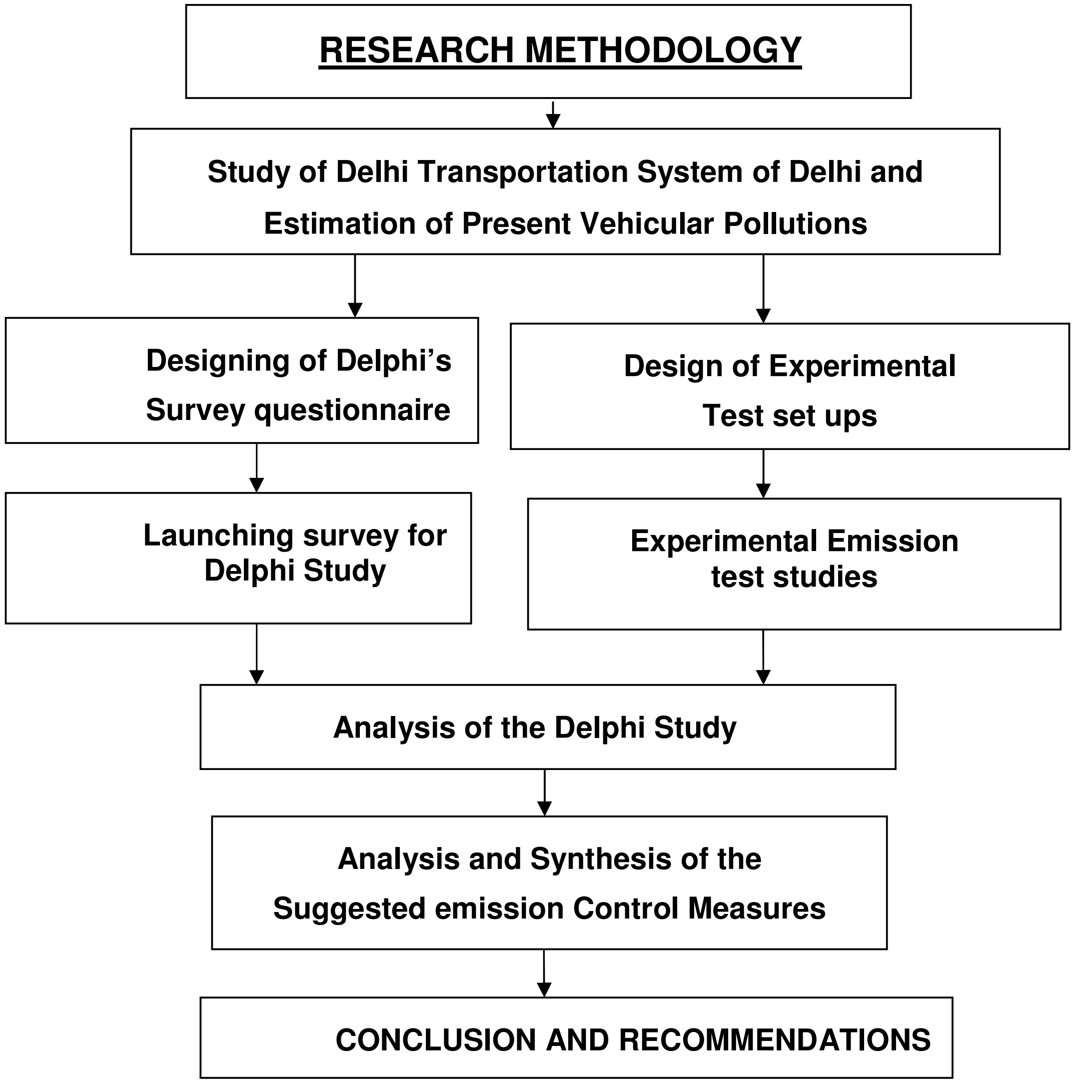


Figure 3.1: Flowchart for the Research Methodology Used

3.6 CONCLUDING REMARKS

In this work an appropriate research methodology for the present work was developed and steps were designed as per the sequence of the tasks desired. And it was decided to divide the research work in three distinct stages to adopt the research methodology designed. The final procedure adopted consists of both experimental investigations and statistical survey. Next chapter gives the analysis of the present status of the vehicular transport system of the capital city of Delhi and the constraints and the problems of the public transportation are discussed.

CHAPTER 4.

THE PROFILE OF TRANSPORTATION SYSTEM OF DELHI

4.1 INTRODUCTION

Delhi's experience with personal vehicles is enlightening to other large cities in the developing world. The unprecedented rise in population and growth in economic activity has led to terrible increase in the problem of vehicle population in Delhi. After independence, the city became a major centre of commerce, industry and education. Being the capital city of India the growth of government departments and office complexes has also contributed to the spread of the city. While the city were spreading its domain, government's policymakers and planners did not anticipated the proper growth, thus civic amenities have not kept pace and unabated in-migration has compounded the problem. In this chapter detailed analysis of the present modes of transport, their main problems and the requirements of the Public Transportation System are discussed.

4.2 INCREASING VEHICLE POPULATION IN DELHI

In India, Delhi is the third largest city, but it ranks first in total vehicles and vehicles per capita. Indeed, its vehicle ownership rate approaches that of many affluent cities. In a study of 1993, it was found that 81 percent of households owned a vehicle, though only 13 percent owned cars. Most vehicle-owning households possess small scooters and motorcycles. Motorized two-and three wheelers represent two-thirds of the total vehicle fleet in Delhi. There has been an exponential growth in the number of vehicles in Delhi, which increased from 26.30 lakh in 1995-96 to 52.30 lakh in 2007-08 at an annual compound growth rate of 5.84 %.

Decennial growth rate is substantially higher in case of personal (Private) vehicles (91.62 %) as compared to commercial vehicles (6.67 %). In the category of personal vehicles, Cars & Jeeps have registered a decennial growth rate of 130.18 %, which is highest among all the categories of vehicles followed by two wheelers (i.e. scooter, motorcycle & moped) with 76.85 %. In the commercial category of vehicles, Buses including Light, Medium & Heavy Passengers vehicle have registered highest decennial growth rate (57.14 %) followed by Taxies (50 %). Auto Rickshaws have registered a negative decennial growth rate of (-) 6.33 % followed by goods vehicles (-) 0.75 %.

Table 4.1 shows the details of number of vehicles in Delhi and their annual and decennial growth rate. Highest growth rates are for the personal vehicles, two wheelers followed by car and jeeps, while auto rickshaws and goods vehicles have shown negative growth, buses too are growing, but present growth rate is insufficient to cater the requirement of the public transport. Main reason for the higher growth of personal vehicle is poor quality and availability of the public transportation system.

In the public transportation system of Delhi, at the bottom of the service scale there are privately operated, indigenously designed auto rickshaws and four-wheelers (sometimes referred to as jeeps) with 8 to 12 seats. These vehicles comprise an estimated 3 percent of the total vehicle fleet. They operate without a schedule and sometimes without a fixed route. They are required to register with the Transport Authority, which requires meters to measure distance and fares, but many are known to evade these requirements. These vehicles are generally highly polluting, inefficient and noisy. They do not adhere to safety and emission standards and very little effort has been made to improve them. The government of Delhi recently issued norms restricting the age of vehicles that can be used or sold new for commercially registered vehicles, but enforcement is spotty.

We estimate that as many as three cycle rickshaws currently travel on Delhi roads, which are operated by over five lakh rickshaw pullers. Current policies regarding cycle rickshaws and other non-motorized vehicles are restrictive based on the notion that efficient (modern) transport systems do not include these vehicles. It is assumed that they may create the traffic congestion on main roads. To improve the PTS these policies must be changed. As this is a true zero emission mode of the transport, if planned properly for the internal colony routes and if the rickshaw pullers are also provided the necessary government support for basic living facilities, it may contribute significantly in the reduction of the air pollution from the transport sector.

Table 4.1 Annual and Decennial Growth Rate of the Vehicles

S. No.	Category	No. of Vehicles, (in Lakhs)		Decennial Growth Rate 1996-97 to 2006-07, (%)	Annual Compound Growth Rate (%)
		1996-97	2006-07		
A. Private Vehicles					
1.	Four Wheelers: Cars, jeeps, Wagon etc.	7.06	15.99	126.49	8.64
2.	Two Wheelers: Scooters/Motorcycle etc.	18.76	33.36	77.82	5.61
	Sub Total	25.82	49.35	91.13	6.54
B. Commercial Vehicles					
3.	Auto Rickshaw	0.80	0.74	(-)7.50	(-)1.37
4.	Taxies	0.15	0.26	73.33	3.71
5.	*Buses	0.30	0.46	53.33	4.07
6.	Goods Vehicles +Tractors	1.41	1.43	1.42	(-)1.11
	Sub Total	2.66	2.89	8.65	(-)0.20
	Total	28.48	53.32**	83.43	6.06

[Source: Economic survey of Delhi, 2007]

*Including light Passenger and Medium Passenger Vehicles

** Including Ambulances and other unidentified Vehicles

Further, year wise vehicles population & their growth rate and the growth of the related infrastructure may be seen in Table 4.3, shows the growth factor with respect to figures of 1971, of vehicles with roads, population, vehicle density etc. It's very alarming to know that the growth factor of vehicles is over 26.83 while population and road length growth rate is just 3.93 and 3.72 respectively. This is a clear indication of traffic congestion and thereby cause of increasing vehicular pollution. Immediate and concrete efforts are necessary to bridge this large gape.

Composition of Delhi vehicles is also very much important, here also two wheelers and car and jeeps are more about 91 %. Table 4.2 shows the Percentage share of Different Vehicle in Delhi's Transport, there is slight decline in two wheelers in previous few years (Most probably due to Delhi Metro), while car and jeeps are continuously growing with a higher percentage. Decline in the growth rate for buses and auto rickshaw is a key reason for the splurge in personal vehicles. The same trend has been observed if data is compared according as per compound annual rate of growth. Table 4.3 shows the vehicle population & its respective growth in Delhi.

Table 4.2 Percentage Share of Different Vehicle in Delhi's Transport

Year / Type of Vehicle	1990-91	1995-96	2000-01	2005-06
Cars & Jeeps	21.98	24.10	28.38	30.47
M/ Cycles & Scooters	67.32	66.23	65.15	63.74
Ambulance	--		0.04	0.04
Auto Rickshaws	3.48	3.00	2.08	1.54
Taxies	0.56	0.52	0.29	0.43
Buses	1.04	1.06	0.50	0.53
ii. Other vehicles			0.37	0.50
Tractors			0.14	0.10
Goods Vehicles	5.62	5.09	3.05	2.65
Total	100.00	100.00	100.00	100.00

[Source: Economic survey of Delhi, 2007]

Table 4.3 Vehicle Population & its Respective Growth in Delhi

Year	Population (Millions)	No of veh. (Millions)	Road Length(km)	Density (Veh/km)	Density (Veh/1000
1971	4.07	0.18	8380	21.48	44.27
1981	6.22	0.52	14316	36.39	83.76
1991	9.42	1.81	21564	84.08	192.44
2001	13.78	3.46	28508	121.26	250.82
2006	16.0	4.83	31183	154.89	483
*Growth	x 3.93	x 26.83	x 3.72	x 7.21	x 10.91

Source: 1. Yearbooks, Department of economics and statistics, Govt. of National Capital Territory of Delhi (GNCTD), 2. Department of Transport, Govt. of National Capital Territory of Delhi (GNCTD)

***Growth factor compared to the figures of 1971**

4.3 THE AUTO-RICKSHAWS

The auto-rickshaws are an important and popular means of public transportation in Delhi, as they are cheaper and easily available than taxis. All the auto-rickshaws are registered with the transport department of the Delhi government, but drivers are not, any commercial driving license holder may drive any auto-rickshaw. At major railway stations and tourist destinations pre-paid auto-rickshaw booths administered by the traffic police are available, which are safe and reliable. Though sometimes at many booths traffic police issues the pre-paid slips but leaves you alone to find the auto-rickshaw yourselves and most of them either not ready to go by the slip or may ask to share the same auto-rickshaw with some other customer. But on most of the residential colonies, office and market locations, hiring an Auto in Delhi is very tricky, as very few auto-drivers agree to standard meter charges and wear proper uniforms. The typical method is to haggle for an agreeable rate and whenever you have an emergency or you have to go to a remote area you may have to pay double the right fare. There is an urgent need for authentic police verification and registration of all of them and to provide the government support for the basic social facilities like insurance and medical etc. and make them feel themselves as a part of the society. Thus the auto-rickshaws may prove a safe option for middle and upper middle class commuters of the society by preparation of appropriate administrative action plans and their faithful implementation.

4.4 THE TAXIS

Though easily available, taxis are not an integral part of Delhi public transport. The Indian Tourism Ministry and various private owners operate most taxis; all are registered with the transport department of the Delhi government. As per EPCA recommendations city's requirement were nearly 10,000 city buses in the city. Considering the climatic conditions of Delhi i.e. peak summer and peak winter, taxis are one of the best option of public transport. Taxis are available in both A/c and non A/c and now radio taxi service; call on demand is also available at a marginally higher rate.

But on the other side a number of disastrous accidents happened (theft, robbery, killing etc.) in Delhi with taxi commuters. Pre-paid taxi services are not available at most of the locations and thus present system lacks safety and reliability. Thus it has not been an attractive alternative for the commuters needing car and the present condition compels the people to buy cars. Taxi services need to be properly controlled for the safety of the commuters and drivers need to be regulated via police verification, registration, training etc. making the people from upper middle and higher class to use them reliably. Assuring the availability of taxies whenever required by a phone call may be ascertained through GPS enabled network and they may persuade the people not to buy personal vehicles. Increasing the use of the auto-rickshaws and taxies may also help in solving the problem of parking and thus traffic congestion up to certain extent.

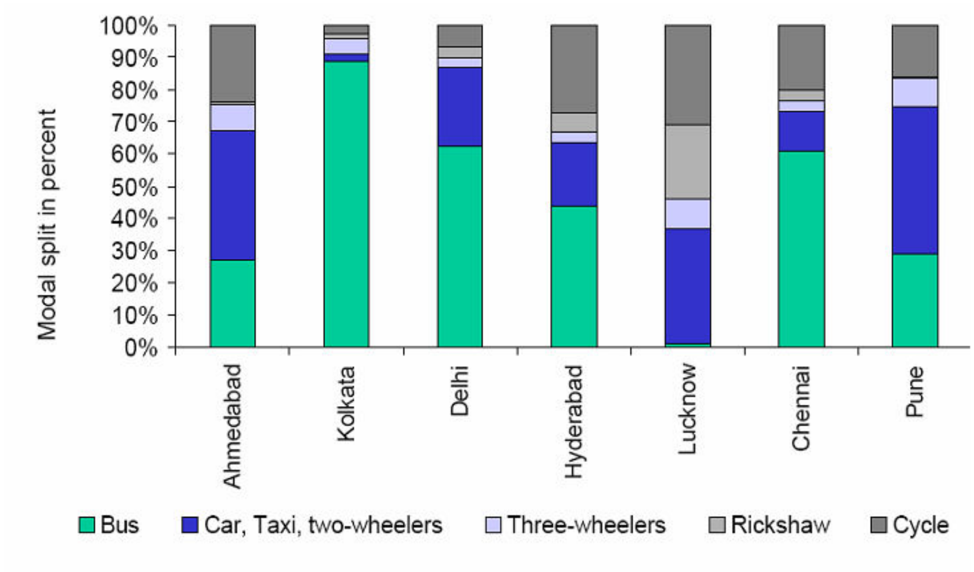
4.5 BUS SERVICES

Buses form the backbone of the transport system in a metropolitan city in any developing country. In Delhi also generally, buses are the most economically and environmentally efficient means of providing transport services to most people. It is estimated that by the year 2010, Delhi would require 30,000 buses to cater to the peak passenger traffic. A study report available at (**www.static.teriin.org/discussion/environ/emission)** reveals that to meet each kilometer of passenger travel demand:

- A car consumes nearly five times more energy than a 52 seater bus with 82 % average load factor, while two-wheelers consume about 2.6 times and three-wheelers 3 times more energy
- A car occupies over 38 times more road space in comparison to a bus. The corresponding figures -for two and three wheelers- are 54 and 15 respectively.
- The fuel cost of two-wheelers is 6.8 times, three-wheeler 7 times, and car 11.8 times, when compared to a bus. While the total cost of operation of two- and three-wheelers is over 3 times and car 9.5 times higher than the bus; and
- A 52-seater bus enjoys similar levels of advantages over other vehicles when emission of all types of air pollutants and greenhouse gases are considered.

Although the city buses carry half of all passenger travel, they receive no preferential treatment in terms of dedicated lanes or preferential traffic management. Now the Government has came up with Bus Rapid Transit (BRT) system which may prove to be a potential promoter of the buses for the daily users and office goers, but it will take a long time, there must be Delhi metro like system for its implementation, so that people must not be affected by its installation problems. Since 1992, Delhi has turned increasingly to the private sector to help and improve bus service. These private buses provide point-to-point service to individual subscribers, schools, and companies and are playing an expanding role in Delhi. Now the government is also planning to give some specific routes to corporate sector to run bus services, which will prevent the present problem of road menace of many private operators operating on same routes. This decision was a response to the widely acknowledged shortcomings of public bus service, including escalating costs, poor maintenance, high labor costs, an aging bus fleet, and erratic service.

DTC bus service is continuously expanding since 2000 by adding more buses, by which the Honourable Supreme Court of India has banned the diesel buses and made operation of CNG buses mandatory. This has resulted in reduction of most of the emissions but recent studies reported higher level of NOx due to CNG vehicles and particulate matter below 2.5 micrometer are also reported growing and their health impact may be severe. Public buses provide a low level of service and comfort, with passengers often traveling on footboards and bus roofs. Large-scale privatization has increased capacity but buses continue to be overcrowded and poorly maintained. As per EPCA recommendations city's requirement were nearly 10,000 city buses in the year 2000 and presently this requirement has gone up to approximately 20,000, whereas present buses are less than half. Present system needs a complete overhaul for the adequate number of buses required, properly planned routes, frequencies and reliability of operation. Now air conditioned and more comfortable low floor buses are changing the old unworthy buses and a number of private companies (Corporate sector) are also being deployed on select routes. Recently Delhi Metro has launched Metro feeder bus service which is very much popular and widely welcomed. There is an urgent need to expand this service to areas not covered and increase the fleet on crowded routes. Figure 4.1 shows the model split of public transport of some of the Indian cities.



Source: World Bank report, 2002.

Figure 4.1: Modal Split Share of the Buses in Public Transport System of the Metro Cities

4.6 THE TWO-WHEELERS

Two-wheelers are a uniquely Asian problem. In Europe and US these vehicles are very small in numbers and contribute very little to the total air pollution load. But two wheelers are the dominant and a very polluting mode of transport in Indian cities. Two-wheeled vehicles in the NCR, largely driven by two-stroke engines, for these have been identified as an increasing source of air pollution in the region. Two strokes have special problems as inefficient combustion, allows fresh fuel charge to go out unburned and lead to high emissions of unburned hydrocarbons. Traditionally, these vehicles have been associated with high hydrocarbon and carbon monoxide emissions and so only these pollutants in addition to nitrogen oxides are regulated from these vehicles. But what has been ignored so far is the very high level of particulate emissions and other toxics like benzene from two-stroke engines.

Though, with the replacement of earlier two stroke two wheeler with the four stroke two wheelers, gradually the exhaust emission component by two wheelers is reducing. Still it is not enough and efforts must be there to gradually reduce the use of two wheelers two third of the present usage. Fiscal measures are needed to renew the old fleet and also control explosive increase in two wheelers is in the long run to improve public transport and discourage the ownership and usage of two-wheelers. Controlling further increase in the numbers and usage of two-wheelers will be effective and possible only if a composite transport policy is framed to improve public transport in the city to meet the mobility demand.

4.7 THE RING RAIL

Ring railway is a circular rail network in Delhi, which runs parallel to the Ring Road and was conceived during the Asian Games of 1982. The system is not popular amongst people, mainly used by very few people who find it suitable due to its close proximity to their offices or homes and highly cheap fares.

Overall this is a total failure as far as public transport is considered. The major reasons for failure of the system are lack of proper connectivity, less population density in areas of reach and rare frequencies. Figure 4.2 shows the present ring rail system of Delhi.

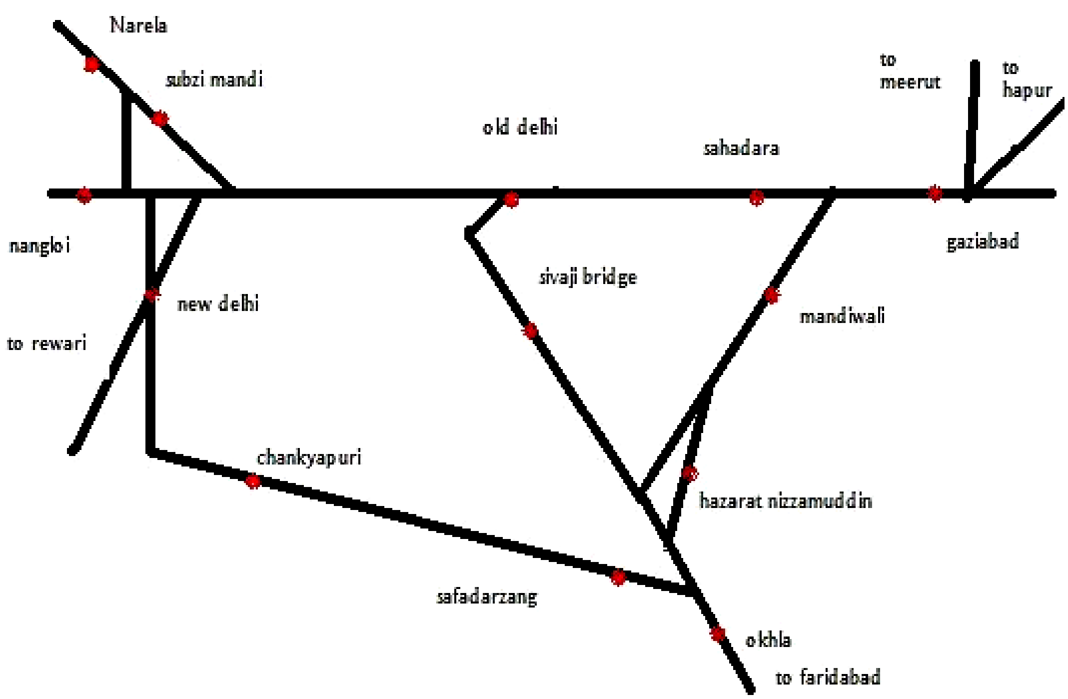


Figure 4.2: The Present Ring Rail System of Delhi.

[Source: Indian railway]

Ring rail is also one of the major areas of the concern in the reduction of the Air Pollution from the transport sector. To reorganize ring rail system its frequencies must be rescheduled and safety of the passengers must be assured. Also it must be properly connected with the city bus routes or Delhi Metro network.

4.8 THE DELHI METRO

Rapid increase of population coupled majorly owing to large-scale immigration due to high economic growth rate has resulted in ever increasing demand for better transport, putting excessive pressure on the city's existent transport infrastructure. Although population of Delhi started increasing at a very high rate since 1947, the single mode of public transport continued till 2002, when first corridor of Delhi Metro was started.

In order to meet the transportation demand in Delhi, the State and Union government started the construction of an ambitious Mass Rapid Transit System (MRTS), popularly known as Delhi Metro in 1998. The project started commercial operations on December 24th 2002. It is said to have set many performances and efficiency records ever since and is continuously expanding at a very rapid pace. As of 2007, the metro operates three lines with a total length of 65.70 km and 59 stations, with per day ridership is more than 8 lakh commuters trips while several other lines are under construction. The CO_2 reduction due to Metro Rail Transport System (MRTS) is estimated at 39730 tonnes in year 2001. The cumulative reduction in the global warming/green house effect causing gas CO_2 will be about 0.7 million tonnes in the life time of MRTS (35 years). However with more share of MRTS trips and improvements in fuel efficiency and energy use efficiency in transport sector in Delhi, the cumulative CO_2 reduction may further increase.

Thus induction of proposed MRTS will not only reduce the need for personalised transport, leading to reduction in the growing road congestion, which causes slow movement of vehicular traffic with consequent fuel wastage and increased emissions, but it will also arrest the rapidly increasing surface transport, pollution load and bring about substantial saving in fuel consumptions which is responsible for rapidly growing oil import expenditure. Table 4.4 gives the description of three Delhi Metro lines that are currently operational. Longest one is Blue Line- Indraprashta - Dwarka sub city of 32 km, and shortest one is Yellow Line - Vishwavidyalaya-Central secretariat, 10.84 km. All these lines are further proposed for the expansion. It is planned for completion of all the phases by 2016. Details of the metro plans are shown in Figure 4.3 for phase 1 and 2 and Figure 4.4 for the Phase 1-2-3 and 4 proposed. Further No. of trains and frequency is to be improved from October, 2009

Table 4.4: Description of Delhi Metro lines

Line	Between stations	Length (km)	No. of stations	Rolling stock
RED LINE	Rithala -Dilshad Gardon	26	21	23 Trains
YELLOW LINE	Jahangirpuri-Vishwavidyalaya -CentralSecretrait	17.4	10	13 Trains
BLUE LINE	Noida-Indraprashta (Yamuna Bank)	47.32	42	32 Trains

Source: http://en.wikipedia.org/wiki/

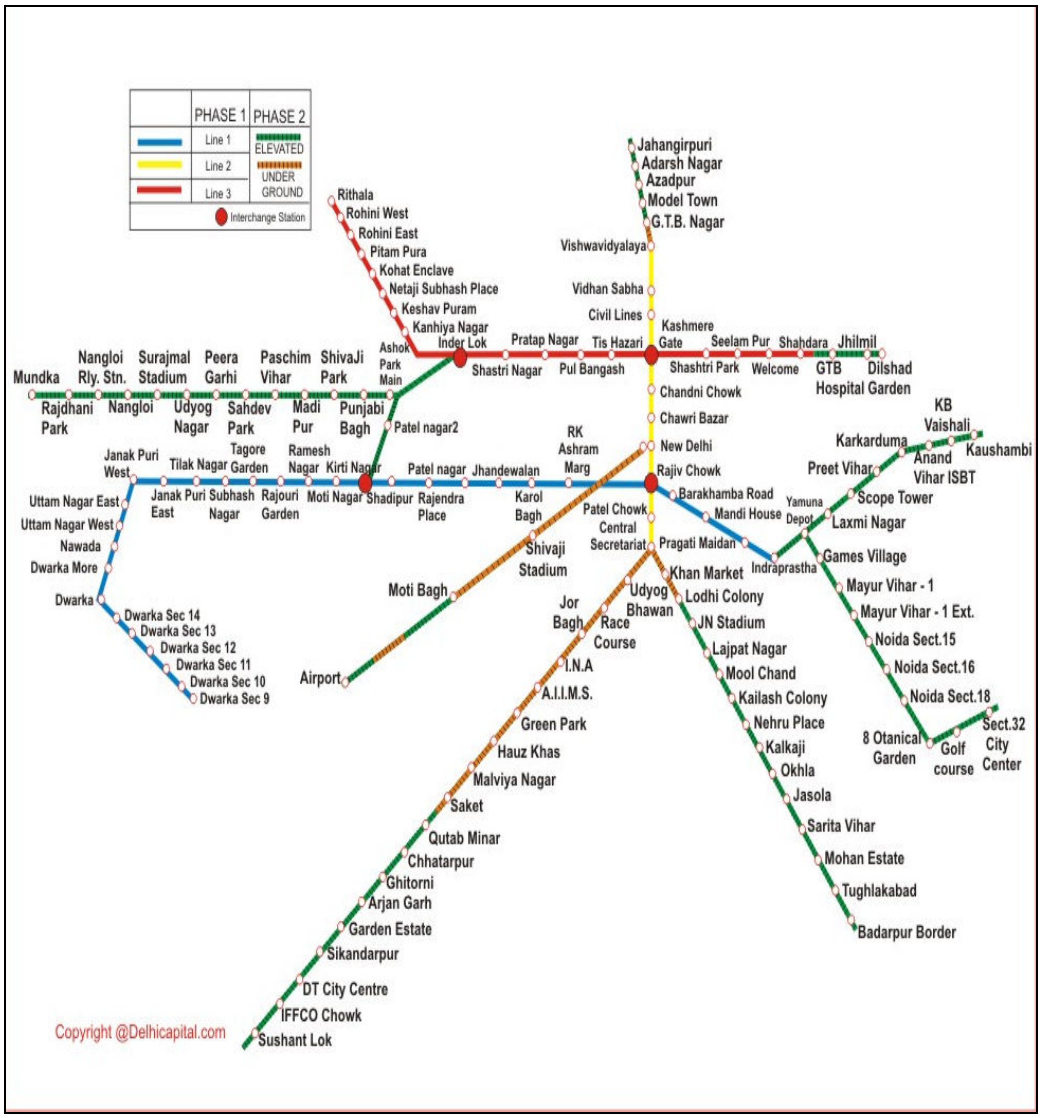
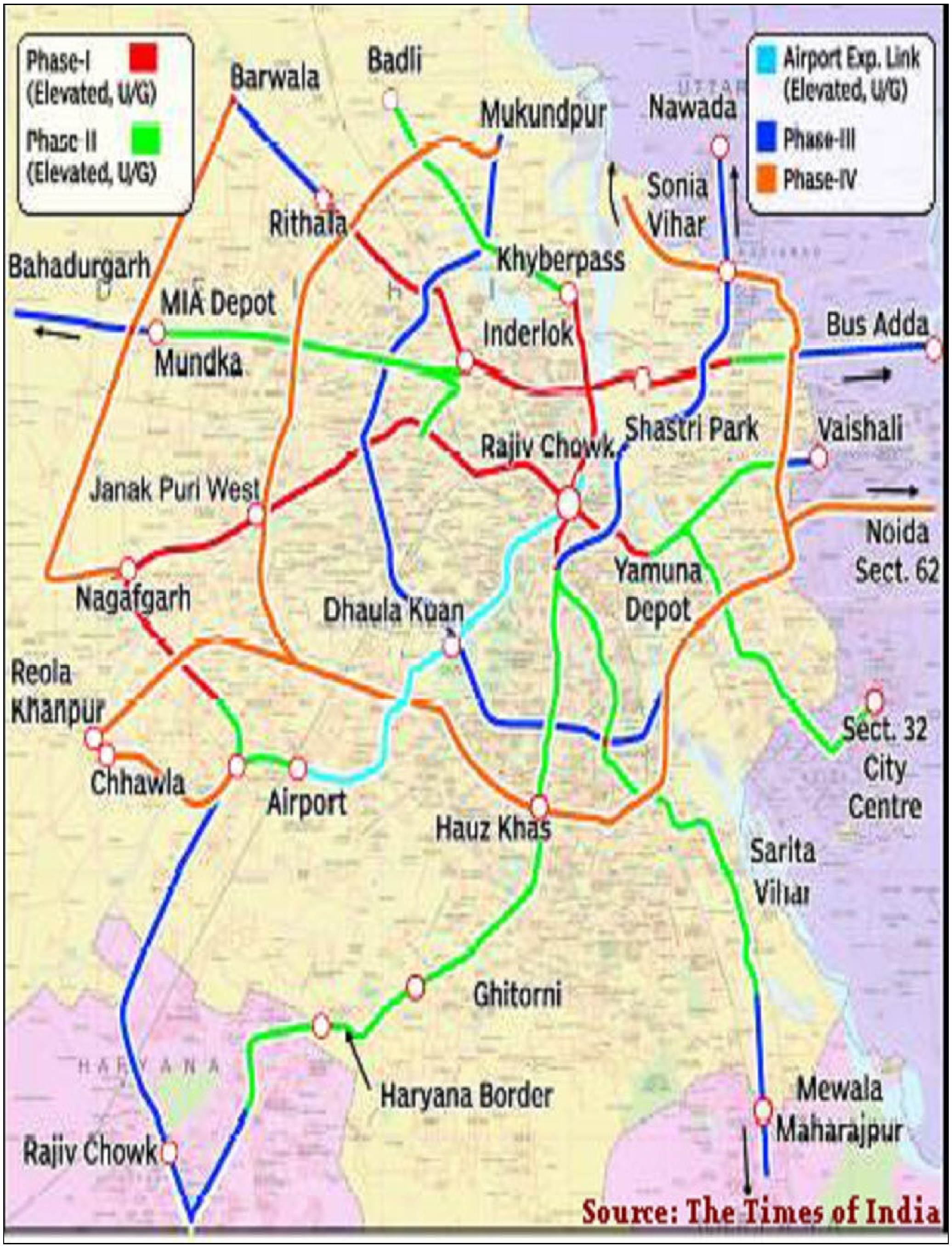


Figure 4.3 Existing and Under Construction Plan of Delhi Metro Phase-II



Source: Delhi Metro Rail Corporation

Figure: 4.4: Detailed plan of Delhi Metro (Phase 1-4)

4.9 THE MONORAIL

To connect the various stations of Delhi Metro, particularly which are located at a substantial distance of about 5 km from the important public crowd places, even before completion of a feasibility study, Delhi government has decided to implement the transport system as a 60 km feeder service to various stations of Delhi Metro. This is despite the fact that internationally, the system has only been implemented in amusement parks or connected tourist destinations. Considered an eco-friendly mode of transport, monorail is usually an elevated network which runs on a single track and has tube tyres. It will have stations similar to our elevated Delhi Metro lines, with access from the road and the track overhead usually aligned to the central divide.

Though the passenger-carrying capacity of monorail is less than that of the Metro, it is considered a cheaper option, at Rs 35-40 crore per kilometer. Delhi government is planning to take up a 15 km stretch as a pilot project. The project is likely to be initiated in the Walled City area. The pilot project will take about two to three years. Delhi is likely to follow Kuala Lumpur, where the system connects a few parts of the city. Indian Railway Construction Company (IRCON) International Limited, a government undertaking, has tied up with Monorail Malaysia Technology (MMT) to implement the system in the capital.

4.10 THE FREIGHT MOVEMENT

Freight movement is a highly decentralized business activity; consequently, data are sparse and understanding of freight activity is poor outside each industry. It is clear that intra-city movement of freight is almost entirely by truck and increasing at a rapid rate. The volume of goods is forecast to increase fivefold from 1995 to 2006, and the number of freight vehicles four and a half times. Goods are carried by various vehicles, ranging from small three-wheelers for local deliveries to large tractor-trailers. As per one estimate the freight vehicles constitute only about 3 percent of all vehicles. However, freight vehicles outnumber buses five to one, and use about 11 percent of the transport energy consumed in Delhi.

About one-fourth of total goods movements in Delhi are believed to be trans-shipments that originate elsewhere and pass through the city. Trans-shipments are mostly by rail. Many changes are occurring in urban freight operations. Most freight from outside Delhi enters by rail on the nation's extensive network, but trucks are quickly increasing the share of freight transport into the city. The National Planning Commission estimates freight traffic by road will increase from 807 billion ton kilometers in 1997 to between 1,276 and 1,700 ton-kilometers by 2002. The transport of most grains, fruits, and veges has shifted to trucks and other road vehicles. These shifts from rail to truck imply more trucks passing through the city, thus further increasing the level of the vehicular pollution.

4.11 CONCLUDING REMARKS

In this chapter the transportation system of the capital city of Delhi is discussed. It was necessary to know the present system only than its complications and problems can be understood. This information is then utilized in preparing the questionnaire for the Delphi Study and computation of the current vehicle exhaust emissions. Next chapter discusses the need and impact of switching the public transportation system of Delhi from Diesel fuel to CNG.

CHAPTER 5.

A CRITICAL ANALYSIS OF THE CNG AS A FUEL IN THE TRANSPORTATION SYSTEM OF DELHI

5.1 INTRODUCTION

In this chapter a meticulous analysis of efficacy of CNG as a transportation fuel in the capital city of Delhi has been made. The deteriorating ambient air quality due to ever increasing vehicular emissions is the major reason for rating the capital city of Delhi as world's fourth most polluted city. The Supreme Court of India, concerned over the deteriorating air quality of Delhi mainly from vehicular sources, in a landmark judgment on 28th July 1998, directed that all the public transport vehicles in Delhi to run only on CNG after 31st March, 2001. Since then, efforts have been made to take Delhi out of this "most polluted" label. This order was implemented on subsequent and strong interventions of the Supreme Court of India. This chapter discusses the administrative and practical difficulties in doing so and the benefits gained together with adverse effects of the introduction of CNG in the transportation system of Delhi in the last five years.

5.2 CNG AS AN ALTERNATIVE FUEL

Natural gas was first used as a fuel in China during the Shu Han dynasty in AD 221-263. The gas was obtained from shallow wells near seepages and was distributed locally through piping made of hollowed-out bamboos. Since then, there are no records on the usage of natural gas until the early 17th century in Northern Italy, where it was used as a fuel to provide lighting and heating. The usage was not popular then due to the fact that natural gas was more commonly used in domestic and industry heating as well as to generate electricity.

The usage of natural gas as a vehicle fuel was discovered back in the early 1920s in Italy. However, after the Second World War, there has been a growing interest on the usage of natural gas as vehicle fuel. This interest led to establishment of approximately 1200 refueling stations and 1500 sub-stations for natural gas in Italy by the early 1950s. As the time moved on, the usage of natural gas spread to North America, Canada, New Zealand

and the Europe. In the 20th century, the usage of natural gas expanded to most part of Western Europe and USA. It became a commercial item in the form of liquefied natural gas (Tiratsoo, 1979) for exports and imports. The conscious endeavour towards searching for alternatives to the polluting conventional fuels started a long time ago. But it was also important to establish the feasibility -both technical and commercial- of the alternatives. Given its characteristics and unmatched advantages, CNG was the obvious choice for an alternative automobile fuel. In 1991, Italy became the leading country in the research of natural gas vehicles. Italy had about 235,000 gasoline vehicles and 20 diesel vehicles that were converted to natural gas. The country with the second highest natural gas vehicles is Argentina, which has about 100,000 gasoline vehicles and 10 converted diesel vehicles (Shamsudin & Yusaf, 1995). Worldwide, more than 1.5 million vehicles, with more than 14 countries having 10,000 vehicles converted to CNG mode, run on natural gas. Exploration for the natural gas source got more intensive after the post-war years.

For automotive use, Natural gas is compressed in a high pressure seamless tank of 18-20 MPa to form compressed natural gas (CNG). Table 5.1 gives the comparative properties of diesel and CNG, which shows that the auto-ignition temperature, octane number and net energy content of CNG is considerably higher as compared to the diesel fuel.

Table 5.1: Comparison of Fuel Properties

PROPERTIES	NATURAL GAS	DIESEL
Boiling Point (K @1 atm)	147	433-655
Density (kg/m^3)	128	785-881
Auto Ignition Temperature (K)	900	477-533
Flash Point (K)	124	325
Octane / Cetane Number	130	46-51
Flammability Limits Range	5.0-15	0.7-5
Net Energy Content (MJ/Kg)	49.5	43.9
Combustion Energy (KJ/m^3)	24.6	36
Vapourization Energy (MJ/m^3)	215-276	192

5.3 THE WORLDWIDE SCENARIO OF CNG USE

A study released by the American Clean Skies Foundation (ACSF) and conducted by Navigant Consulting, Inc. (NCI) concludes that the United States has 2,247 trillion cubic feet (tcf) of natural gas proved reserves and unproved technically recoverable resources. Reserves at that level would supply natural gas for 118 years at current production levels. Table 5.2 gives the details of the nations using CNG.

Canada

Canada is a large producer of natural gas, so it follows that CNG is used in Canada as an economical motor fuel. Canadian industry has developed CNG-fueled truck and bus engines, CNG-fueled transit buses, and light trucks and taxis. Both CNG and propane refueling stations are not difficult to find in major centers.

South America

Argentina and Brazil are the two countries with the largest fleets of CNG vehicles. Conversion has been facilitated by a substantial price differential with liquid fuels, locally-produced conversion equipment and a growing CNG delivery infrastructure. A ‘Blue-network’ of CNG stations is being developed on the major highways of the Southern Cone (including Chile and Bolivia) to allow for long-haul transportation fuelled by CNG.

New Zealand

The New Zealand CNG program commenced in 1979, by 1985, over 100,000 vehicles were on CNG and the New Zealand program was leading the world. All these vehicles were converted from gasoline or diesel and over 10 % of the national fleet had access to natural gas. There were more than 450 refueling stations.

Europe

In Germany, CNG-generated vehicles are expected to increase to two million units of motor-transport by the year 2020. The cost for CNG fuel is about half to the cost of other fossil fuels in Europe**.**

Asia

In Asian countries India and Pakistan are using CNG vehicles. China is also using CNG as a alternative fuel but not as much as India and Pakistan. The National Capital Territory of India, Delhi is using world’s largest CNG bus fleet. In Asian Economies such as India, CNG costs are at rupees 18.90 per kg compared with rupees 50.56 per liter of petrol (prices as on 10th October 2008 in Delhi, they may vary slightly with time). The cost saving is immense along with reduced emissions and environment friendlier cars. CNG has been made mandatory for all public transport in the Indian capital city of Delhi. CNG has grown into one of the major fuel sources used in car engines in Iran, Pakistan, Bangladesh and India. Table 5.2 gives the details of the leading CNG adopting nations and their infrastructure.

Availability in India and Pakistan may further improve if the India-Pakistan-Iran pipeline is successfully commissioned. Bangladesh may also prove to be a substantial exporter of CNG to India. In Singapore CNG is being increasingly used by public transport vehicles like buses and taxis, as well as goods vehicles. However, according to 'Channel News' Asia on April 18, 2008, more owners of private cars in these countries are converting their petrol-driven vehicles to also run on CNG, are motivated by fiercely-escalating petrol prices.

Table 5.2: The Leading Nations Adopting CNG around the World

World Standing	Country	Vehicles	Fuelling Stations
1	Argentina	1.5 million	1,400
2	Brazil	1.1 Million	1,200
3	Pakistan	1.0 Million	1,000
4	Italy	0.4 Million	500
5	India	0.25 Million	200
6	USA	130,000	1,300
7	Iran	115,000	140
8	China	97,000	360
9	Ukraine	67,000	150
10	Egypt	63,000	100
11	Colombia	60,000	90
12	Bangladesh	55,000	120
13	Bolivia	45,000	60
14	Venezuela	44,000	150
15	Russia	42,000	210
16	Armenia	38,000	60
17	Germany	33,000	650
18	Japan	25,000	300
19	Canada	20,000	220

5. 4 STATUS OF ADOPTATION OF CNG AS A FUEL IN DELHI

The vehicle population in the capital city of Delhi is growing at an exponential rate and is fast approaching the 4.6 million mark (Sengupta B., 2003). Delhi faces the same transportation, economic and environmental challenges as other megacities. Population, motor vehicles, pollution, and traffic congestion are all increasing. In the past 35 years, its population more than tripled and vehicles increased almost fifteen fold. Most of these vehicles are small, inexpensive motorcycles and scooters, rather than automobiles. This proliferation of vehicles in a relatively poor nation is indicative of the strong desire for personal transport–a phenomenon commonly observed.

The Supreme Court's involvement in policies to curb air pollution in Delhi began with public interest litigation brought to the court by M. C. Mehta in the form of a petition no. 13029 filed on December 17, 1985. Concerned about rising levels of air pollution and the government's apparent lack of interest in dealing with this growing problem, Mehta asked the court to direct various government ministries and departments to implement the Air Act of 1981 in Delhi. After Mehta's petition to the court, several new environmental laws were enacted, as were policies to curtail tailpipe emissions from vehicles and to move polluting industries from Delhi. However, these policies were rarely implemented, and even those that were, can be characterized as largely piecemeal. There was no evidence of a comprehensive plan to tackle the growing problem of air pollution. There were a plethora of environmental plans and policies to reduce Delhi's air pollution; each of them announced by the government and then abandoned or ignored. Starting from the early 1990s, however, the court began to push the government to make good on its promises.

5.5 BOTTLENECKS IN THE ADAPTATION OF CNG

The switchover to CNG from traditional fuels for transportation needs in Delhi was a tedious and long drawn affair. It took considerable initiative from the Supreme Court of India, apart from Public Interest Litigations (PIL) and hard work of various agencies to implement CNG as a viable alternative automobile fuel in Delhi. Between 1986 and 1990, isolated trials were reported to have been attempted by the ONGC with one or two vehicles. However more details about the same are unavailable. Detailed study on use of CNG began when a CNG pilot project was commissioned by Gas Authority of India Limited (GAIL) in the year 1992-93 in Delhi, Mumbai and Baroda with the objective of identifying and resolving technical, institutional, regulatory and economic issues that would have an impact on using CNG as an alternative fuel. During the pilot phase six buses of DTC were converted to CNG/Diesel dual fuel mode on an experimental basis. The trial results indicated limited replacement of diesel by CNG (approx. 34 %), primarily due to frequent start/stop nature of traffic, extra fuel consumption and maintenance problems. The trial was discontinued by DTC after logging about 650,000 kms out of which over 300,000 kms was in dual-fuel mode. In 1999, the Indraprastha Gas limited (IGL) acquired the ongoing city gas distribution project from GAIL, including nine CNG Stations and the City Gas distribution network in many areas in Delhi. IGL appointed GCI-Kenney, an Australian consulting firm to carry out detailed feasibility studies to establish technical, commercial and financial viability of the project.

The report was received in April 1999, which established that the City Gas distribution project was feasible in all respects in Delhi and NCR and the market survey established the consumer's willingness to use Natural Gas as an alternative to existing fuels.IGL started implementing the Supreme Court of India's directives for increasing the number of CNG stations from nine to eighty, including 54 new IGL owned stations. By 2000, the number of vehicles converted to CNG crossed the 5000 mark including 20 DTC buses and seven auto rickshaws. With the number of CNG filling facilities increasing and the consequent increased availability of CNG in Delhi, the number of vehicle conversions also grew.

CNG adaption in Delhi was fraught with numerous challenges and hurdles. Various issues such as multiplicity of agencies involved, reluctance of public transport operators, misconceptions about CNG and inadequacy of Natural Gas supply, were hurdles in the path of CNG adaption. The city government sought a ban on conversion of private vehicles to CNG. It requested the court that Euro II complaint diesel buses should be allowed. Anti-CNG lobby proclaimed that CNG will not work (Nraian and Krupnick, February 2007). The following hurdles were faced in adopting the CNG transportation system.

- Limited natural gas allocation leading to delay in management decisions on expenditure commitment.
- Uncertainty about conversion of vehicles & therefore the demand for CNG.
- Lack of indigenous technology.

- Capital intensive project (a mother station cost would be 5-6 times the cost of a petrol pump).
- Pipelines need to be placed.
- Infrastructural constraints (electricity, land etc.)
- Delay in getting permissions from statutory authorities.
- Objection from local people, encroachment.
- Low storage capacity of on board cylinders, thus requiring frequent refills.

When it was brought to EPCA's notice that the government agencies have been unable to formulate and finalise quality standards for the CNG currently being used in the automobile programme in the capital and other cities. EPCA then set up a multi-stakeholder committee, which included representatives of the gas companies, vehicle manufacturers, gas distribution companies and senior scientists. This committee in 2007, proposed the automotive CNG fuel specifications as given in Table 5.3

Table 5.3: Proposed automotive CNG fuel specifications

Constituents	Value	Tolerance
Wobbe number (Btu/ft3)	1340	Variation shall be limited to ± 30 units during normal operation
Free water, mg/m3	8	Maximum
Total sulphur, mg/m^3	20	Maximum (including H_2S)
N2 + CO2, vol %	3.5	Maximum*
Oil mist content, ppm		Insignificant
Oxygen, vol. %	0.5	Maximum
Methane (C1)	87%	Minimum**
Ethane (C2)	6%	Maximum
C3 and higher HC	3%	Maximum
C6 and higher HC	1%	Maximum
Total unsaturated HC	1%	Maximum
Hydrogen (mole %)	0.1	Maximum
Carbon monoxide (mole %)	0.1	Maximum

Note: *occasionally may go up to 7 per cent when shutdown of a processing/handling plants/facilities happen however such events are to be duly notified and should be limited to 10% of time in a year

** In case of process upset/plant s/d may reach a level of 84 however such events are to be duly notified and should be limited to 10% of time in a year.

Source: EPCA Report No. 29 (January 2007).

5.6 IMPACT OF ADOPTATION OF CNG ON THE AIR POLLUTION OF DELHI

After CNG adaption, pollution levels in general have decreased in Delhi. The fight against air pollution in the capital, which began in right earnest in 1997, finally started yielding results. Statistics have shown that adoptation of CNG has not only checked the the rising trend in pollution level been checked, but the levels of various pollutants in the ambient air are also coming down. The results of data analysis of pollution levels in Delhi, before and after adaption of CNG as an automotive fuel, point to the success of a number of policies implemented in Delhi but also to a number of areas of growing concern.

The policies that led to the switchover to CNG from conventional fuels has helped to reduce SO_2, CO and PM_{10} concentrations but, contrary to popular belief, have not contributed much to increase the NOx levels in Delhi. But it is unfortunate that the gains accrued from switchover to CNG from diesel for buses are being lost by increased pollution from three-wheelers. The recent trend in Delhi towards an increase in the proportion of Diesel-fuelled cars also is having a somewhat mixed impact on air quality. If the number of all vehicle types continues to increase then the gains from CNG, adaption would be negated and lost. As it is not reasonable to limit the mobility of people, it is important for the government to augment the public transport infrastructure and advocate and promote the usage of public transportation means, such as buses, Delhi Metro etc.

But in the wake of use of CNG as an alternate fuel, the contribution of vehicular sector towards air pollution has been reduced in the subsequent years. This is also supported by the fact that there is a significant improvement in the air quality. The best place to witness this change is the busy ITO traffic intersection, where toxic fumes no longer irritate the eyes as was the case earlier.PM_{10} and Sulphur Dioxide levels have shown a significant declining trend, as it is evident from the Figures 5.1 to 5.4, one can see that SPM has shown a slight decrease, whereas the Nitrogen Dioxide levels earlier there was slight increase which now shows a declining trend. This may be due to the differences in the emissions of Nitrogen Dioxide levels from retrofitted and dedicated CNG vehicles.

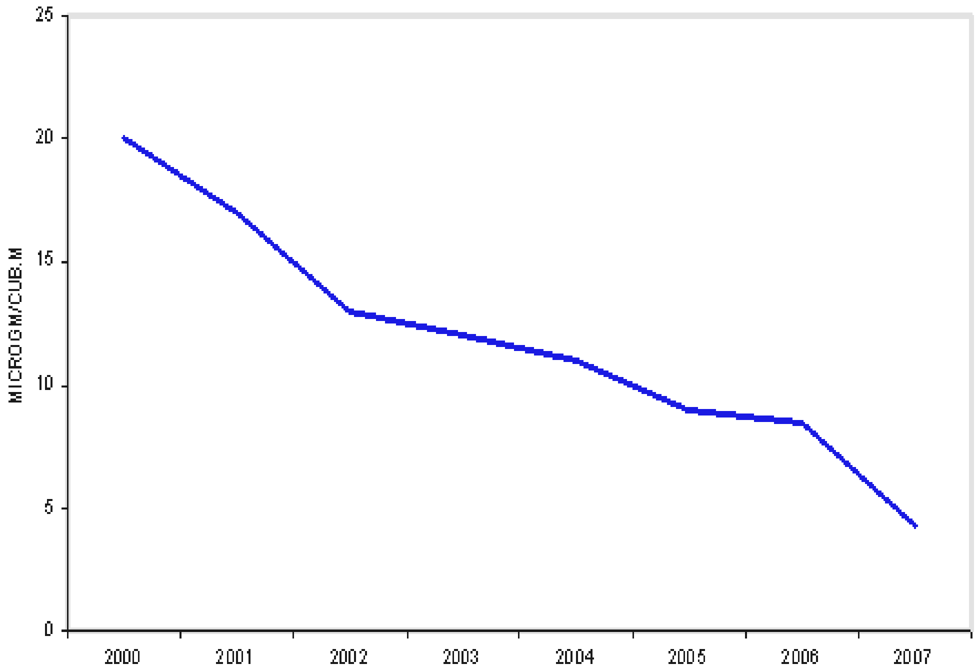


Figure 5.1: Emission Trend for SO_2 [Source: www.cpcb.nic.in]

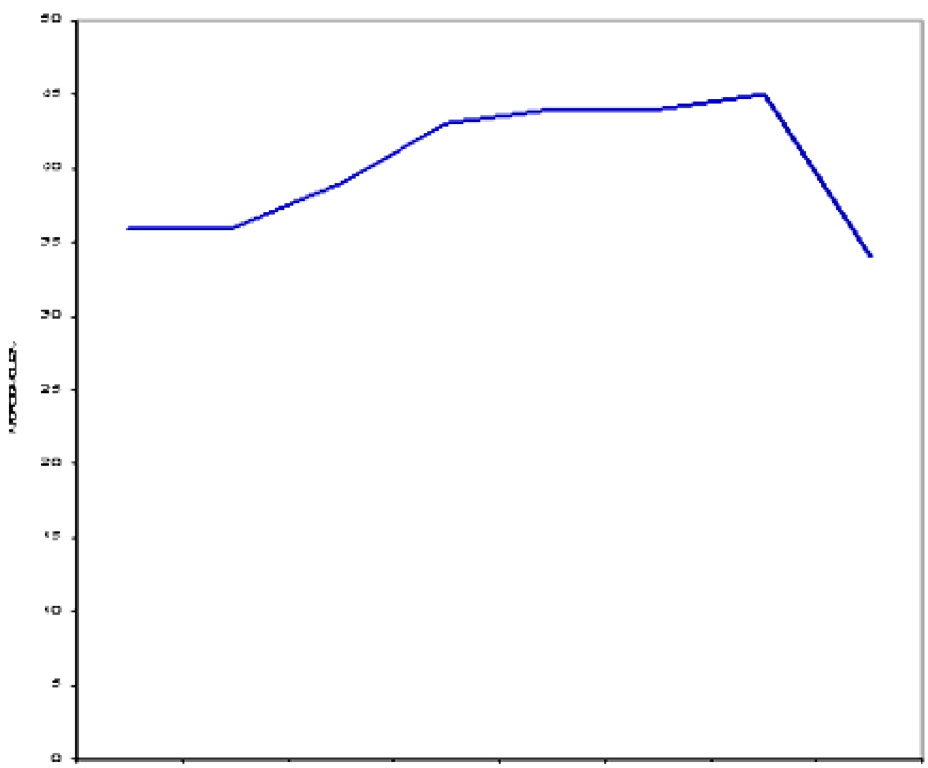


Figure 5.2: Emission Trend for NO_X [Source: www.cpcb.nic.in]

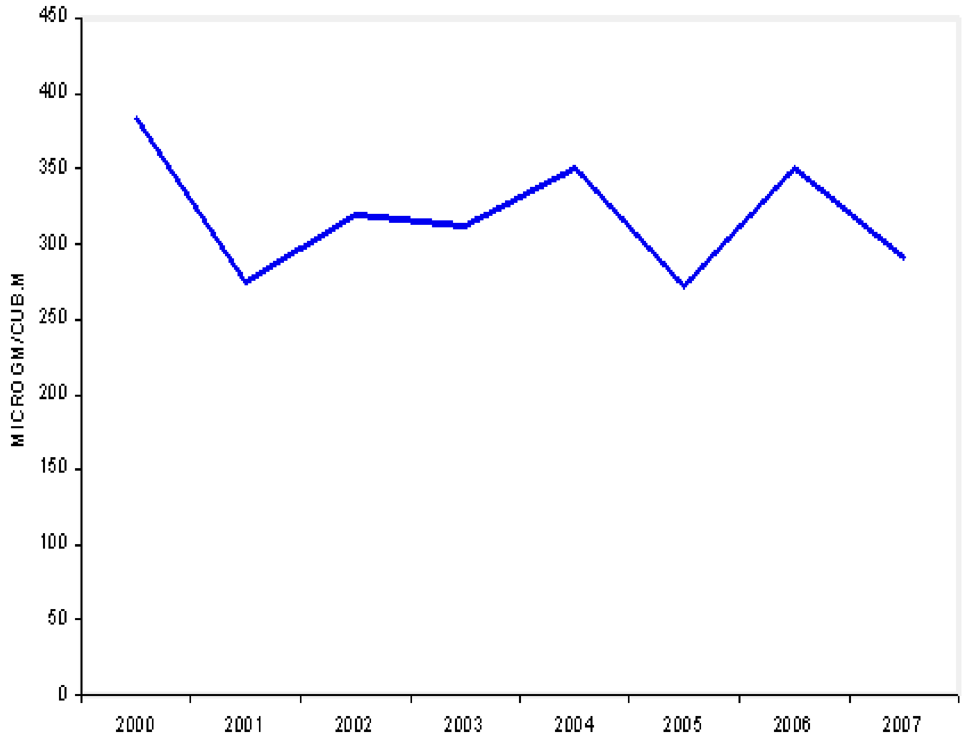


Figure 5.3: Emission Trend for SPM [Source: www.cpcb.nic.in]

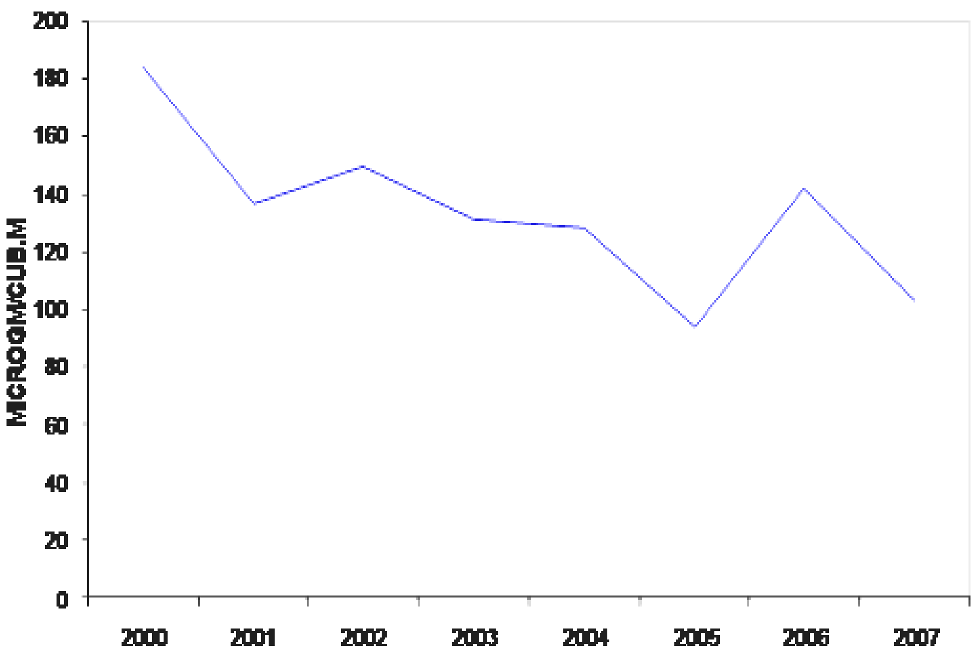


Figure 5.4: Emission Trend for PM_{10} [Source: www.cpcb.nic.in]

5.7 ADVERSE EFFECTS OF CNG USAGE

Two-stroke two-wheelers, followed by cars, were responsible for CH_4 emission but after conversion of diesel buses into CNG. The buses are the major contributor to the methane emissions. It has been observed that CNG vehicles might be emitting high NOx on account of poor maintenance. Some studies also suggested that while bringing the PM level down, CNG is producing a higher number of below 10 micron, 5 micron and 2.5 micron pollutants which may prove harmful to human health in long term and takes more time to settle in the atmosphere.

The current vehicle inspection programme is too weak to monitor this. Under the current Pollution Under Control (PUC) tests, only CO is monitored. In future it is being suggested to enforce the HC and NOx limits on PUC Certification. There are no international loaded test procedures available for CNG three wheelers, as all Delhi three wheelers have been converted to CNG. However the Automotive Research Association of India (ARAI) has taken lead to develop simple loaded test for two-wheelers and a variant of this can be developed for three-wheelers as well. But these tests will have to be developed and enforced fast before it is too late.

In August 5, 2001 a CNG bus caught fire and 5 people are injured due to the leakage from the CNG cylinder, (Times of India, August 6, 2001) and many such incidents are occurring regularly till date, due to ineffective control of the transport department. Though Government of Delhi has established a specific CNG vehicle testing and certification centre at Burari in Delhi, the same is not sufficient for the total fleet of buses and a strict vigilance system is necessary to ensure proper fitness of all the CNG vehicles, it would be better if such certificate are to be displayed mandatorily on the front screen of these vehicles. Thus in Delhi more such facilities need to be developed and regular checkups must be planned to enhance the safety and reliability of the CNG transport system. There were number of problems faced by the commuters during the process of conversion of public transport vehicles to CNG, including the lack of availability of the buses on the road and long queues for refilling and unavailability of CNG on filling stations, which lead to complete chaos on city roads and consumed many precarious human lives.

5.8 CONCLUDING REMARKS

The CNG adaption process in Delhi has been a success. Delhi today has one of the world's largest public transport fleet of buses running on CNG. Although CNG adaption has helped a lot to reduce pollutant concentrations in Delhi, but the gains have been negated by- poor technology, increase in number of diesel cars and an overall increase in the number of all types of vehicles. Therefore, while implementing any such necessary changeovers; proper plan must be prepared, for the minimization of the chaos on roads and availability of alternative means of transport to the commuters of Delhi.

In view of the above findings, it is recommended that:

a) The Governments and the regulating agencies need to aggressively advocate and promote the use of public transportation system.
b) To promote the public transportation system, there is an urgent need to increase the infrastructure for public transport
c) The emission norms for diesel cars need to be made more stringent and separate emission standards for the CNG vehicles must be enforced.
d) Any city or authority thinking of adopting CNG as an automotive fuel, must learn from the experiences of the agencies involved in CNG adaption in Delhi
e) Moreover as safety is the most important parameter while handling CNG, therefore adequate infrastructure must be developed for inspection of CNG vehicles, especially for the public transport vehicles.

Next chapter presents the details of the experimental work carried out on the compression ignition engines with alternative fuels for finding their suitability in use of CNG and their impact on performance and emissions.

CHAPTER 6.

EXPERIMENTAL INVESTIGATIONS OF EMISSIONS DUE TO COMPRESSION IGNITION ENGINES

6.1 THE OBJECTIVE

Due to its higher thermal efficiency and diesel being sold cheaper as compared to Gasoline in India, has made Compression Ignition (CI) engines, popular amongst the commercial vehicles and the personal vehicles used by the people traveling for larger distances. But Diesel engines are the major contributor to the hazardous PM levels due to their high smoke opacity. A number of alternative and renewable fuels are being tested to bring down the smoke opacity of the diesel engines. In this work we tried to validate those results through our experimental work and to find out the reliability of alternative fuels in combating the vehicular emissions from C. I. engines.

6.2 ALTERNATIVE FUELS USED IN THE STUDY

In this experimental work bio-diesel diesel blends and ethanol-diesel blends and CNG are used as alternate fuels for the performance and emissions study.

6.2.1 Biodiesel

ASTM International defines biodiesel as "*the Mono alkyl esters of long chain fatty acids derived from renewable lipid feed stocks, such as vegetable oils and animal fats, for use in compression ignition engines*." Biodiesel research is behind the ethanol, but it has the enormous potential to combat the twin problem of scarcity of fossil fuels and environmental degradation. Detailed information on biodiesel properties, production and demand is given in the appendix IV for the benefit of readers of this report.

6.2.2 Ethanol Blends

Alternative fuels such as ethanol contribute to at least two policy goals. Improving environmental quality and enhancing farm income. Using ethanol-blended fuels mainly reduces carbon monoxide emissions in motor vehicles. Ethanol also creates markets for farm commodities, particularly corn. There has been strong demand for ethanol as an oxygenate blend for gasoline also. Eethanol has been proven worldwide an effective alternative to combat the twin problem of scarcity of fossil fuels and environmental degradation. Detailed information on ethanol is given in the appendix IV for the benefit of the readers of this report.

6.2.3 The CNG

Discussion on CNG has already given in chapter 5, where we had discussed the details of CNG conversion of the transportation system of Delhi, here we will discuss some other salient details of CNG. Natural gas consists mostly of methane and is drawn from gas wells or in conjunction with crude oil production. Compressed natural gas (CNG) vehicles store natural gas in high-pressure fuel cylinders at 3,000 to 3,600 pounds per square inch.

Since CNG is colorless, odorless and tasteless, an odorant is normally added to it for safety reasons. Liquefied natural gas (LNG) vehicles store natural gas as a cryogenic liquid. CNG as an alternative automotive fuel is gaining wide acceptance all over the world and especially in India where in Delhi it has helped in significantly reducing the pollution levels.

CNG Properties

Physically, CNG is colorless, tasteless, relatively non-toxic and not a volatile organic compound (VOC). It exists in our environment at normal temperature and pressure, which gave it its name. To use natural gas as fuel in vehicles, it has to be compressed at a high pressure of about 18-20MPa at normal temperature in vessels before it can be supplied to the engine’s combustion chamber. Generally, natural gas is lighter than air with a vapour density of 0.68 relative to air. Therefore, if leaking happens, it will not cause explosion but instead it will disperse to the atmosphere. Natural gas has a high auto-ignition temperature compared to gasoline or diesel, which is the lowest temperature for it to ignite through heat alone and without any spark or flame. Higher ignition temperature means that natural gas is more difficult to ignite. This can significantly reduce the fire hazard, and constitute anti-knocking ability especially when it is compressed in a very high pressure in the combustion chamber. This property is certainly useful for the design of a dual-fuel engine. The ignition temperature for natural gas is about 900 K.

Other physical properties such as the flammability limits range, octane rating, and flash point also play an important role in the analysis of compression ratio and combustion efficiency of the engine. The flammability limit range is the concentration of natural gas in air to cause an explosion. This is between the lower explosive limit (LEL) of 5% to the upper explosive limit (UEL) of 15%. If the concentration of natural gas is more or less than this range, an explosion would not occur. This will certainly reduce the risk of explosion of CNG in air due to leaking because CNG can only burn in air when its concentration is high This is having an octane number of 96, much higher than gasoline. This property is important as it determines the time needed for the natural gas and air to mix homogeneously in the combustion chamber to minimize knocking or detonation.

6.3 THE DIESEL CNG DUAL FUEL EXPERIMENT ON A CI ENGINE

In this work a Tata Indica engine were operated on diesel and CNG-Diesel dual fuel mode to evaluate various performance and emissions data. Use of CNG in S. I. engines is discussed in chapter 7.

6.3.1 Dual-Fuel Engine Technology

The dual fuel engine is a diesel engine that operates on gaseous fuels while maintaining some liquid fuel injection to provide a deliberate source for ignition. Such a system attempts usually to minimize the use of the diesel fuel by its replacement with various gaseous fuels and their mixtures while maintaining satisfactory engine performance. There are some problems associated with the conversion of a conventional diesel engine to dual fuel operation. At light load, the dual fuel engine tends to exhibit inferior fuel utilization and power production efficiencies with higher unburned gaseous fuel and carbon monoxide emissions, relative to the corresponding diesel performance. Operation at light load is also associated with a greater degree of cyclic variations in performance parameters, such as peak cylinder pressure, torque, and ignition delay, which have narrowed the effective working range for dual fuel applications in the past. A measured quantity of natural gas is mixed with the air just before it enters the cylinder and compressed to the same levels as the diesel engine to maintain efficiency. The natural gas mixture does not ignite spontaneously under compression, so the Dual-Fuel engine uses a small injection of diesel fuel, around 10% of the total energy of the fuel, to ignite the main charge of gas and air. This small "pilot" injection acts like a multitude of microscopic spark-plugs, setting off clean and efficient combustion of the lean gas-air mixture.

6.3.2 Dual-Fuel Engine Technology Facts:

The dual fuel engine has the following advantages over pure diesel and dedicated CNG engine.

1. Keep your diesel engine, modify it and run with CNG also.
2. Fuel flexibility, if gas is interrupted full diesel operation is available instantly while generating power.
3. Full original power capacity.
4. Diesel cam timing keeps exhaust cooler and provides better scavenging contributes to higher power density and longer valve life.
5. Higher compression ratio, better efficiency, nearly all dual fuel engines have better efficiency than spark gas.
6. Lean burn combustion capacity contributes to reduced misfire leads to better efficiency, higher power density, reduction in NO_X emission. Diesel pilot fuel with clean gas provides lubrication to valves and rings.
7. Exhaust emissions, specifically Nitrogen oxides, CO_2 and particulates are significantly reduced if a problem exists with the gas system full diesel backup is instantly provided.
8. No changes should be made to your standard engine warranty (affected by the attitude of local dealer). It should be noted that certain aspects of a lean burn spark gas and dual fuel are similar.

6.3.3 The Diesel CNG Dual Fuel Operation: Basic Test Set-up

The setup consists of a Diesel engine as per specifications given in Table 6.1, connected to eddy current type dynamometer for loading. It is equipped with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for p-θ and p-v diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The basic engine test setup is shown in Figure 6.1 and 6.2, while the schematic diagram 6.3 shows the schematic engine test setup.

Table 6.1: Technical Details of the engine setup

S.No.	Component	Specifications
1.	**Make**	Telco, Model Tata Indica,
2.	**Type**	4 Cylinder, 4 Stroke, Diesel water cooled,
3.	**Rated Power**	39 kW at 5000 rpm,
4.	**Torque**	85 Nm at 2500 rpm,
5.	**Cylinder volume**	1405 cc
6.	**Compression ratio**	22:1
7.	**Dynamometer**	Saj eddy current, water cooled, with loading unit

6.3.4 Methodology of Experimentation

Dual-fuel engine refers to diesel engine operating on a mixture of natural gas and diesel fuel. Natural gas has a low cetane rating and is therefore not suited to compression ignition, but if a pilot injection of diesel occurs within the gas/air mixture, normal ignition can be initiated. Between 50 and 75% of usual diesel consumption can be replaced by gas when operating in this mode (Papagiannakis and Hountalas, 2003). The engine can again revert to 100% diesel operation. The setup enables study of engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Windows based Engine performance analysis software package “Enginesoft” is used for on line performance evaluation. Emissions are measured with the help of AVL smoke meter and multi gas analyser. To use the diesel-CNG in dual mode we have introduced CNG from a cylinder of 60 liters water capacity as shown in Figure 6.4 in which CNG is stored at a high pressure about 200 bar. A pressure regulator for CNG kit is shown in Figure 6.5 which is used to reduce the pressure of CNG from 200 bar to about the atmospheric pressure. A CNG flow meter (rotameter) is used to check the flow of CNG. Compressed Natural Gas is supplied to the C. I. engine with the help of a CNG-air mixer, shown in Figure 6.6 through the suction pipe. This mixture of air and CNG is compressed in compression stroke.

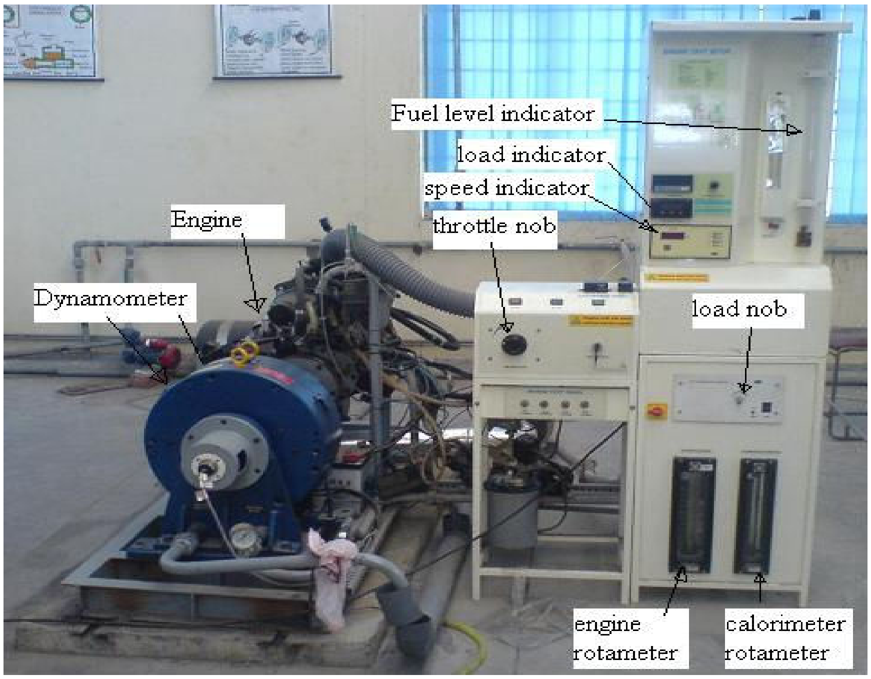


Figure 6.1: Experimental Set-up Component Details

Figure 6.2: Experimental Setup-Details of Tata, Indica Engine Used in the Study

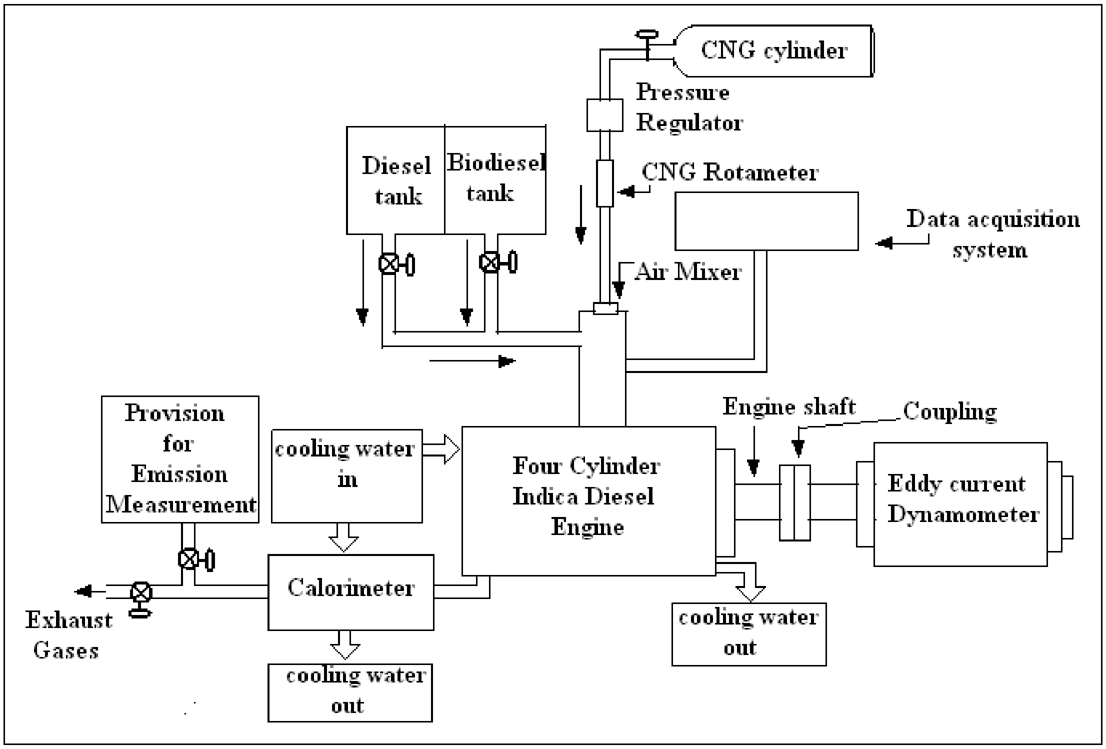


Figure 6.3: Schematic Diagram of Experimental Set-up

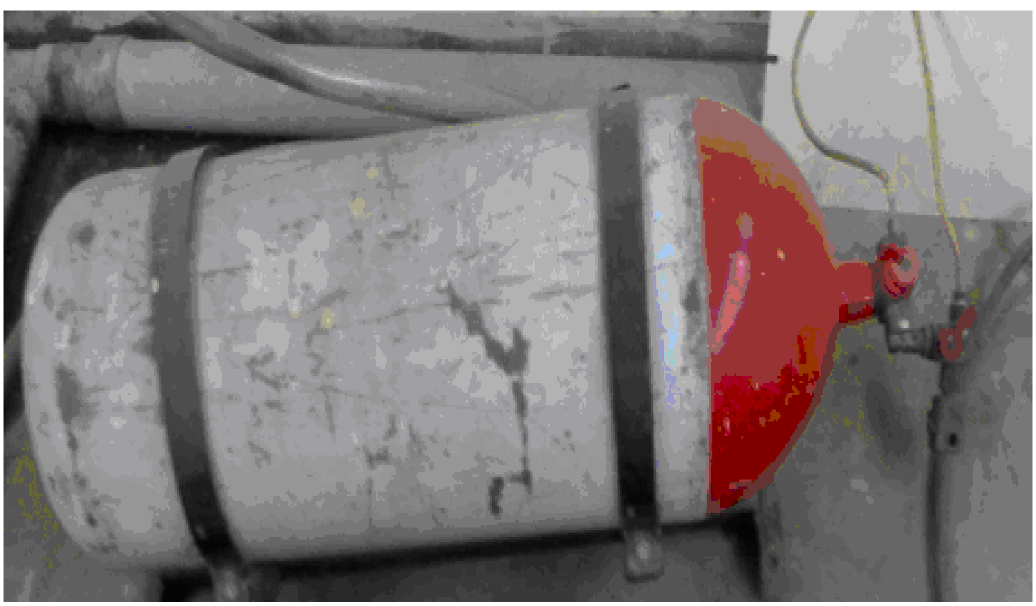


Figure 6.4: CNG Cylinders Kit

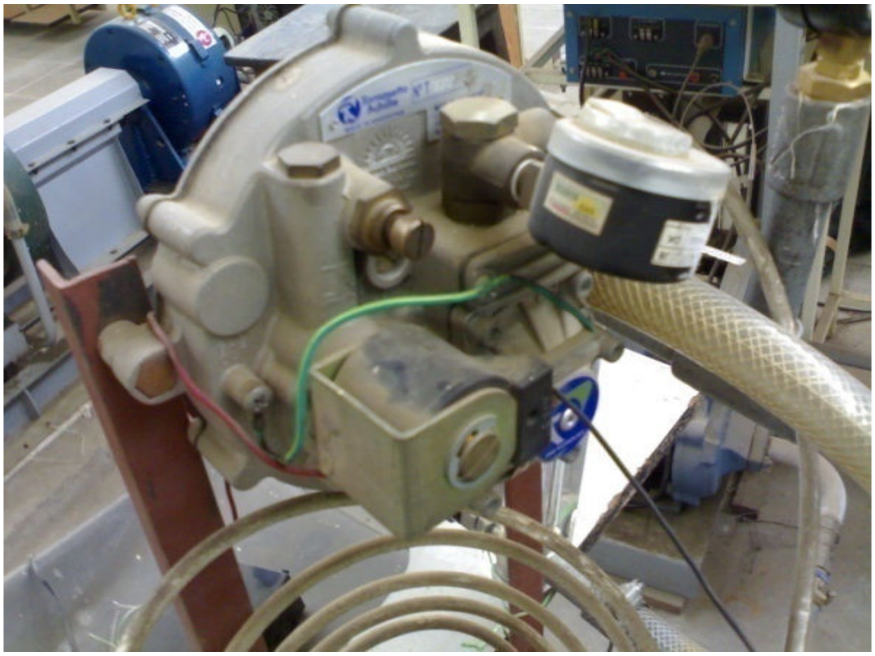


Figure 6.5: CNG Kit Pressure regulator

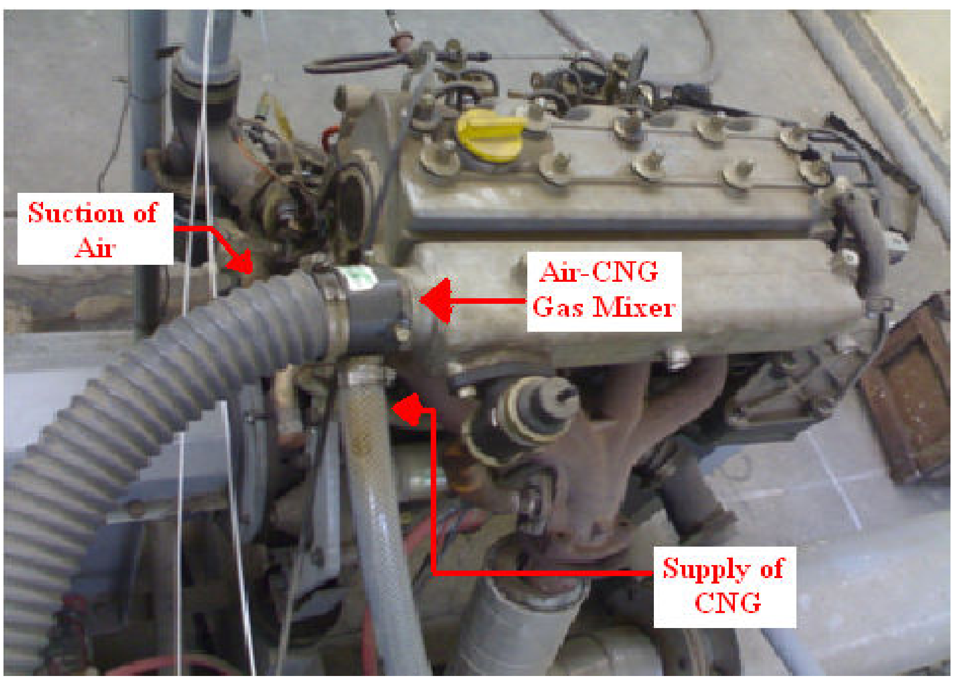


Figure 6.6 Attachment of Air-CNG Mixer on Diesel Engine

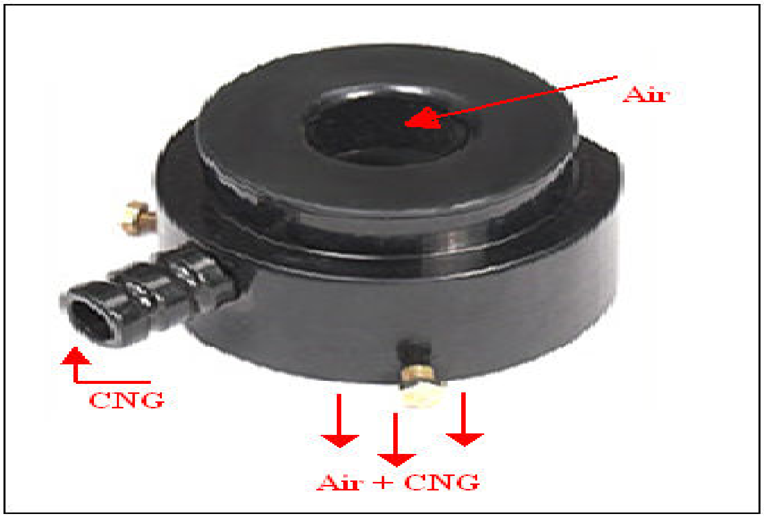


Figure 6.7: CNG air Mixer

6.3.5 DISCUSSION ON PERFORMANCE AND EMISSIONS PARAMETERS

The engine performance and emissions parameters were recorded for the diesel, biodiesel and diesel-CNG. Their graphical summary and a brief discussion on these is presented in the following sections:

6.3.5. 1 Discussion on Pressure Angle (p-θ) Curves

The p-θ curves represent the cylinder pressure at the instant crank angle. It is useful in determining peak cylinder pressure, rate of pressure rise, ignition delay and also to determine IMEP. These p-θ curves can be observed directly from "ENGINESOFT" software. Figure 6.8(a) shows the p-θ curve for pure diesel, biodiesel and diesel-CNG dual fuel mode at 1000 rpm. The p-θ curves are almost similar with slight change in peak pressure. The Figure shows that the pressure is almost same for the diesel and diesel-CNG dual fuel. Similarly for the blends of biodiesel pressure is same. The highest maximum pressure is obtained in case of pure diesel is 54 bar. The maximum pressure in diesel-CNG dual mode is not to much less than diesel initially it is just equal to diesel case.

Figure 6.8 (b) shows the p-θ curve for pure diesel, biodiesel and diesel-CNG dual fuel mode at 2000 rpm. The pattern is same for all the fuels in case of pure diesel and diesel CNG dual mode pressure it is higher than others blends of biodiesel. The maximum pressure at 2000 rpm is obtained in case of pure diesel. The maximum pressure is obtained in dual mode is slightly higher than diesel. For the blends of B10 diesel the pressure is lower than 50 bar and it is lowest in case of B30. Figure 6.8 (c) shows the p-θ curve for pure diesel, biodiesel and diesel-CNG dual fuel mode at 3000 rpm. The pressure change at this speed was not too much less. There was only a nominal change in pressure level. The maximum pressure was obtained in case of pure diesel was highest. The maximum pressure obtained in case of diesel-CNG dual fuel is less than diesel at 3000 rpm. The lowest maximum pressure was recorded in case of B20.

Figure 6.8 (d) shows the p-θ curve for pure diesel, biodiesel and diesel-CNG dual fuel mode at 4000 rpm. In this case the highest maximum pressure (64 bar) is obtained in biodiesel blend of 10% (B10). After B10 the maximum pressure is obtained with B20. The maximum pressure in pure diesel was lower than the blends of biodiesel. The lowest maximum pressure (54 bar) was recorded is diesel-CNG dual fuel. Figure 6.8 (e) shows the p-θ curve for pure diesel, biodiesel and diesel-CNG dual fuel mode at 5000 rpm. At higher speed the temperature and pressure of cylinder increases so the pattern of maximum cylinder pressure was different at 5000 rpm. The highest maximum cylinder pressure is obtained in case of biodiesel blend B30. The maximum pressure of cylinder for pure diesel was lower than different blends of biodiesel. The lowest maximum pressure was again obtained in case of diesel-CNG dual fuel mode. The conclusion from the above p-θ curves at different engine speeds varying from 1000-5000 rpm is that the maximum cylinder pressure in diesel-CNG operation always remains lower than the pure diesel, however the high pressure remains for a longer duration than diesel mode. But the maximum pressure in case of different biodiesel blends varies with speed. At the initial level the pressure in Diesel-CNG was not to much less than the pure diesel. As soon as speed increases the maximum pressure varies with speed and percentage of CNG supplied.

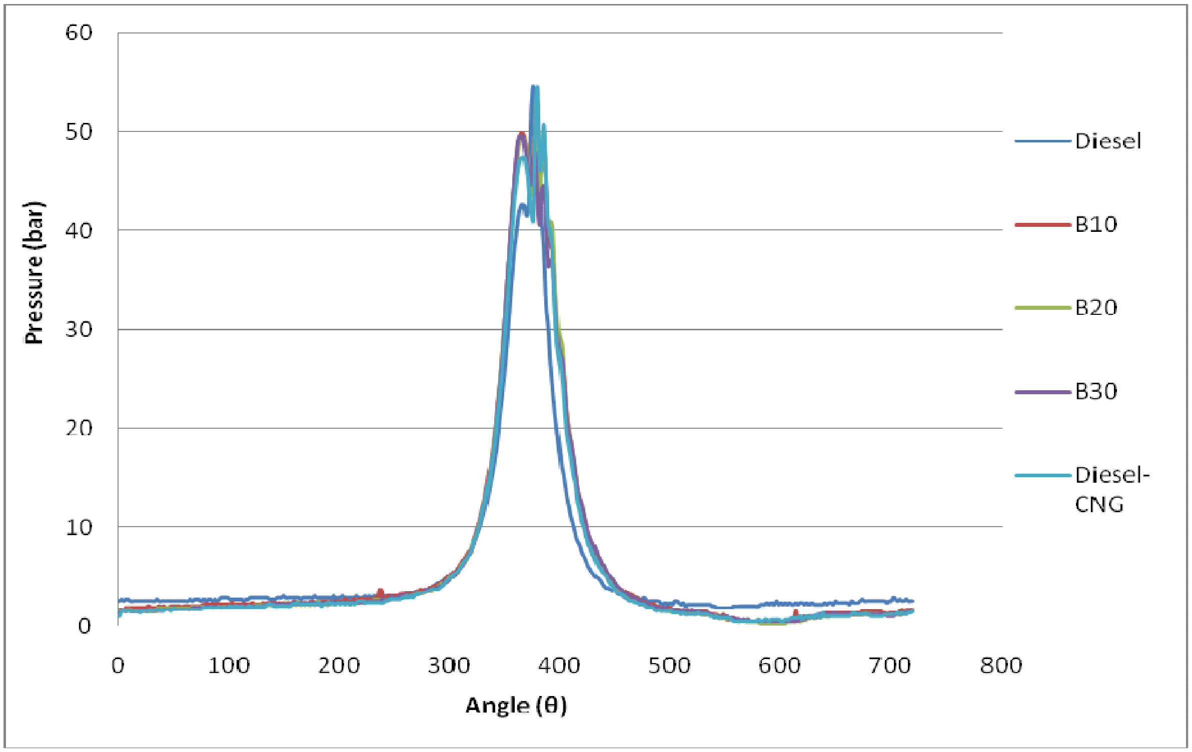


Figure 6.8 (a): p-θ Curves at 1000 rpm

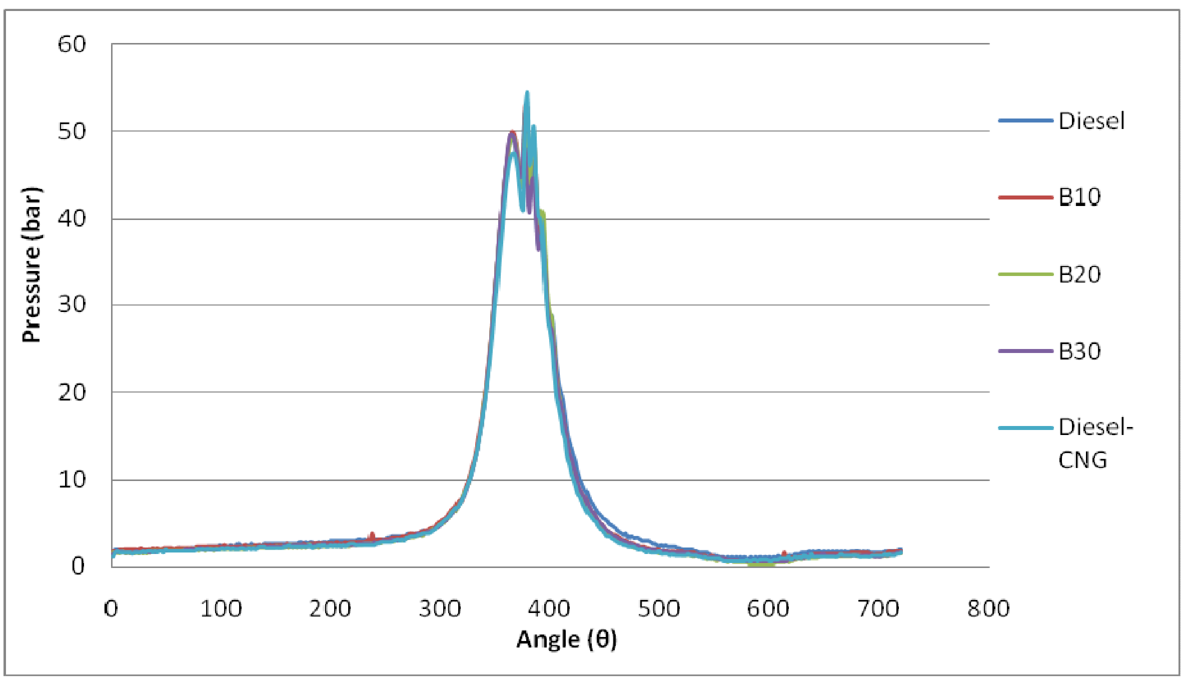


Figure 6.8 (b): p-θ Curves at 2000 rpm

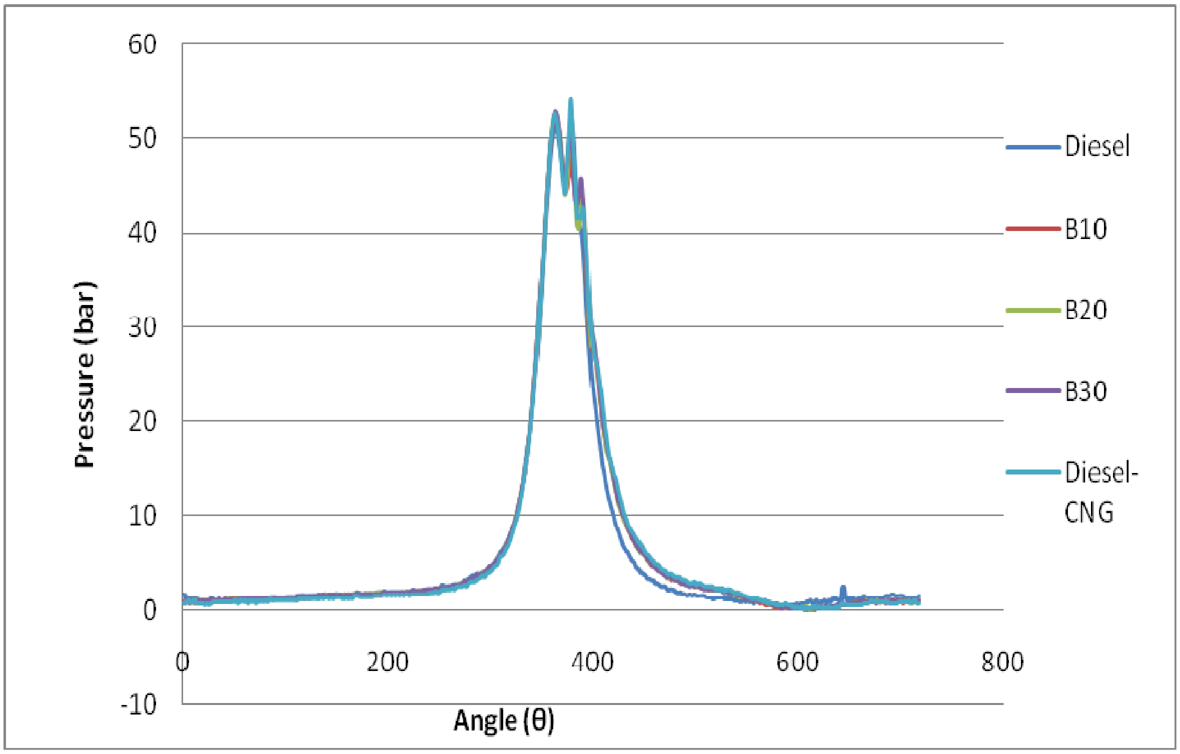


Figure 6.8 (c): p-θ Curves at 3000 rpm

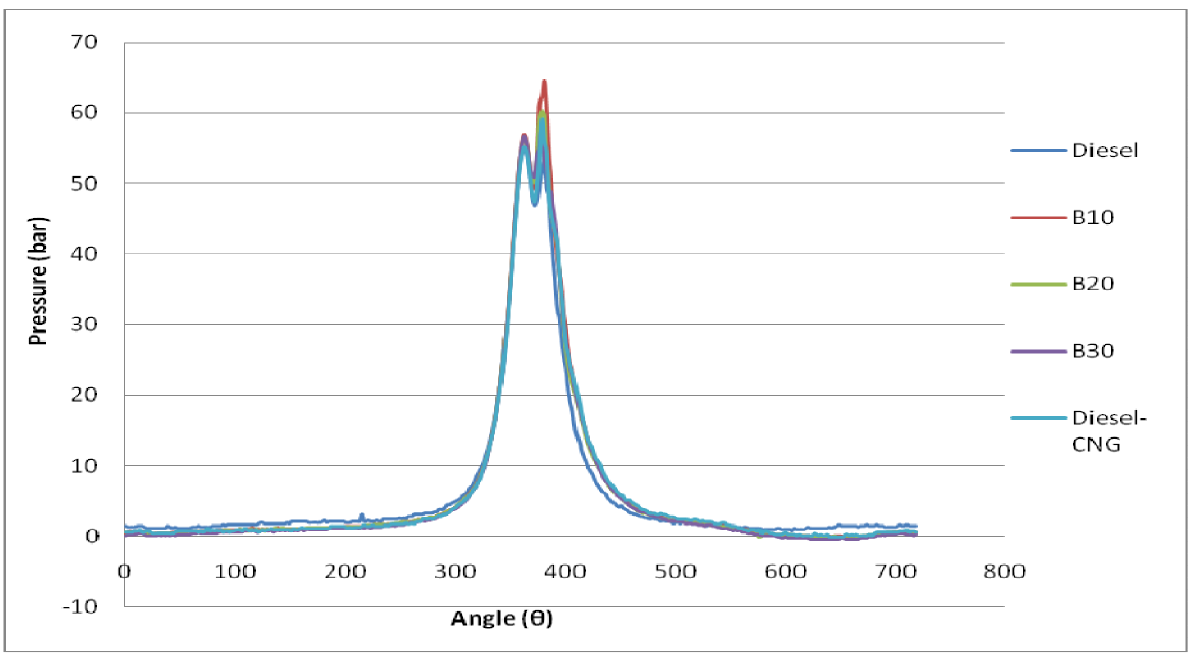


Figure 6.8 (d): p-θ Curves at 4000 rpm

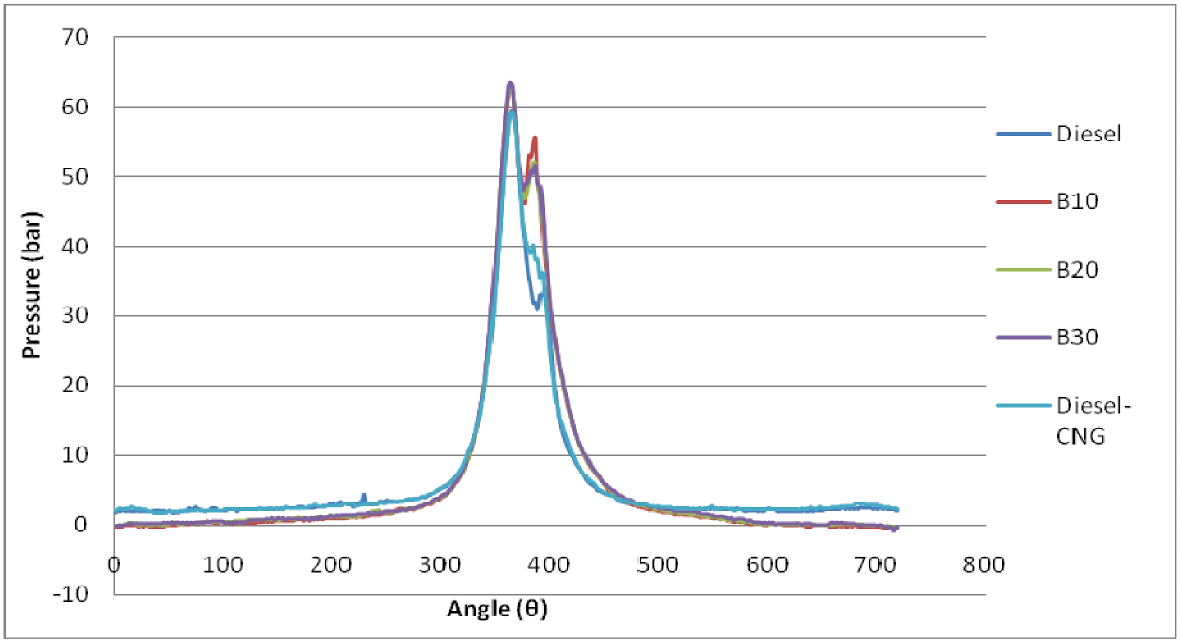


Figure 6.8(e): p-θ Curves at 5000 rpm

6.3.5 2 Discussion on Performance Parameters

The performance parameters are used to judge that how efficiently the engine uses input energy or how efficiently it provides the useful energy. The performance parameters of this test are discussed below:

Figure 6.9(a) shows the **variation of torque** with speed for pure diesel, different blends of biodiesel and diesel-CNG dual fuel mode. In all cases initially the torque rises sharply with increase in engine speed upto 3000 rpm. The variation of torque between 3000-4000 rpm remains almost constant. Further increase in speed causes slight decrease in torque. The pattern of curves is same for all blends. The maximum torque is obtained in case of diesel-CNG dual fuel mode is 7.8 kg-m at 3400 rpm. At the initial speed diesel-CNG dual fuel has more torque. Maximum change in torque is obtained in case of diesel-CNG dual fuel at 1000 rpm which is about 35% more than the pure diesel. Minimum change in torque is obtained in case of B20 at 4000 rpm.

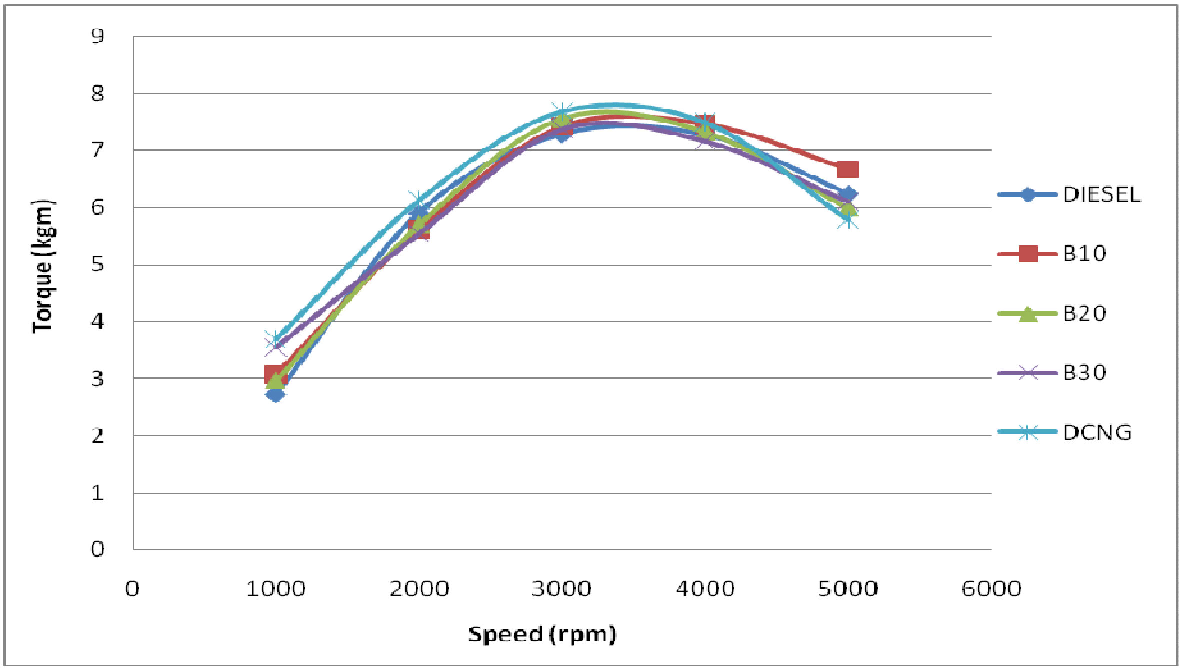


Figure 6.9 (a): Comparison of Torque Vs Speed for Different Fuels

Figure 6.9 (b) shows the **brake power** for pure diesel, blends of biodiesel and for diesel-CNG dual fuel. The variation of brake power for different fuels is almost similar. Initially for all fuels the increases sharply up to 4000 rpm except pure diesel. In pure diesel it increases sharply upto 3000 rpm than increases slowly. After 4000 rpm the brake power increases slowly. Between 4000 rpm to 5000 rpm brake power remains almost constant. In starting at 1000 rpm B30 has the maximum power. Between 2000 rpm to 4000 rpm brake power is maximum for pure diesel. At higher speed 5000 rpm B10 has the maximum power. The brake power in case of diesel-CNG always remains lower than pure diesel. In starting it is same as in other fuels but at 2000 rpm it increases slightly. At higher load as soon as speed increases the brake power remains lower than other fuels. Here pure diesel is taken at base line. At initial speed 1000 rpm B30 has the maximum brake power. At higher speed 4000 rpm and 5000 rpm the percentage change in brake power is lower than in initial speeds. The minimum percentage change in brake power is at 4000 rpm which is just equal to brake power in case of pure diesel.

Figure 6.9 (c) shows the variation of **Brake Thermal Efficiency** (BThE) for pure diesel, blends of biodiesel and for diesel-CNG dual fuel. The pattern of variation of BTheE for different fuels is almost similar. At initial speed BThE is almost same for all the fuels. In starting BThE increases with increase in speed. At 2000 rpm BThE is maximum for B30 and minimum for pure diesel. After 2000 rpm BThE in case of diesel-CNG increases with speed and remains higher than all the fuels at higher speed. The maximum BThE is obtained in case of B30 at 4000 rpm. First BThE increases with speed and after 4000 rpm BThE decreases with speed. At 5000 rpm diesel-CNG has maximum BThE. The maximum change in BThE 14.5 % is obtained in diesel-CNG dual fuel at 5000 rpm. There was a decrease in BThE at 1000 rpm for B30 only while in all the cases it increases with speed.

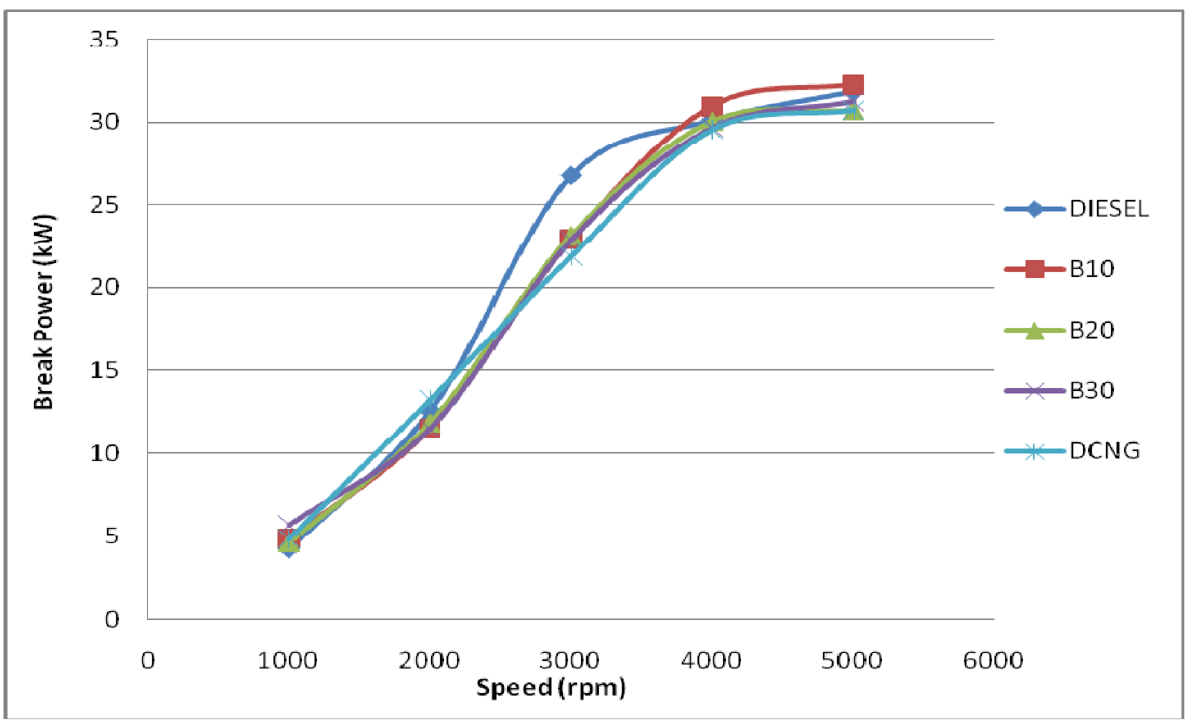


Figure 6.9(b): Comparison of BP Vs Speed for Different Fuels

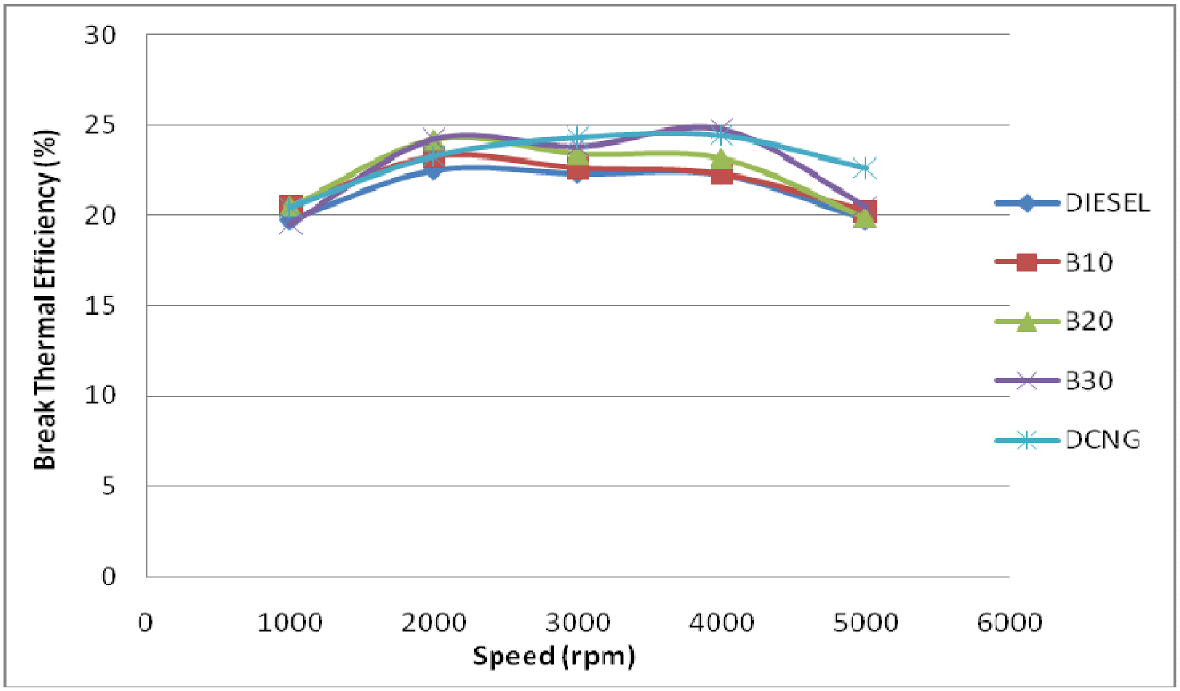


Figure 6.9(c): Comparison of BThE Vs Speed for Different Fuels

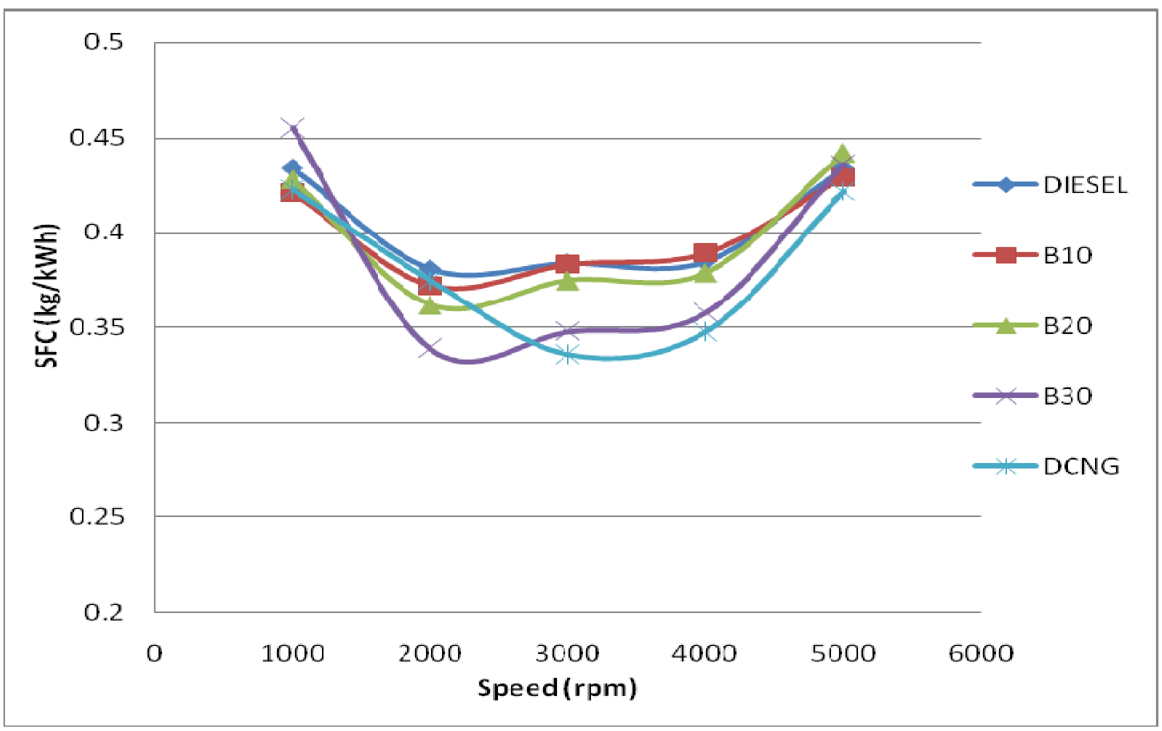


Figure 6.9(d): Comparison of SFC Vs Speed for Different Fuels

Figure 6.9 (d) shows **Specific Fuel Consumption** (SFC) with engine speed. The variation of SFC is almost similar in case of pure diesel, B10 and B20. At initial speed the SFC decreases with speed up to 200 rpm. Between 2000 rpm to 4000 rpm it remains almost constant at higher speed after 4000 rpm SFC increases with increase in speed upto 5000 rpm. The minimum SFC is in case of diesel-CNG dual fuel at 3500 rpm. SFC in case of diesel-CNG dual fuel always remains lower than the other fuels. SFC remains lower in almost all the cases excepting B30 at 1000 rpm, B10 at 4000 rpm and B20 and B30 at 5000 rpm. The maximum decrease in SFC is in case of diesel-CNG at 3000 rpm and a minimum decrease is at 3000 rpm in case of B10. Similarly maximum increase in SFC is in case of B30 at 1000 rpm. The maximum reduction in SFC is 12.5% in diesel- CNG dual fuel.

6.3.5.3 Discussion on Exhaust Emissions

The emission results obtained with the help of smoke meter and gas analyser from the tests performed on the engine setup are discussed below.

Figure 6.10(a) shows the variation of **smoke opacity** with engine speed. The pattern of variation in opacity is same for all the fuels. The opacity in case of pure diesel found to be higher than the other fuels. The opacity of smoke increases with increase in speed thus at the higher speed opacity is maximum for all the fuel used. The opacity in case of diesel-CNG throughout the test remains lower than the other fuel but at a higher speed of 5000 rpm there is little increase in the smoke opacity due to improper A/F mixture. The percentage change in opacity with engine speed taking diesel as reference fuel, opacity increase is maximum 7 % in case of B20 at 1000 rpm. At 1000 rpm decrease in opacity is maximum 20% in case of B30. At 2000 rpm decrease in maximum opacity is in case of B30 while at 3000 rpm decrease in opacity is maximum 25% in case of diesel-CNG dual fuel. Similarly at 4000 rpm decrease in opacity is maximum 19% in case of diesel-CNG dual fuel.

Figure 6.10 (b) shows the **variation of CO** emission with engine speed. The CO emission increases with increase in engine speed for all the fuels. The maximum CO emissions are found at 5000 rpm in case of diesel-CNG dual fuel. CO emissions are higher for diesel-CNG dual fuel throughout the test. Maximum increase in CO emission is recorded in case of diesel-CNG dual fuel. The increase in CO emission is highest in case of diesel-CNG 2000 rpm and is lowest in B20 at 1000 rpm. With all biodiesel blends there is reduction in CO emissions as compared to pure diesel.

Figure 6.10 (c) shows the **variation of HC** emission with engine speed. The pattern of increase in HC emission with speed is almost similar for all the fuels. The HC emissions are lowest in case of pure diesel at 1000 rpm and maximum HC emission is in case of diesel-CNG dual fuel at 5000 rpm. With all biodiesel blends there is reduction in HC emissions as compared to pure diesel. HC emission for diesel-CNG dual fuel is increasing with increase in speed in comparison to other fuels. It remains higher than pure diesel throughout the test.

Figure 6.10 (d) shows the **variation of NO_X** emission with increase in engine speed. The pattern of NO_X emission is same for all the fuels. It can be observed from the Figure that the level of NO_X emission is lower for diesel-CNG throughout the test. NO_X emission is lowest in case of diesel-CNG dual fuel at 1000 rpm. At 5000 rpm NO_X emission is also lowest in comparison to other fuels. While for other fuels increase in NO_X emission is almost same as that of pure diesel and B10. NO_X emissions are higher in case of B20 & B30. The maximum increase in NO_X emission 14% is obtained in case of B20 at 2000rpm. While the maximum decrease in NO_X emission is in case of B30 at 1000 rpm. Further increase in engine speed causes maximum decrease in NO_X emission in case of diesel-CNG dual fuel mode.

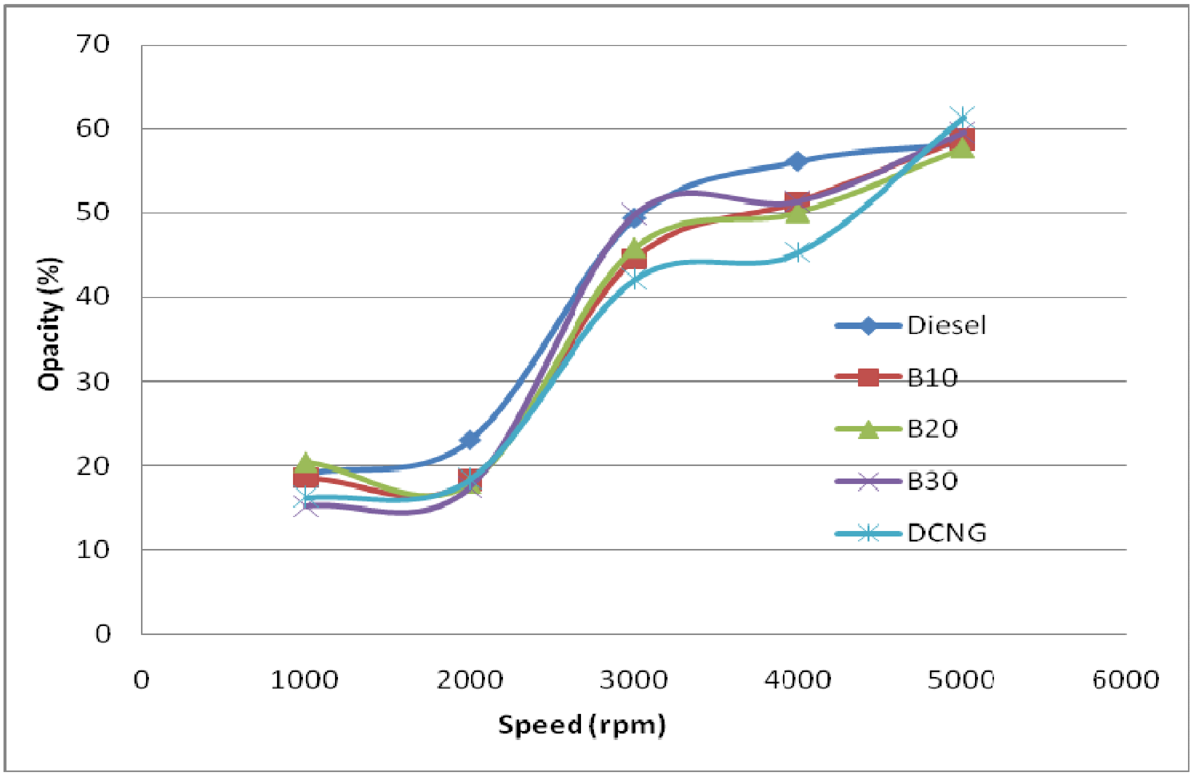


Figure 6.10(a): Comparison of Smoke Opacity v/s Engine Speed for Different Fuels

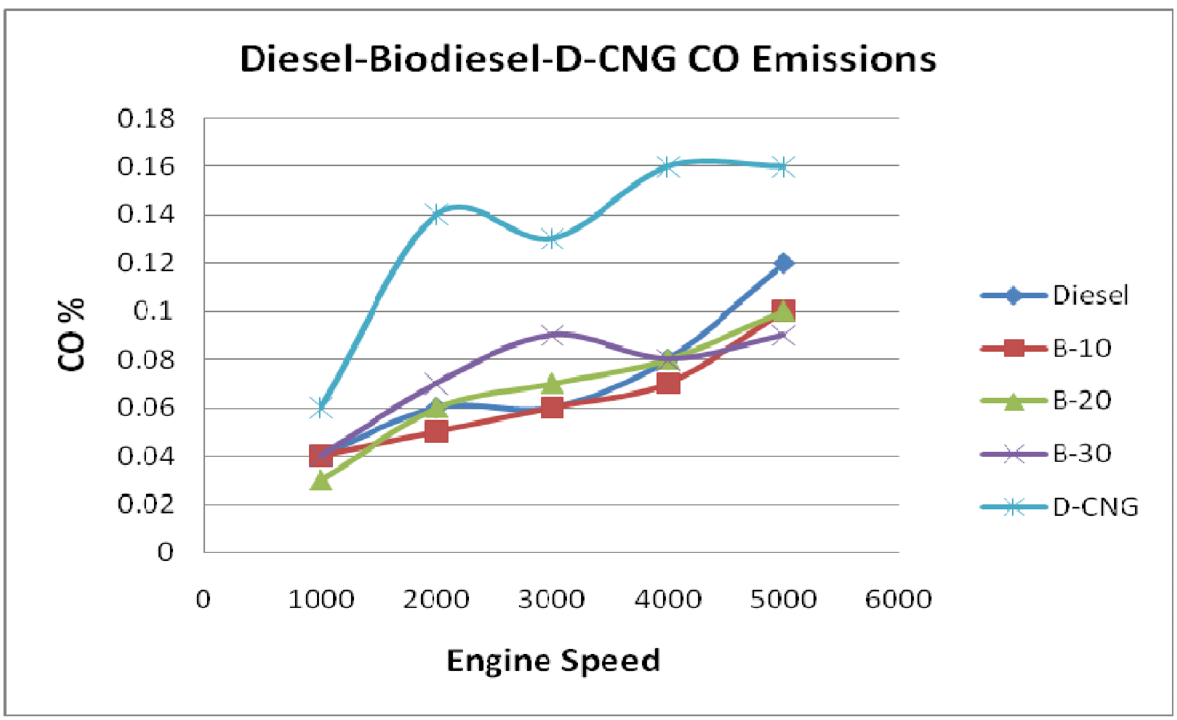


Figure 6.10 (b): Comparison of CO v/s Engine Speed for Different Fuels

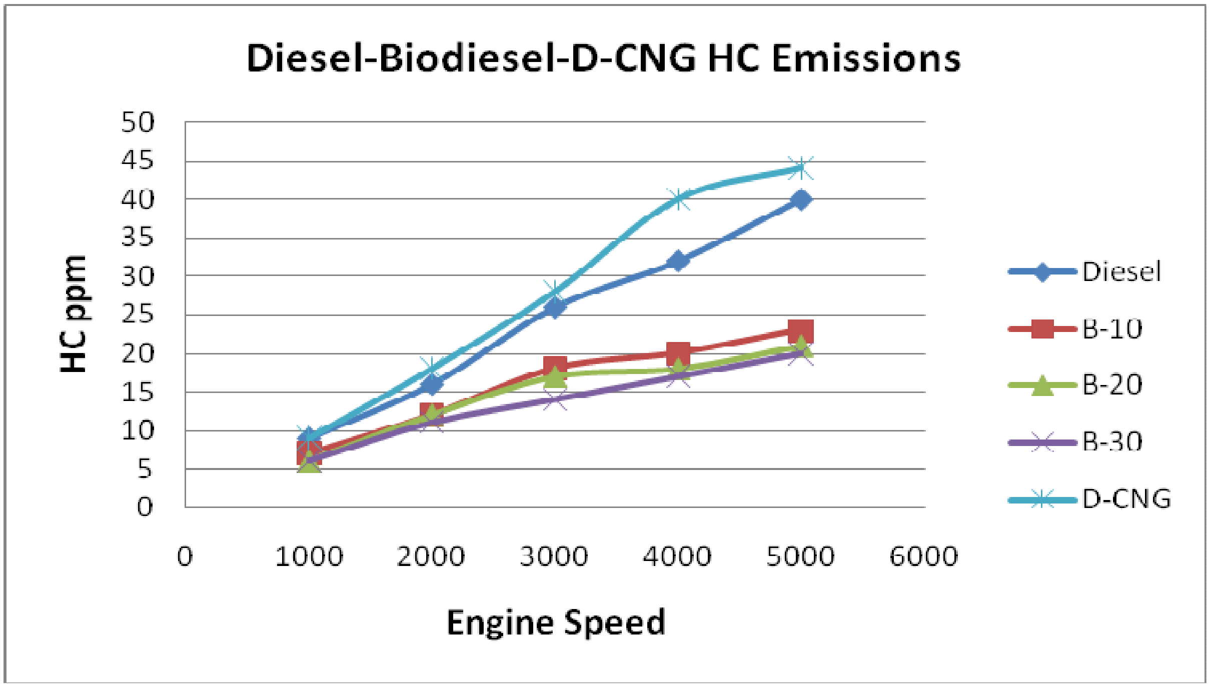


Figure 6.10 (c): Comparison of HC v/s Engine Speed for Different Fuels

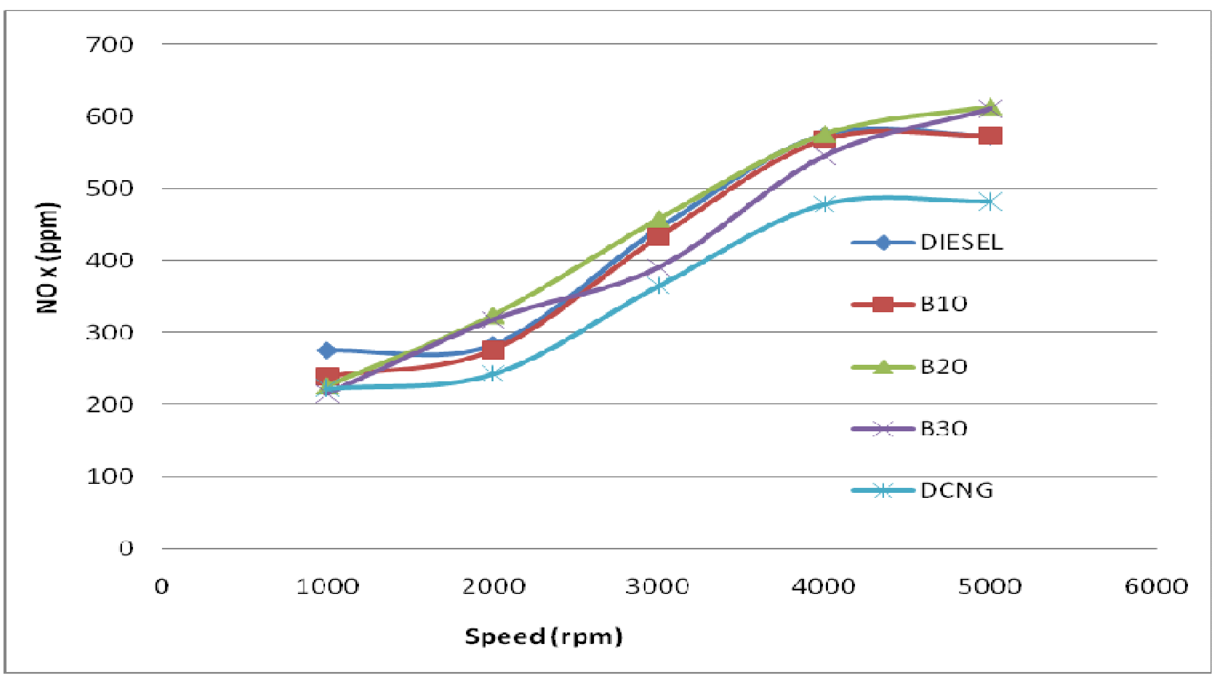


Figure 6.10 (d): Comparison of NO_X v/s Engine Speed for Different Fuels

6.4. VCR C I ENGINE – EXPERIMENTS WITH DIESEL ETHANOL BLENDS

6.4.1 VCR Engine Concept

The concept of variable compression ratio (VCR) promises improved engine performance, efficiency, and reduced emissions. The higher cylinder pressures and temperatures during the early part of combustion and small residual gas fraction owing to higher compression ratio give faster laminar flame speed. Therefore, the ignition delay period is shorter. As a result, at low loads, the greater the compression ratio, the shorter is the combustion time. The time loss is subsequently reduced. Therefore, it seems reasonable that fuel consumption rate is lower with high compression ratios at part load. The VCR can make a significant contribution to thermo dynamic efficiency of I.C. engines. The main feature of the VCR engine is to operate at different compression ratios, depending on the vehicle performance needs. In a VCR engine, thermodynamic benefits appear throughout the range. At low power levels, the VCR engine operates at a higher compression ratio to capture high fuel efficiency benefits, while at high power levels the engine operates at low compression ratio to prevent knock.

The optimum compression ratio is determined as a function of one or more vehicle operating parameters such as inlet air temperature, engine coolant temperature, exhaust gas temperature, engine knock, fuel type, octane rating of fuel, etc. In a VCR engine, the operating temperature is more or less maintained at optimum, result in higher efficiency. It has been proven that a VCR engine develops much more power for the same engine dimensions, thus it is very compact and has a high power to weight ratio without any penalty on specific fuel consumption.

6.4.2 Need for the VCR Engine

The present challenge in automotive engine technology is to improve the efficiency and hence the fuel economy and lower emission levels. One of the key features affecting thermal efficiency is the compression ratio, which is always a compromise in fixed compression ratio spark ignition (SI) engines.

The air standard cycle efficiency is

$$\eta = 1 - [1/r_c^{(\gamma - 1)}]$$

Where η is the efficiency of the cycle;

r_c is the compression ratio; and γ is the ratio of specific heat of air at constant volume to specific heat at constant pressure, (approximately 1.40).

Higher compression ratio results in higher thermal efficiency and improved fuel economy in the internal combustion engine. Generally, the operating conditions of SI engines vary widely, such as stop and go city traffic, highway motoring at constant speed, or high-speed freeway driving. In a conventional SI engine, the maximum compression ratio is set by the conditions in the cylinder at high load, when the fuel and air consumption are at maximum levels. If the compression ratio is higher than the designed limit, the fuel will pre-ignite and cause knocking, which could damage the engine. Figure 6.11 shows the effects of compression ratio with respect to thermal efficiency. As the engine load decreases, the temperature in the end gas drops, so that high compression ratio could be employed without the risk of knocking in naturally aspirated or boosted engines.

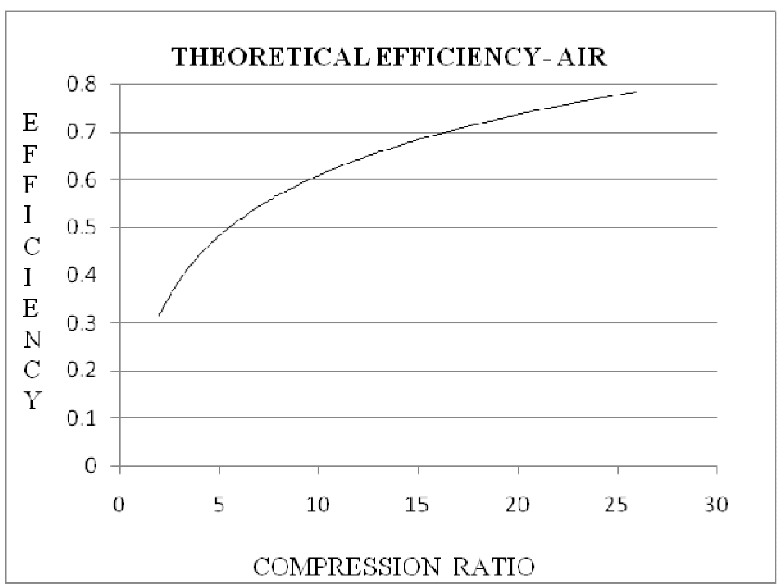


Figure 6.11: Effect of Compression Ratio on Thermal Efficiency

Unfortunately, most of the time SI engines in city driving conditions operate at relatively low power levels under slow accelerations, low speeds, or light loads, which lead to low thermal efficiency and hence higher fuel consumption. The characteristics that have the dominant effects on thermal efficiency are compression ratio and air–fuel mixture strength. The fuel–air cycle efficiency increases with the compression ratio in the same manner as the air standard cycle efficiency, principally for the same reason, i.e. more scope for expansion work. Raising the compression ratio from 8 to 14 produces an efficiency gain from 50 to 65 per cent (a 15 per cent gain), whereas going from 16 to 20 produces a gain from 67 to 70 per cent (a 3 per cent gain). The 'percent theoretical fuel' is the ratio of actual fuel–air ratio to chemically correct fuel–air ratio, in percentage terms. The maximum output is obtained when the air–fuel capacity of the engine is utilized, i.e. when the maximum amount of fuel can be burnt efficiently. The maximum brake mean effective pressure (b.m.e.p.) in SI engines is 12 bar whereas in diesel engines it is 18 bar.

A higher compression ratio increases the pressure and temperature of the working air–fuel mixture, which increases the tendency of the engine to knock. For knock, key variables are: end-gas temperature, pressure, and composition; time/speed; and fuel octane rating (Heywood, 1989 and Taylor, 1960).

6.4.3 Effect of Compression Ratio on Power Output and Efficiency

The power delivered from an engine is directly proportional to the mean effective pressure (mep) developed in the engine cylinder. The fuel conversion efficiency, i.e. sum of thermal and mechanical efficiency, increases with increase in compression ratio implying the power output increases with compression ratio under a given set of operating conditions.

The basic limitation in using higher compression ratio for spark-ignited engines arises out of the properties of the fuel used. The range of operating compression ratio found in the literature is between 8 and 14. For spark-ignited engines with the compression ratio less than 12, for a unit change of compression ratio, the output changes by about 3 %.

Engine efficiency also gets affected due to the change in compression to similar extent. Depending upon the cylinder sizes and the operating conditions, Heywood indicates that, for a unit change in the compression ratio in the range of 9 to 11, the relative change in efficiency is between 1 and 3 percent. Further the effective change in efficiency is found to be in the range of 1 – 1.4 % per unit change in compression ratio. It is also found from the work of Sridhar et al that the factor is about 1.3 per unit change in compression ratio with different operating conditions.

6.4.4 Methodology of Experimentation

The test engine used was a kirloskar, single cylinder, Variable Compression Ratio Engine with range of CR from 12-18, water cooled, direct injection, normally aspirated, four stroke diesel engine. The engine was coupled directly to an electric dynamometer, for loading and measurement. The components used are detailed out in Table 6.2. The actual test setup is shown in Figure 6.12.

The engine was used to run on pure diesel mode as well as ethanol diesel blends. The blends were prepared in the laboratory itself by mixing appropriate volume of diesel with ethanol and n-butanol(which is used as a surfactant- an additive to facilitate the mixing of ethanol in diesel). The blends are referred as Z5E10D85, Z5E10D85, Z5E10D85, Z5E10D85, Z5E10D85, In this format Z5 represents 5 percent of n-butanol, the number followed by E represent the percent of ethanol and the number followed by D represent the percent of diesel in the blend.

Figure 6.12: The Actual Test Set-up of VCR engine

Table 6.2: Component Used for the VCR Experimental Set-up

S. no.	Components	Details
1.	Engine	Make Kirloskar, Type 1 cylinder, 4 stroke Diesel, water cooled, power 3.5 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cc, CR 18, Modified toVCR engine CR range 12 to 18
2.	Dynamometer	Make Saj test plant Pvt. Ltd., Model AG10, Type Eddy current
3.	Dynamometer Loading unit	Make Apex, Model AX-155. Type constant speed, Supply 230V AC.
4.	Manometer	Make Apex, Model MX-104, Range 100-0-100 mm, Type U tube, Conn. 1/4`` BSP hose back side,
5.	Fuel measuring unit	Make Apex, Glass, Model:FF0.012
6.	Piezo sensor	Make PCB Piezotronics, Model HSM111A22, Range5000 psi, Diaphragm stainless steel type & hermetic sealed
7.	Crank angle sensor	Make Kubler-Germany Model 8.3700.1321.0360 Dia: 37mm Shaft Size: Size 6mmxLength 12.5mm, Supply Voltage 5-30V DC, Output Push Pull (AA,BB,OO), PPR: 360,
8.	Data acquisition Device	NI USB-6210 Bus Powered M Series
10.	Temperature sensor	Make Radix Type K, Ungrounded, Sheath Dia.6mmX110mmL, SS316, Connection 1/4"BSP (M)
11.	Temperature sensor	Make Radix, Type Pt100, Sheath Dia.6mmX110mmL, SS316, Connection 1/4"BSP(M) adjustable compression fitting
12.	Temperature transmitter	Make Wika, model T19.10.3K0-4NK-Z, Input Thermocouple (type K), output 4-20mA, supply 24VDC, Calibration: 0-1200deg.C
13.	Temperature transmitter	Make Wika, Model T19.10.1PO-1 Input RTD(Pt100), output 4-20mA, supply 24VDC, Calibration: 0-100°C
14.	Load sensor	Make Sensotronics Sanmar Ltd., Model 60001,Type S beam, Universal, Capacity 0-50 kg
15.	Load indicator	Make Selectron, model PIC 152–B2, 85 to 270VAC, retransmission output 4-20 mA
16.	Fuel flow transmitter	Make Yokogawa, Model EJA110-EMS-5A-92NN, Calibration range 0-500 mm H2O, Output linear
17.	Air flow transmitter	Range (-) 250 mm WC
18.	Rotameter	Make Eureka Model PG 5, Range 25-250 lph,and 40-400 lph Connection ¾” BSP vertical,

6.4.5 Discussion on Variation of Performance and Emissions Parameters

A set of reading was obtained first by running the engine with diesel at CR of 18 and varying the load from idle to rated load of 3.5 kW in steps of 1 up to 3 kW and then to 3.5 kW. The engine performance characteristics were recorded by using the software Engine Soft and instrumentation provided by the National Instruments. The emissions were recorded for each load by using Gas Analyzer AVL Di Gas 444 and the opacity was recorded by Smoke meter (AVL 437).Then, the engine was run on blends of ethanol-Diesel and the parameters were recorded as above. The calorific value and density values were entered accordingly in the Engine Soft.

Similar sets of readings were recorded for the compression ratio of 16 and 14. For this purpose, the engine was started at compression ratio of 18 and then the compression ratio was changed by using the tilting head arrangement.

6.4.5.1 Discussion on Pressure Angle (P-θ) Curves

Figure 6.13 to 6.15 show the combustion chamber pressure data with the variation of crank angle. It is found from these curves that for all the blends maximum pressure attained in the combustion chamber is for the Z5E15D85 which is closely followed by Z5E10D85 and Z5E20D75 blends. Here Z5 represents use of 5% n-butanol as surfactant. The trend is same for all the compression ratios used in the experiment. It is also observed that there is significant maximum pressure loss with the reduction of the compression ratio. And hence best results are with the compression ratio of 18, however there is a need to check the performance for the compression ratio higher than 18.

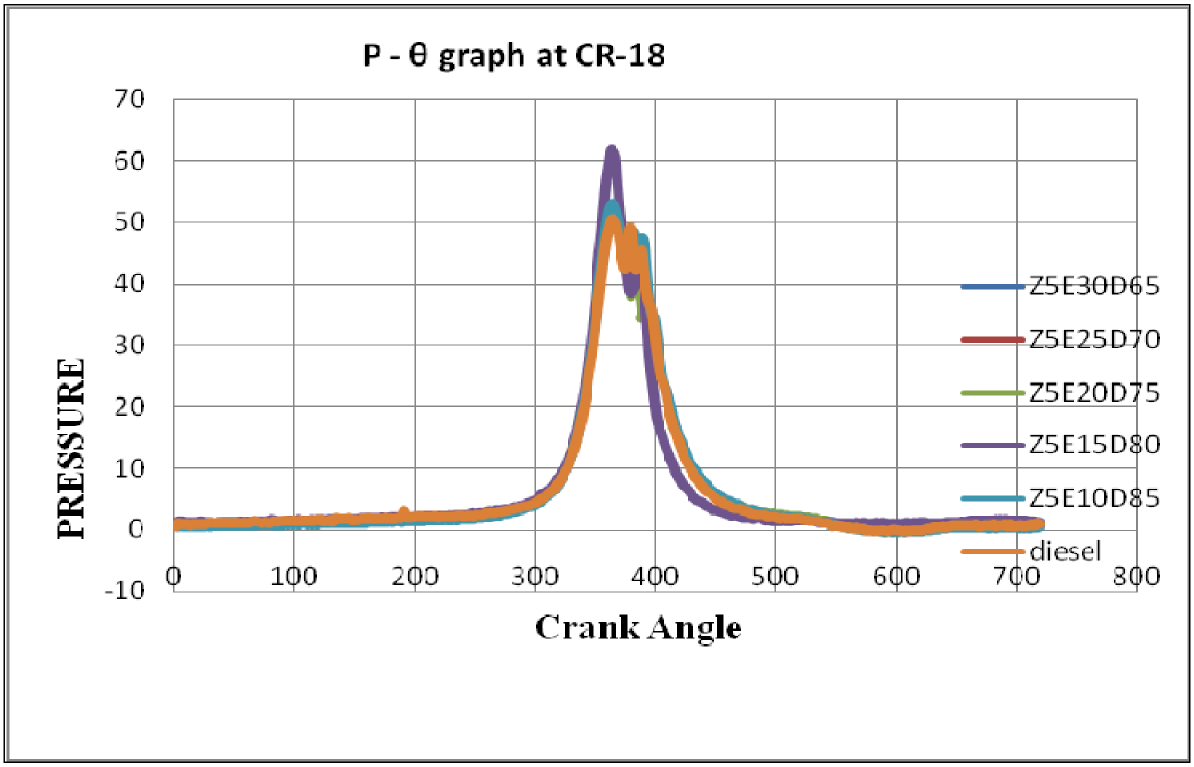


Figure 6.13: p-θ at CR-18

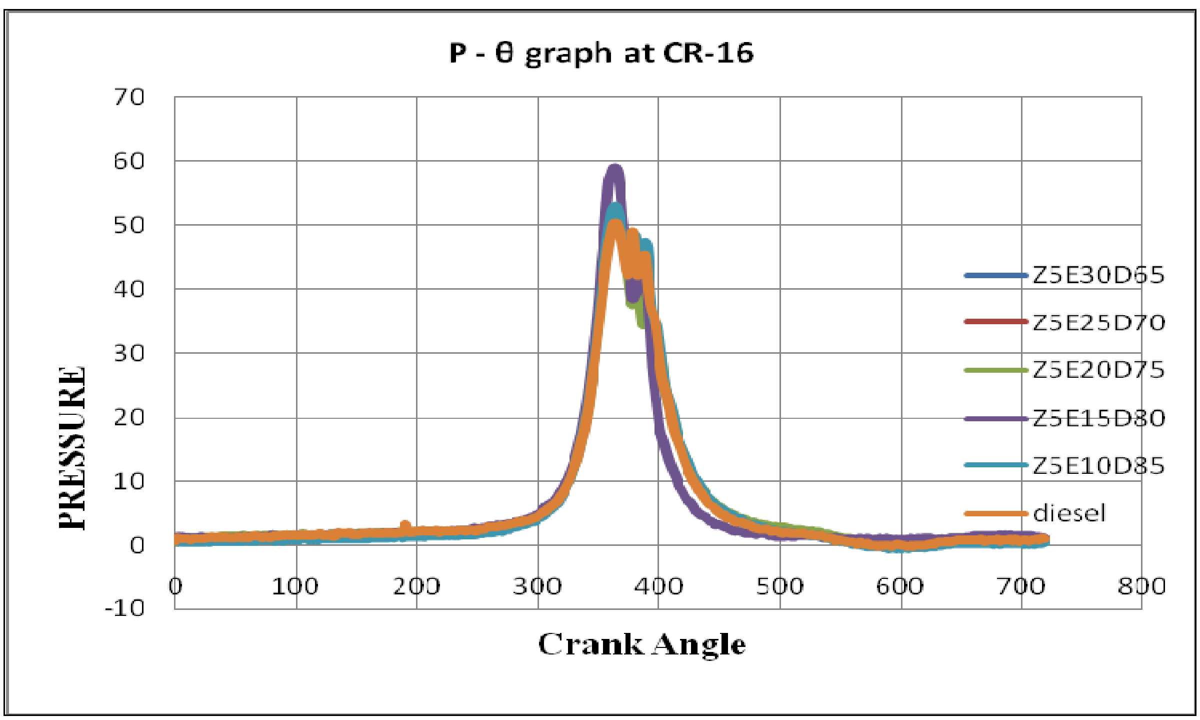


Figure 6.14: p-θ CR-16

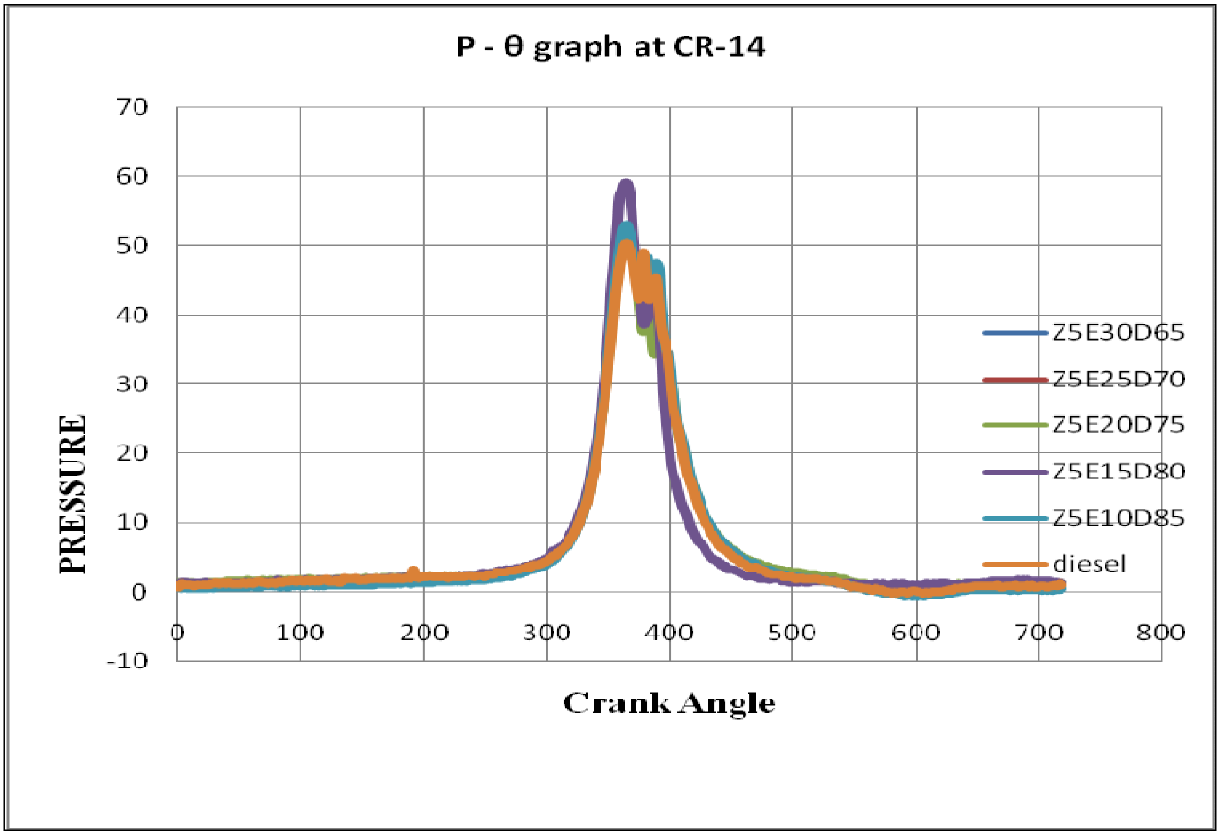


Figure 6.15: p-θ at CR-14

<u>6.4.5.2 Discussion on Variation of Performance Parameters</u>

Brake Thermal Efficiency v/s Brake Power

Figure 6.16 shows the results of the thermal efficiencies of engine with the engine power when fuelled by different fuel blends and the pure diesel at CR-18. The test results show that there are some differences for the brake thermal efficiencies for different blends compared with those of diesel. When the engine ran at the different brake power, from 0 to 2 kW for the different blend, the thermal efficiency were decreased. But higher load 2.5 kW to 3.5 kW, efficiency increased as we increase the percentage of ethanol into diesel up to 30% blending of ethanol into diesel.Similar trend was found at different compression ratio with substantial decrease in efficiency for lower compression ratio 16 and 14(Figure 6.167and 6.18)

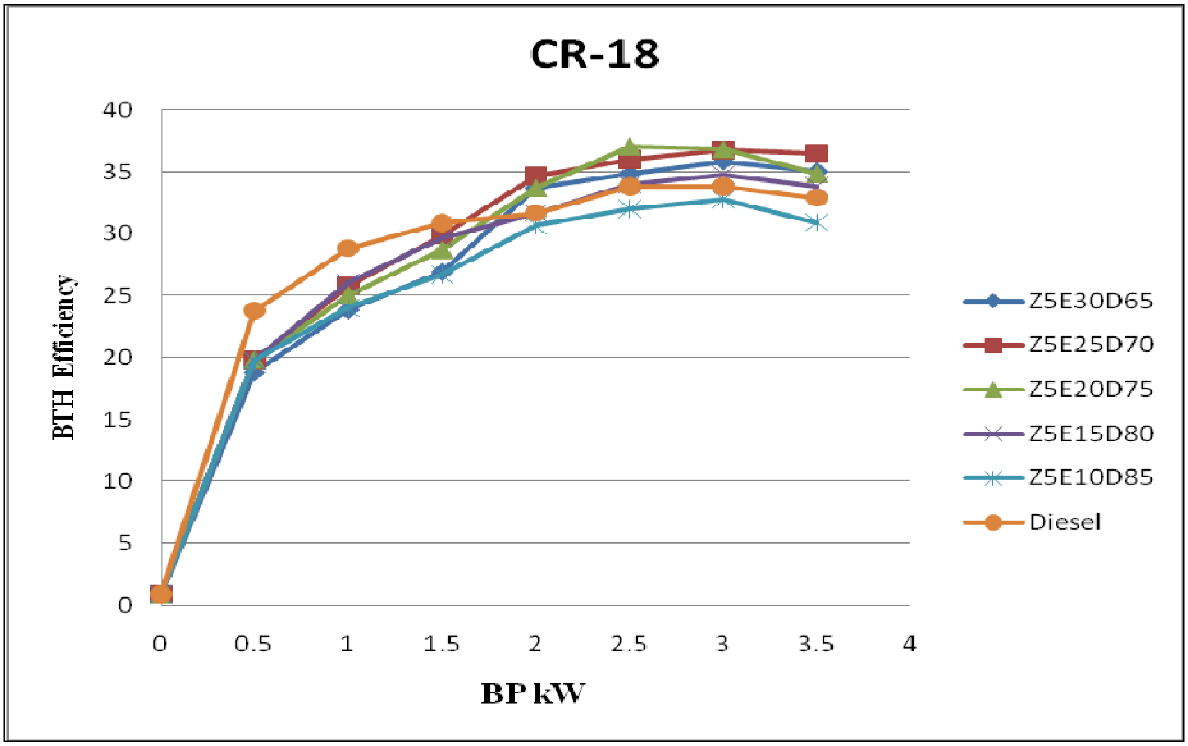


Figure 6.16: Brake Thermal Efficiency v/s Brake Power at CR-18

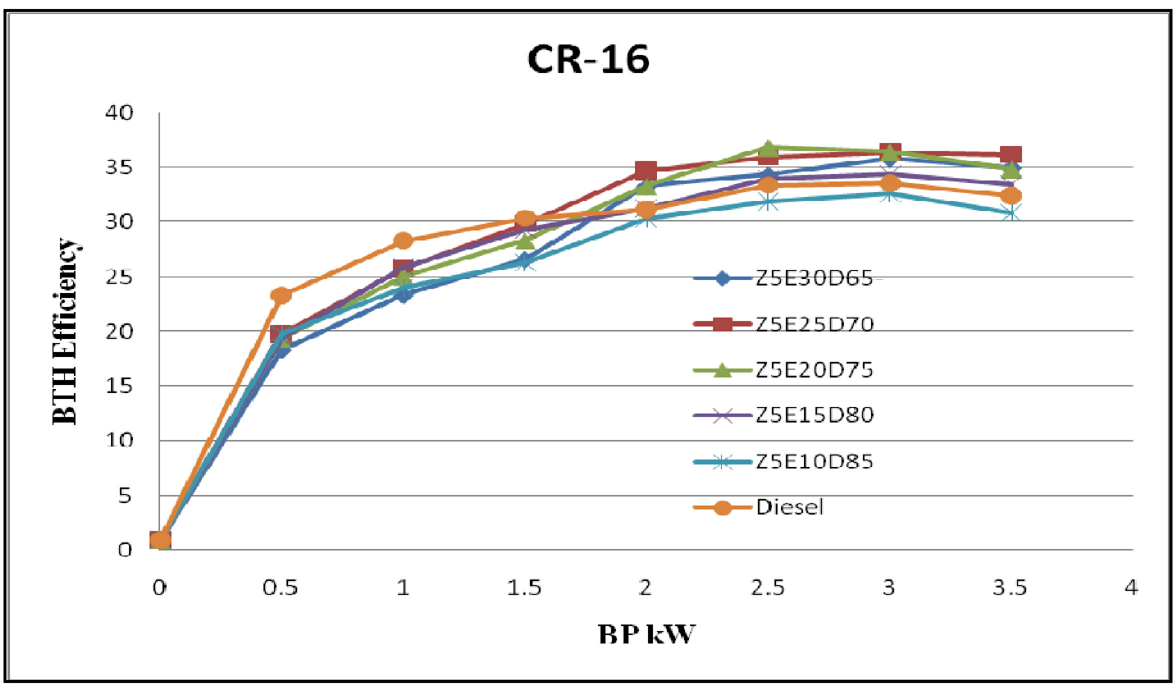


Figure 6.17: Brake Thermal Efficiency v/s Brake Power at CR-16

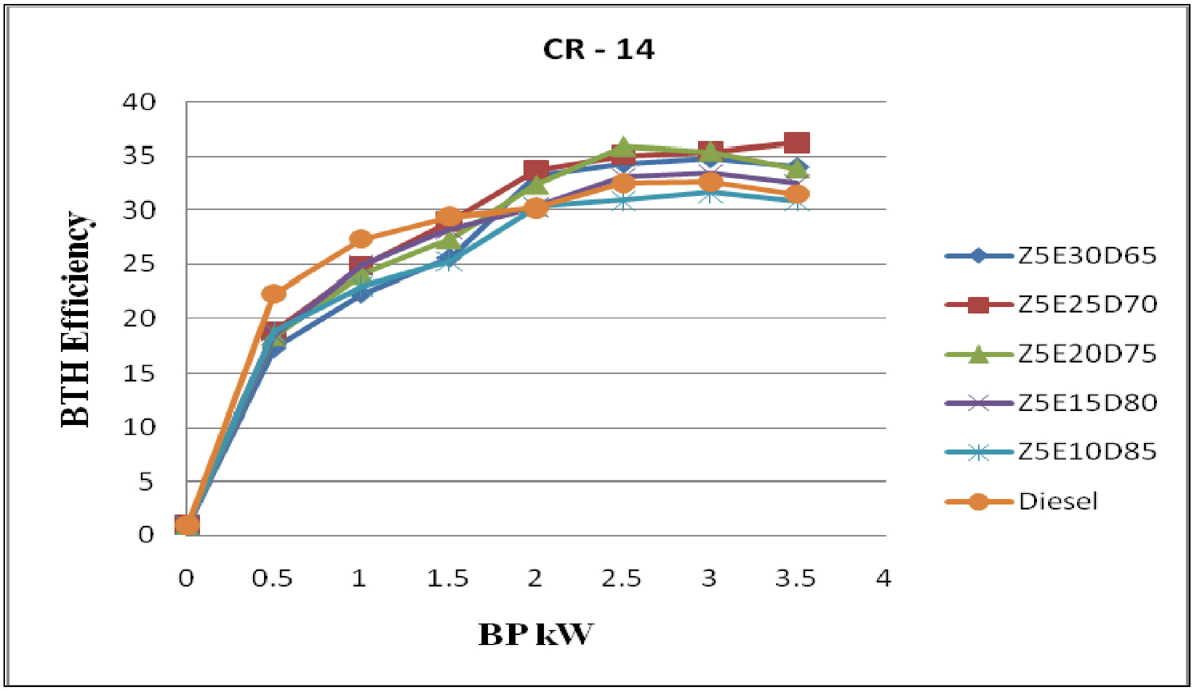


Figure 6.18: Brake Thermal Efficiency v/s Brake Power at CR-14

Specific Fuel Consumption v/s Brake Power

Figure 6.19 shows the test results of the brake specific fuel consumptions (BSFCs) with the engine power outputs, when the engine fuelled by different fuel blends and diesel. From the results, it can be seen that the engine power could be maintained at the same level when fuelled by different fuel blends with some extent increases of fuel consumption; the more ethanol was added in, the more fuel consumption was found, compared with those fuelled by pure diesel. These increases of fuel consumption are due to the lower heating value of ethanol than that of pure diesel. The results show the trend of the increase of fuel consumption with the increase percentage of ethanol in the blends. Similar results and trend can be seen when the engine ran at lower compression ratio 14 and 16 on different engine loads with some decrease in fuel consumption (Figure 6.20and 6.21).

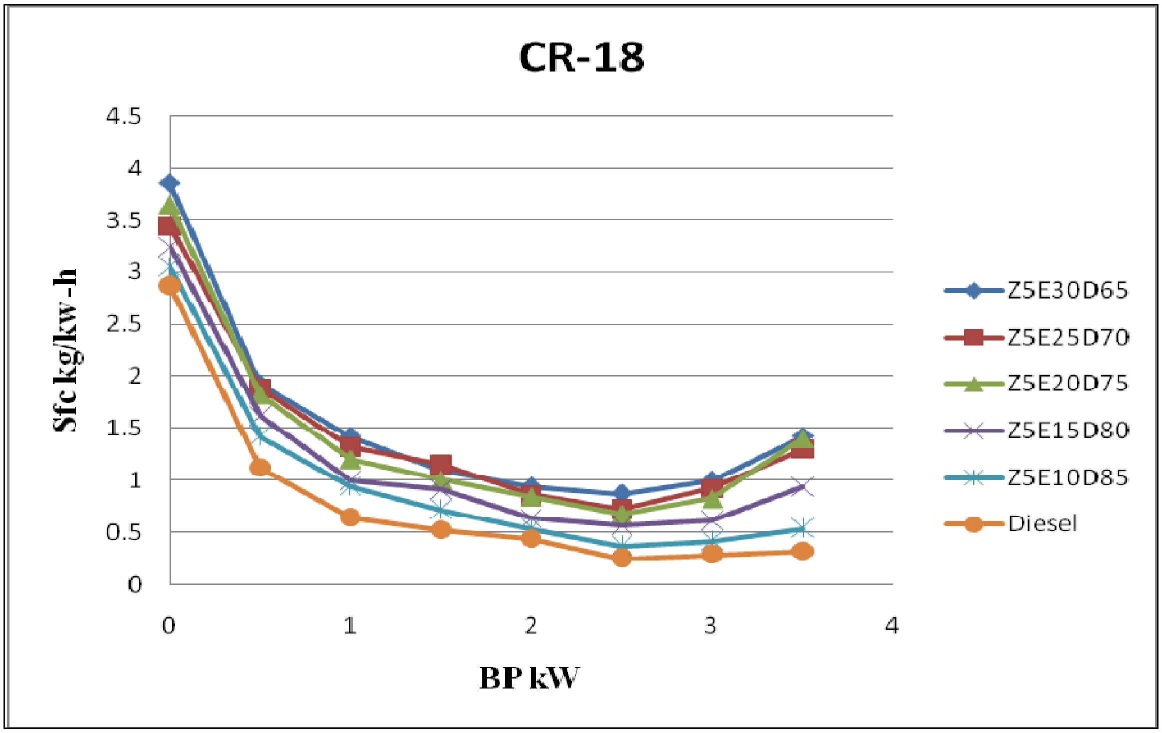


Figure 6.19: Specific Fuel Consumption v/s Brake Power at CR-18

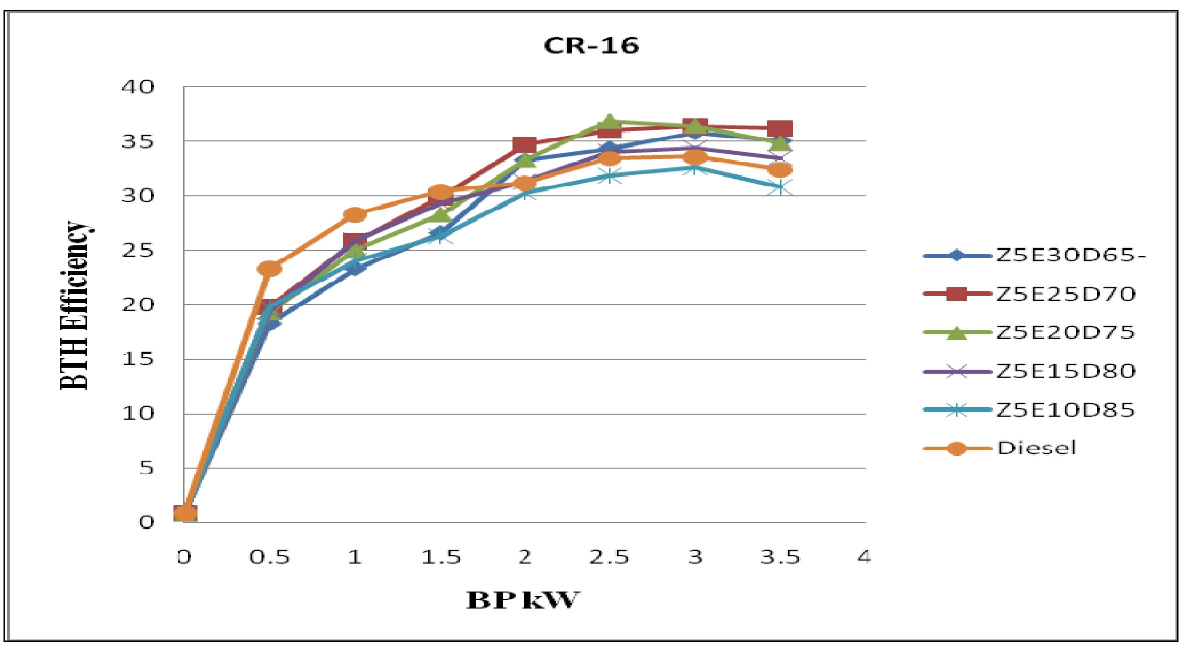


Figure 6.20: Specific Fuel Consumption v/s Brake Power at CR-16

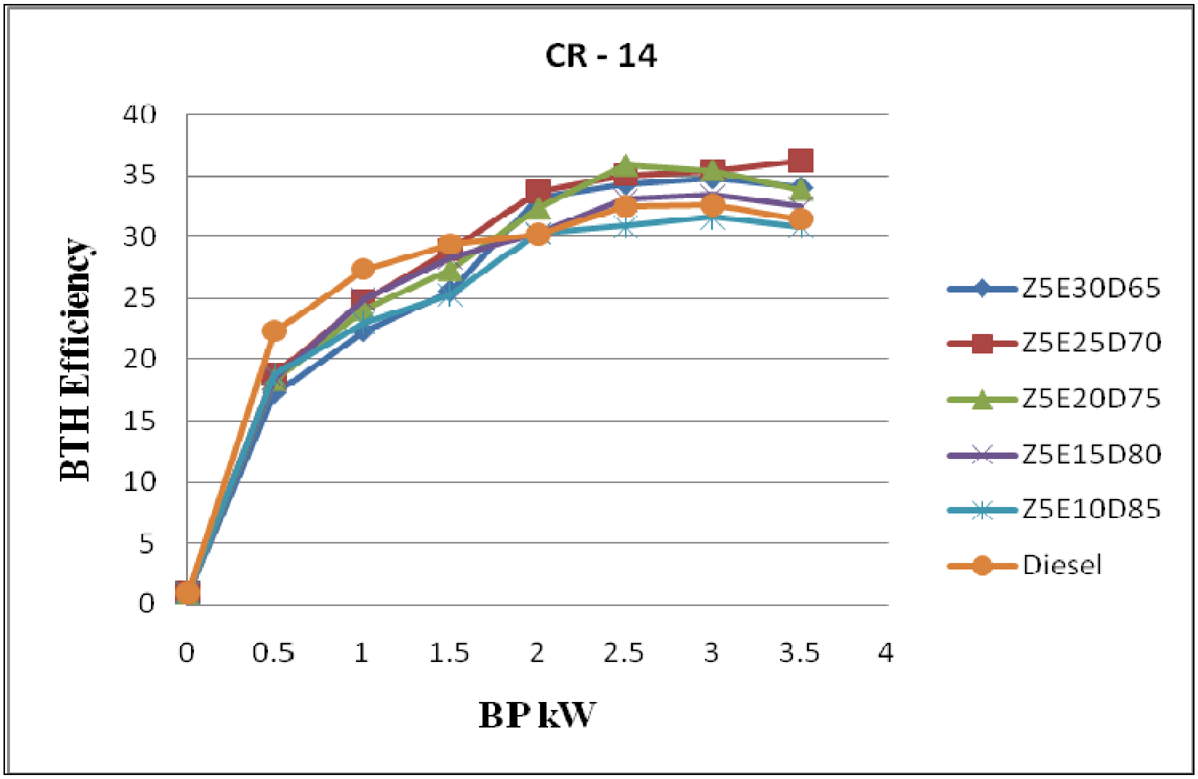


Figure 6.21: Specific Fuel Consumption v/s Brake Power at CR-14

6.4.5.3 Discussion on variation of Exhaust Emissions

The Nitrogen Oxides (Nox) Emissions from the Engine

The test results for the NOx emissions from the engine are shown in Figure 6.22. When the engine ran at CR 18 and above half of the engine load (2 kW); the NOx emissions from the engine were higher than those of diesel when fuelled by Z5E10D85, when the engine loads were less than 2 kW, the NOx emissions were reduced . The NOx emissions from the engine were all lower than those of diesel when fuelled by the other blends. When fuelled by Z5E25D70, the NOx emissions from the engine were not stable, at different engine loads. Similar trend were found at lower compression ratio (14 and 16) with slight increase in the NOx (Figure 6.23 and 6.24).

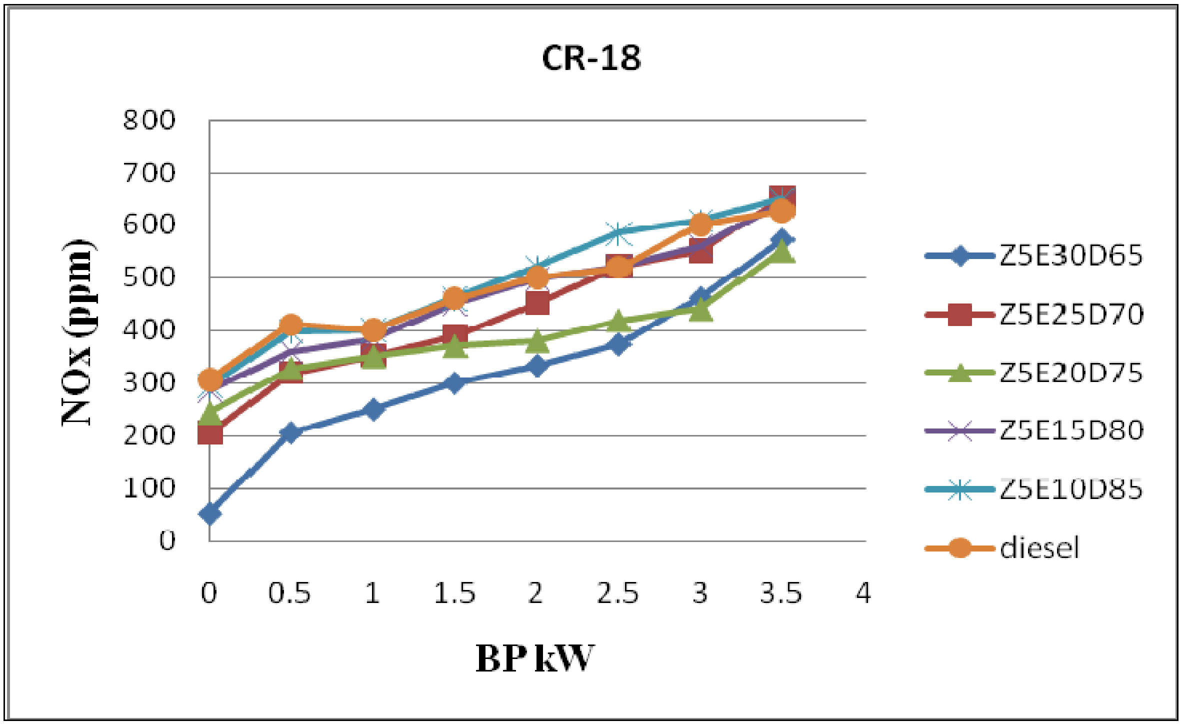


Figure 6.22: NOx v/s Brake Power at CR-18

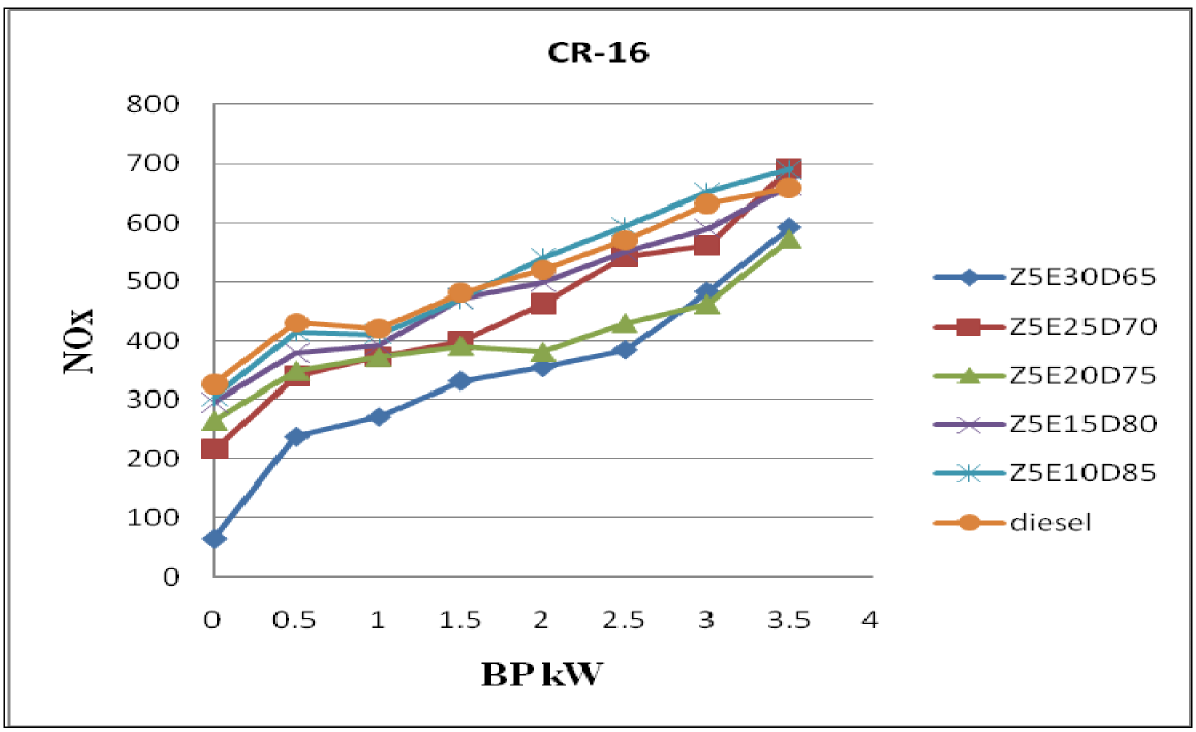


Figure 6.23: NOx v/s Brake Power at CR-16

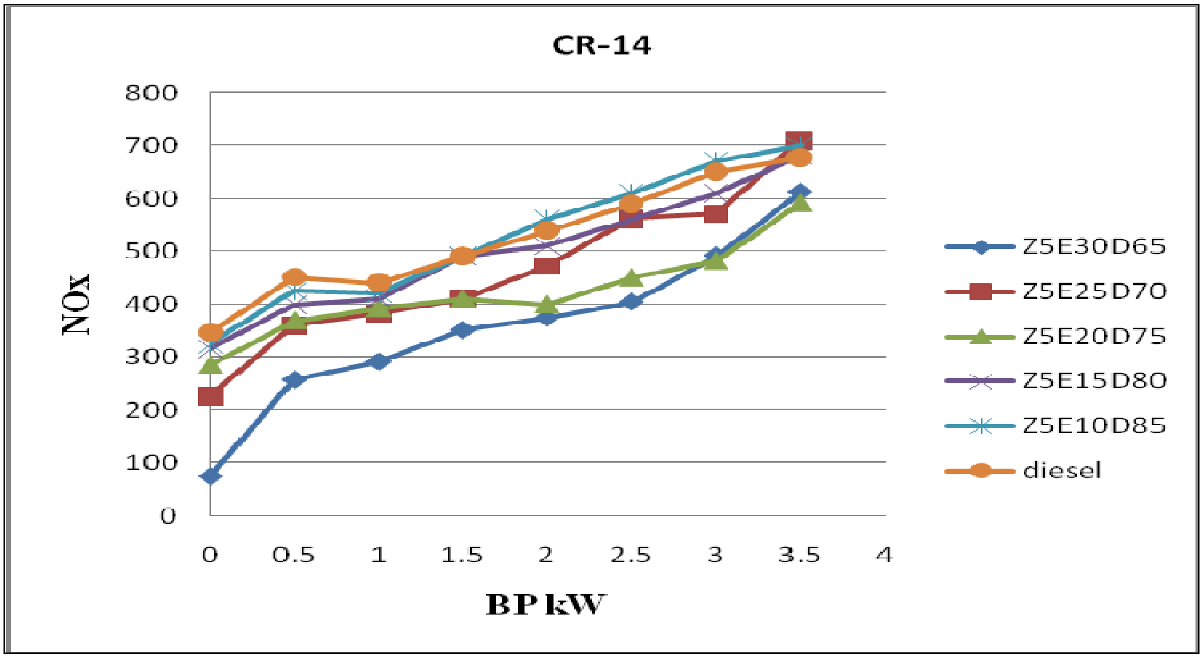


Figure 6.24: NOx v/s Brake Power at CR-14

The Unburnt Hydrocarbon (HC) Emissions from the Engine

The test results for the unburned HC from the engine are shown in Figures 6.25. The results showed that the HC emissions from the engine for the blend fuels were all higher when the engine ran on the 14 and 16 compression ratio, as shown in Figure 6.33and 6.34 respectively; and the HC emissions became less as the loads increased. A similar trend can be seen for the engine ran on 18 compression ratio, except at the point of top power output, as shown in Figure 6.32 At this point, the HC emissions for all blends were lower than that fuelled by diesel; this is due to the high temperature in the engine cylinder to make the fuel be easier to react with oxygen when the engine ran on the top load and high speed. There is a marginal increase in HC emissions with reduction in the compression ratio. Similar trend were found at lower compression ratio (14 and 16) with slight increase in the HC (Figure 6.26 and 6.27).

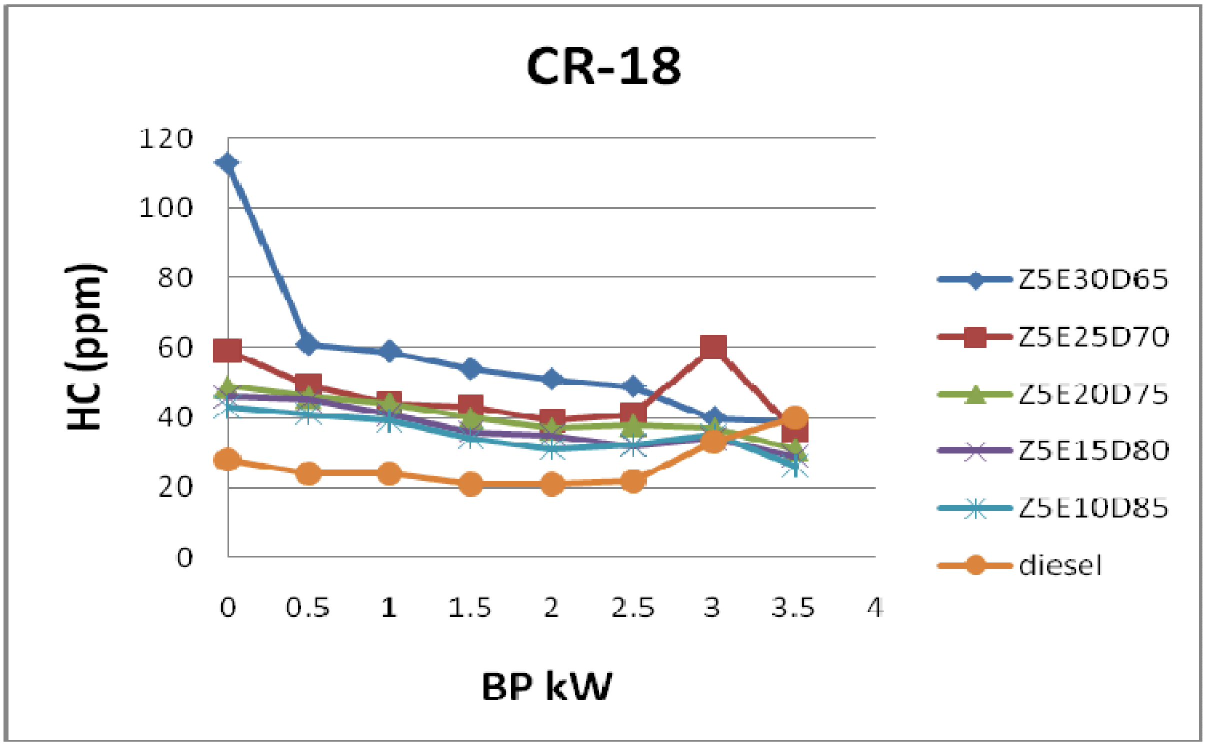


Figure 6.25: Unburnt hydrocarbon (HC) emissions v/s Brake Power at CR-18

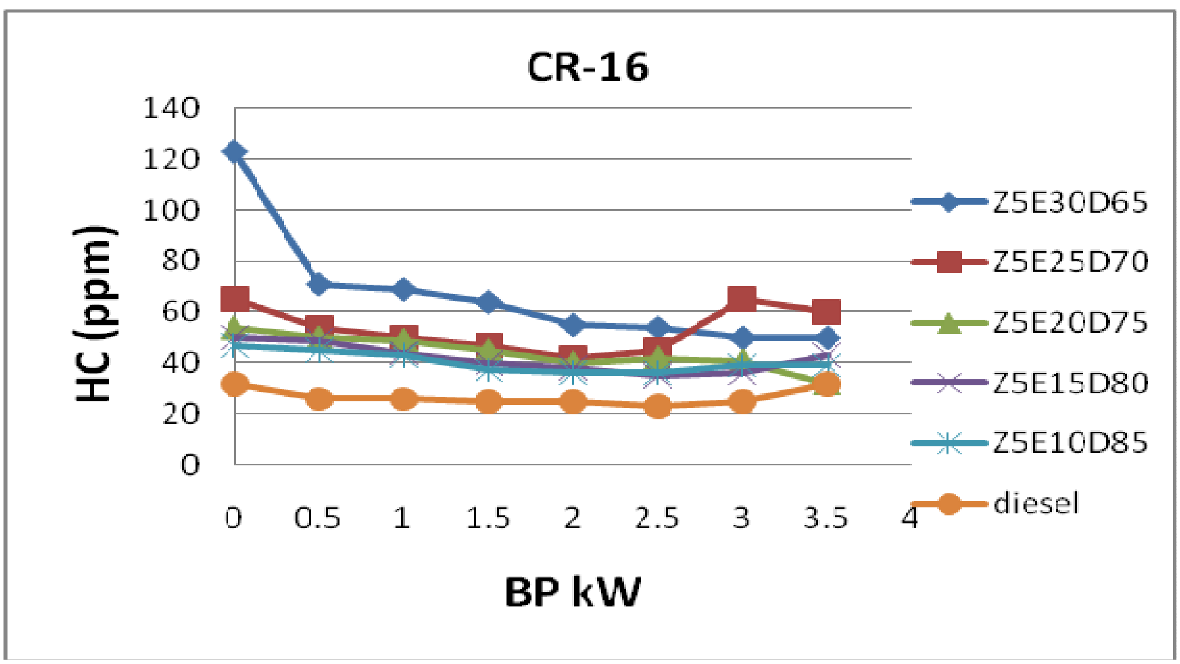


Figure 6.26: Unburnt Hydrocarbon (HC) Emissions v/s Brake Power at CR-16

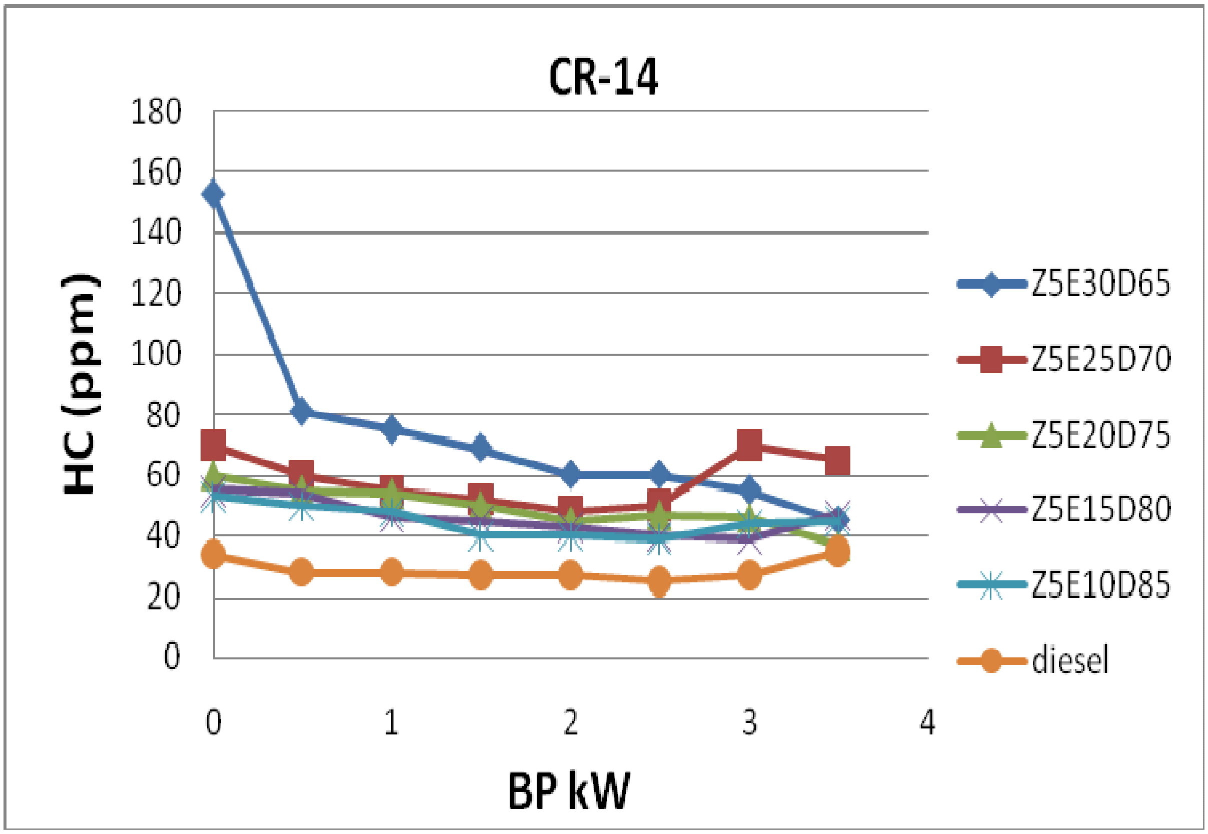


Figure 6.27: Unburned hydrocarbon emissions Vs break power at CR-14

The Carbon Monoxide (CO) Emissions from the Engine

Figure 6.28 to 6.30 shows the CO emissions from the engine exhaust at the compression ratio 14, 16 and 18 when fuelled by different fuels. When the engine ran at CR 18 and at lower loads, the CO emissions from the engine fuelled by the ethanol blends were higher than those fuelled by pure diesel. The higher the percentages of the ethanol the more CO emissions happened (Figure 6.34). But at the engine higher loads which were about above half of the maximum engine load, the CO emissions became lower than that fuelled by diesel for all the blend fuels. This may be attributed to the oxygenating effect of the ethanol, while at part loads the burning remains incomplete. The CO emission observed to be increasing with the reduction in the compression ratio.

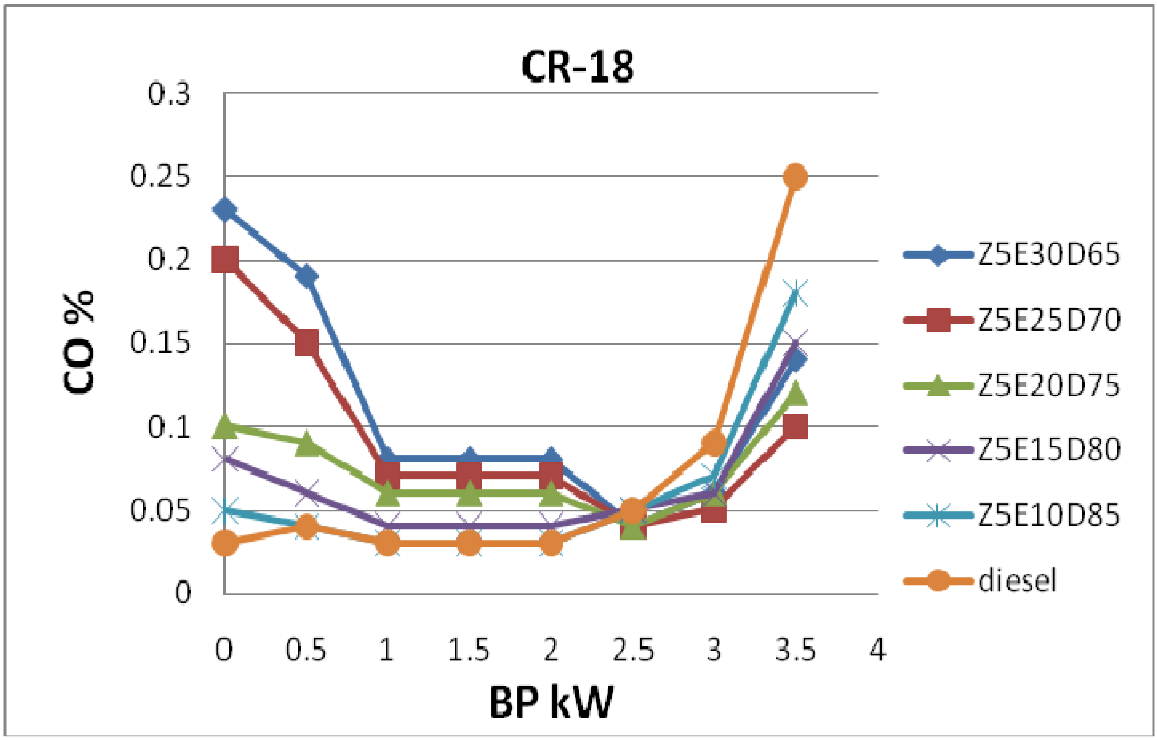


Figure 6.28: Carbon Monoxide (CO) Emissions v/s Brake Power at CR-18

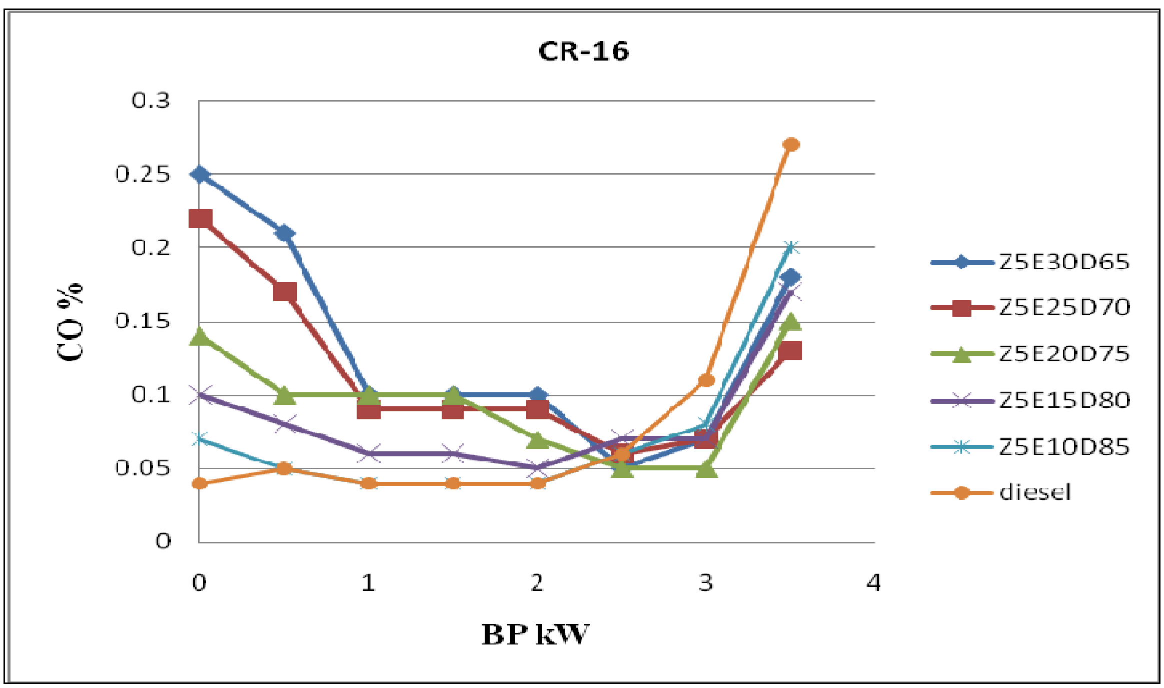


Figure 6.29: Carbon Monoxide (CO) Emissions v/s Brake Power at CR-16

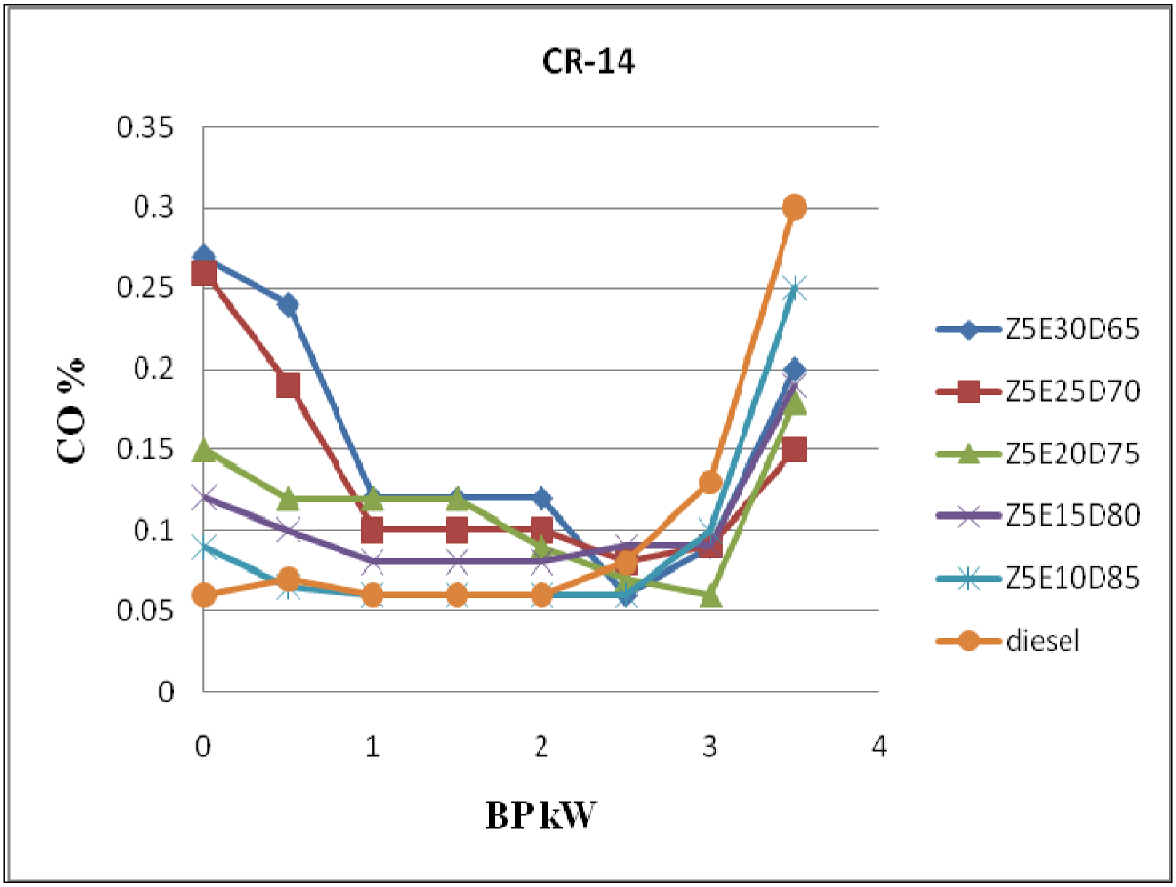


Figure 6.30: Carbon Monoxide (CO) Emissions v/s Brake Power at CR-14

Smoke Opacity v/s Brake Power

Figure 6.31-33 shows the test results of smoke emissions from the engine when fuelled by different fuels. The results show that the smokes from the engine were all lowered down using blends at the 18 compression ratio (Figure 6.31). A similar trend can be found on compression ratio 14 and 16 for the different blends and pure diesel but a significant increase in the smoke opacity on reducing the compression ratio with reference to the CR 18 is observed as shown in the Figure 6.32 and 6.33.

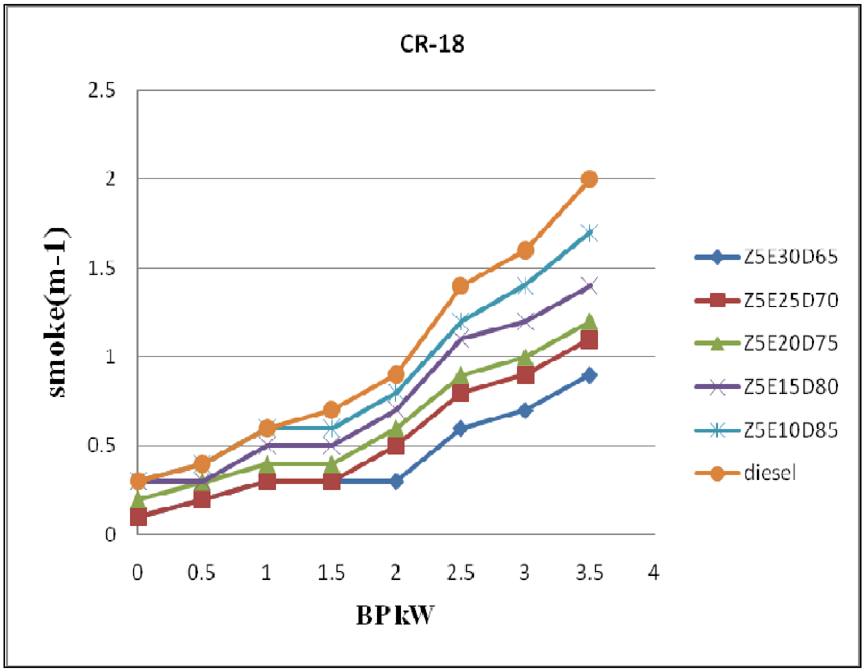


Figure 6.31: Smoke Opacity v/s Brake Power at CR-18

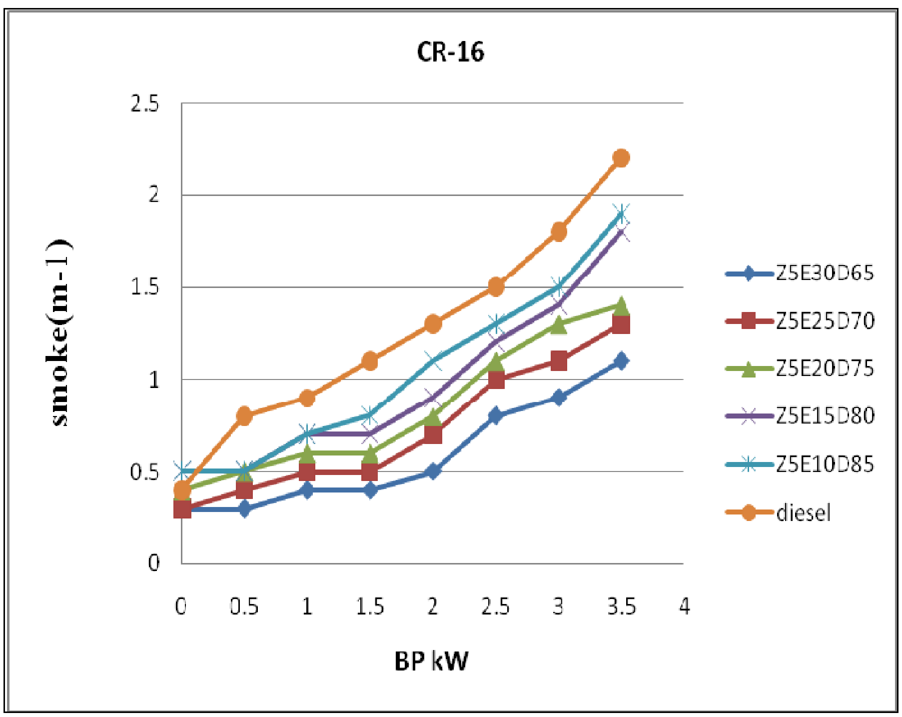


Figure 6.32: Smoke Opacity v/s Brake Power at CR-16

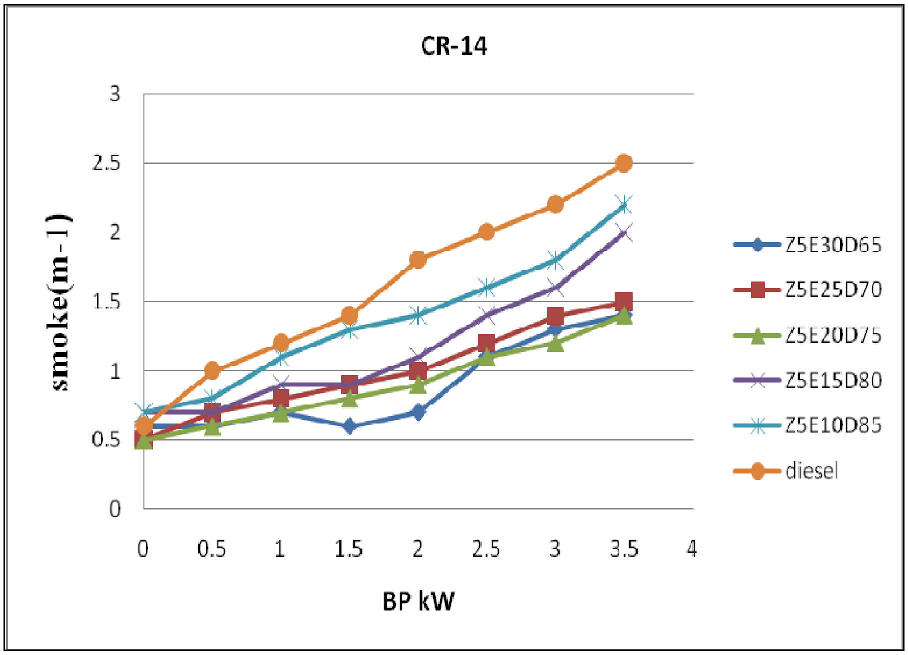


Figure 6.33: Smoke Opacity v/s Brake Power at CR-14

6.5 Concluding Remark

In this work an attempt has been made to find the suitability of various alternative fuels to reduce the exhaust emissions of CI engines. It has been established that the alternative fuels like ethanol, biodiesel and CNG can be conveniently used in CI engines without any major modification and it is also validated that all these alternative fuels are helpful in reducing the exhaust emissions and improve the overall performance of the CI engines. Further in next chapter an attempt is made to evaluate the utility of the alternative fuels in the S. I. engines.

CHAPTER 7.

EXPERIMENTAL INVESTIGATIONS OF EMISSIONS DUE TO SPARK IGNITION ENGINE

7.1 THE OBJECTIVE

A Spark Ignition (SI) engine is a most preferred prime mover for the personal vehicles. Due to its lower compression ratio it has smaller size than that of a diesel counterpart. It has been noticed in the literature review that a lot of work has been done by the researchers to find the suitability of alternative fuels in reducing the SI engine emissions. In this work we tried to validate those results through our experimental work and made an attempt to find out the reliability of various alternative fuels in combating the vehicular emissions. We have performed rigorous experiments on the basic setup shown in the Figure 7.1, to obtain the performance and emission data of E-Gasoline, CNG and LPG.

7.2 ALTERNATIVE FUELS USED IN THE STUDY

In this experimental work ethanol-gasoline blends and CNG/LPG are used as alternate fuels for the performance and emissions study.

7.2.1 CNG

Discussion on CNG has already given in chapter 5 and 6, where we had discussed the details of CNG conversion of the transportation system of Delhi and its suitability as an I.C. engine fuel

7.2.2 LPG

LPG is a clean, high octane, abundant and eco-friendly fuel. LPG is obtained from natural gas through fractionation and from crude oil through refining. It is a mixture of petroleum gases like ethane and butane. The higher energy content in this fuel results in a 10 % reduction of CO_2 emission as compared to CNG. LPG is a gas at atmospheric pressure and normal temperatures, but it can be liquefied when moderate pressure is applied or when the temperature is sufficiently reduced. This property makes LPG an ideal energy source for a wide range of applications; it can be easily condensed, packaged, stored and utilized. When the pressure is released, the liquid makes up about 250 times its volume as gas, so large amount of energy can be stored and transported compactly.

The composition of LPG depends on its source: whether it is extracted from natural gas or produced during the refining of petroleum.LPG is primarily propane, although it may contain significant amounts of ethane and butane as well. Data from the California Air Resources Board (CARB) indicate that the propane content of LPG delivered to CARB over a seven-year period (1982-1989) varied from -63% to 96%. Other sources place the range of propane in LPG from 50%-100%. Further data from the CARB analysis indicated that the ethane content of the fuel was -15% in the early 1980s, but only 4**%** later in the late 1980s. Commercially, there are four grades of LPG:

Commercial propane, which is predominantly propane and/or propylene

Commercial butane, which is predominantly butanes and/or butylenes

Commercial butane-propane mixtures, which are mixtures of butanes, butylenes, propane, and propylene HD-5 propane, which has not less than 90% liquid volume propane and not more than 5% liquid volume propylene. According to Russell et al. only HD-5 propane is suitable as a fuel for spark ignition engines.

Benefits of LPG

Cost of fuel: It is considerably cheaper to run a vehicle on LPG rather than on Gasoline. In the times of ever increasing prices of gasoline, running one's vehicle on LPG gives enormous savings.

Cleaner emissions: LPG impacts greenhouse emissions less than any other fossil fuel when measured through the total fuel cycle. Using LPG as an automotive fuel results in a less emissions compared to Gasoline**.** LPG produces significantly less carbon monoxide, hydrocarbons and oxides of nitrogen emissions as well as a smaller percentage of carbon dioxide emissions than petrol. LPG also emits 90% less particulates, in weight, than diesel engines. It generated no smoke of fumes. It emits extremely low levels of Carbon Monoxide, Hydrocarbons and Nitrogen Oxides. It emits virtually no Sulphur Oxide and no particular matter. Conversion of Petrol to LPG helps substantially reduce air pollution caused by vehicular emissions. The general exhaust emissions of vehicles running of Auto LPG are as following:

- 75 % less CO
- 85 % less Hydrocarbons
- 40 % less NO
- 87 % less Ozone depletion as compared to vehicles running on petrol.

Better for engine oil: LPG users do not need to replace their vehicles as often. The average gas powered engine will last longer than a petrol engine.

Limitations

Initial cost: The cost of legal conversion (including approved conversion kit, CCOE approved LPG fuel tanks, piping, fitment charges and RTO endorsement) is approx. Rs.15000/- to Rs.25000/- depending on type of vehicle and the cylinder shape and capacity.

Lack of filing stations: As on 2007 more than 150 Auto LPG Dispensing Stations (ALDS) have been set up in Metros / Major Cities in India. Many other ALDSs have been mechanically completed & are likely to be commissioned couple of month. But compared to CNG, of which there are more than 180 Stations in Delhi itself, there is a great shortfall of LPG filling facilities.

Tank space: Converting a gasoline driven vehicle to LPG reduces the space in the vehicle. The tank may be located in the boot, reducing space for luggage and possibly meaning the loss of the spare wheel.

Safety Considerations: Its vapour flammability limits in air are wider than those of petrol, which makes LPG, ignite more easily.

Worldwide use of LPG:

There are around 4 million vehicles in several countries around the world using LPG as automotive fuel, supported by 21,000 dispensing stations. Turkey has the maximum number of vehicles running on LPG (around 1,100,000)followed by Italy (10,00,000) Australia (around 490,000) North America (around 400,000) and the Netherlands (around 360,000) In Japan, almost all the taxis run of Auto LPG and the country has the highest usage of Auto LPG in the world. With effect from April 24, 2000, the use of Auto LPG as an automotive fuel was made legal in India, albeit within the prescribed safety terms and conditions. However, use of domestic LPG cylinders in automobiles is illegal. With rising automotive fuel prices at the global level, customers are increasingly opting for economical and eco-friendly fuel alternatives, one of which is Auto LPG. Auto LPG has less impact on greenhouse emissions than any other fossil fuel when measured through the total fuel cycle. The higher energy content in this fuel results in a 10% reduction of CO_2 emission compared to other fuels and substantially reduces air pollution caused by vehicular emissions. With a switchover to Auto LPG–driven cars, customers can save about 30% on their fuel bills.

7.2.3 Ethanol Blends

A brief discussion for the use of ethanol in C.I. engines as ethanol blended (Desihol) is already given in chapter VI but due to its easy miscibility with petrol and a higher octane number ethanol is preferably blended in with gasoline and. The comparison of various properties of CNG/LPG/Ethanol and Gasoline fuel is summarised in Table 7.1.

Table 7.1 The Comparisons of The S.I. Engine Fuels

Parameter	**LPG**	**CNG**	**Ethanol Blends**
Fuel Quality	Stable Quality, since produced in Refineries under controlled conditions.	Varying composition since it is supplied direct from the wells without any processing.	Improves Quality of Gasoline due to its oxygenating characteristic
Storage Pressure	10 bar	200 bar	At atmospheric Pressure
Refueling Time	Like gasoline, 4 to 5 minute	High, 5 to 10 minutes, depending on the differential pressure, gaseous handling.	Like gasoline, 2 to 3 minute
Engine Performance	Better than Petrol under high speed and heavy load conditions. Better emissions improvement	Improved combustion, Compression ratio may be increased to increase the efficiency Best emission improvement	Improved combustion and improved emissions
Availability	Can be made available in any part of the Country by installing Storage facility.	Available only on select cities where pipeline has been laid.	Enough, a by-product of sugar industry, some additional setups need to be installed
Cost of Dispensing infrastructure	Approx. 40 Lakhs Rs at an existing Retail Outlet	Approx.150 Lakhs Rs at an existing Retail Outlet.	Negligible, Facility may be provided at petrol pumps
Cost of conversion of vehicle	Rs.15000/- to Rs.25000/-	Rs.35000/- to Rs.40000/- (for 3 /4 wheelers). Rs.300000/- for buses.	No additional cost up to 10 to 15 %, for higher blends minor modifications required.

7.3 RATIONAL FOR THE EXPERIMENTATL MODULES

There was a Maruti Wagon R MPFI Engine in the Automobile Engineering laboratory. The setup designed consists of four cylinders, four strokes, Petrol (MPFI) engine connected to eddy current type dynamometer for loading. It is provided with necessary instruments for measurements of combustion pressure and crank-angle; details of the system are shown in schematic diagram 7.1 and actual test setup is shown in Figure 7.2.

These signals are interfaced to computer through engine indicator for p-θ & p-v diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. To generate the desired data on engine performance and emissions with different alternative fuels it has been converted to different modules, which are described below

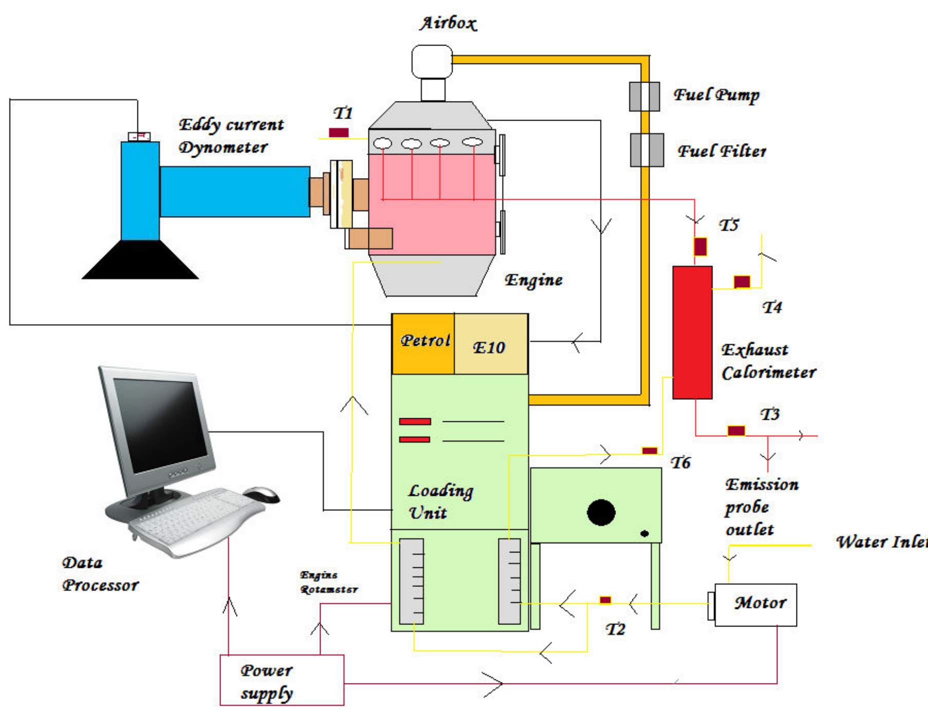


Figure 7.1: Schematic Diagram of the S.I. Engine Test Set-up

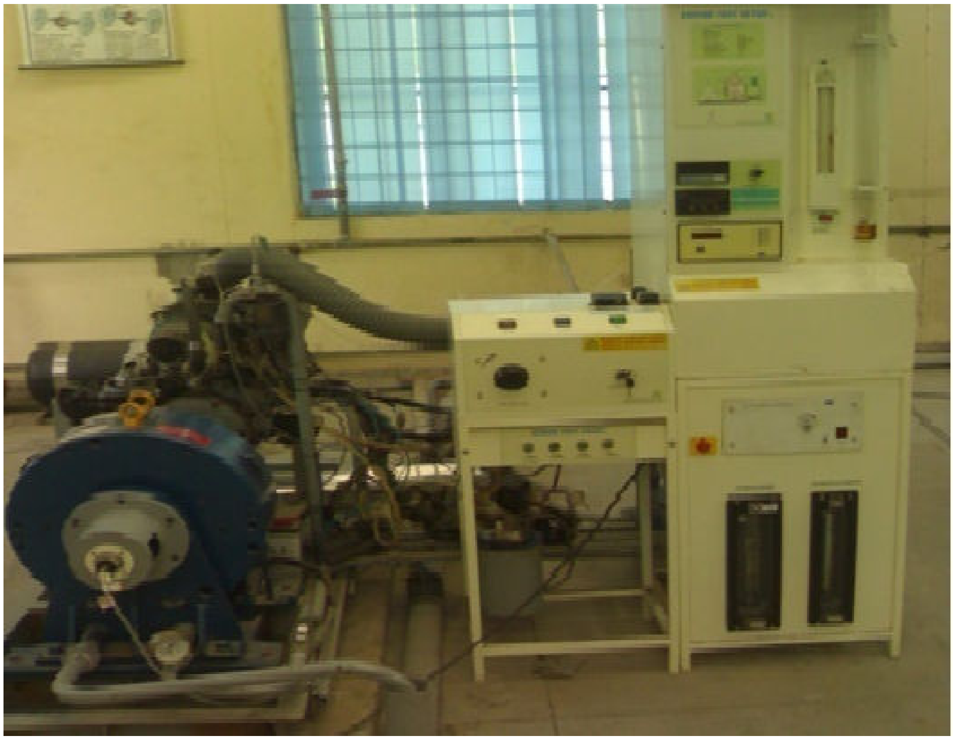


Figure 7.2: The Actual Test Set-up of Maruti Wagon (R) MPFI Engine

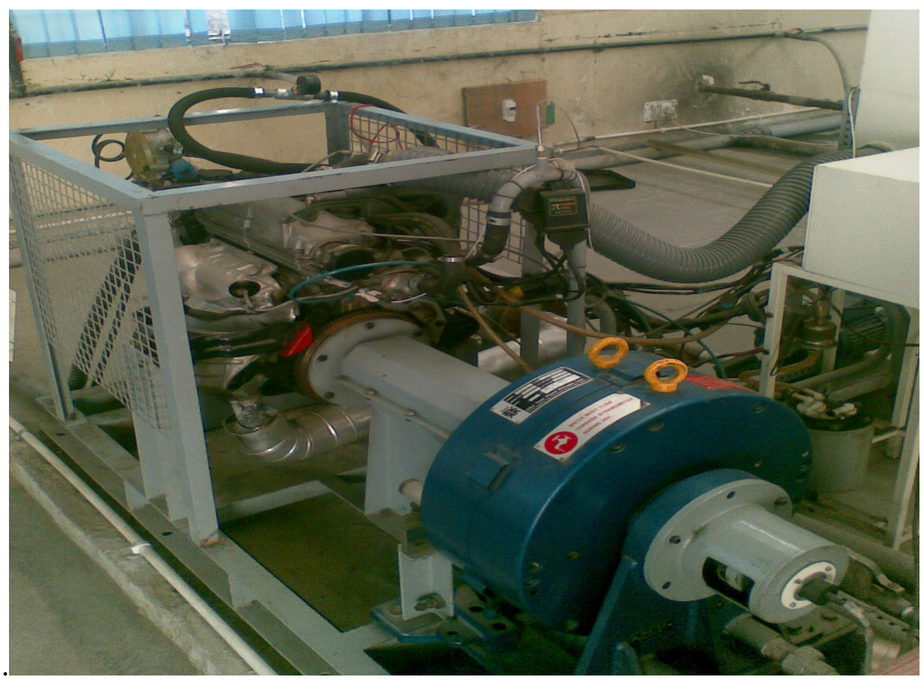


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Figure 7.3: Wagon R Engine Coupled to the Eddy Current Dynamometer

Figure 7.4: The CNG Conversion Kit –Pressure Regulator

Figure 7.5: The LPG Conversion Kit–Pressure Regulator

The CNG can be used in an S.I. Engine designed for the Gasoline Fuel with the installation of a CNG supply system kit as shown in Figure 7.4 and a CNG storage cylinder. The Characteristics and specifications of main components of CNG/LPG and E-Gasoline module are given in Table 7.2 The CNG is stored at a pressure of 20-25 MPain the strage cylinder and need to be brought at atmosphric pressurebefore being fed into the combustion chamber. For measuring the performance and emissions we also need to measure the CNG flow for which a rotameter and a pressure gauges are requiredith gasoline and used similar to as that of Gasoline.

Figure-7.6 LPG and CNG Conversion Kits Mounted on the Engine

7.4 METHODOLOGY OF THE EXPERIMENTAL WORK

Various alternative fuels such as CNG/LPG/Ethanol were used on Wagon® S.I. Engine the above experimental setups at different loads and the data on thermal efficiency, specific fuel consumption, exhaust emission level etc. were recorded. An overview of the Methodology used for the experiments is given in the Table 7.3

Table 7.2: Characteristics/Specifications for the CNG/LPG/Ethanol Module

S. No.	Component	The CNG Module	The LPG Module	The E-Gasoline Module
1.	**Engine**	Make-Maruti, Model Wagon-R MPFI 4Cylinders, 4Stroke, Power44.5 kW at 6000 rpm, Torque 59 Nm at 2500rpm, Stroke 61mm, Bore 72mm,Vol. 1100 CC, CR 9.4:1	Same as that of CNG module	Same as that of CNG Module
2.	**Dynamometer**	Type eddy current, water cooled, with loading unit, Make- Saj test plant Pvt. Ltd., Model AG80	Same as that of CNG module	Same as that of CNG Module
3.	**Propeller shaft**	With universal joints, Make Hindustan Hardy Spicer.	Same as that of CNG module	Same as that of CNG Module
4.	**Air box**	M S fabricated with orifice meter and manometers (Orifice dia 40 mm)	Same as that of CNG module	Same as that of CNG Module
5.	**Fuel tank**	CNG High Pressure storage cylinder, 12 Kg at 200 bar	LPG Cylinder	Same as that of Gasoline module
6.	**Calorimeter**	Type Pipe in pipe, 25-250 LPH	Same as that of CNG module	Same as that of CNG Module
7.	**Rotameter Dynamometer**	Make Eureka Model PG 5, Range 25-250 lph, Connection ¾” BSP vertical, screwed, packing Neoprene	Same as that of CNG module	Same as that of CNG Module
8.	**Rotameter Calorimeter**	Make Eureka, Model PG 9, Range 100-1000 lph, Connection 1” BSP vertical, screwed, packing, Neoprene	Same as that of CNG module	Same as that of CNG Module
9.	**Piezo sensor**	Make PCB Piezotronics, Range 5000 psi, Diaphragm stainless steel type & Hermetically Sealed	Same as that of CNG module	Same as of CNGModule
10.	**Load indicator**	Make Selectron, model PIC 152–B2, 85to270VAC	Same as of CNG module	Same as of CNG Module
11.	**Temperature sensor**	Make Radix Type K, Ungrounded, Sheath Dia.6mmX110mmL, SS316, Connection 1/4"BSP (M) Adjustable compression fitting	Same as that of CNG module	Same as that of CNG Module
12.	**Fuel Flow Rotameter**	Make JSP Range 0-100 LPM	Make JSP Range 0-50 LPM	Similar to Gasoline
13.	**Temperature Transmitter**	Make Wika, K0-4NK-,Input, Thermocouple (typeK), output 4-20mA, supply 24VDC,Range 0-1200deg.C	Same as that of CNG module	Same as that of CNG Module
14.	**Load indicator / sensor**	**D**igital, Range 0-50 Kg, Make Sensotronics, Type S beam, Universal, Capacity 0-50 kg	Same as that of CNG module	Same as that of CNG Module
15.	**Air flow transmitter**	Air flow transmitter **/** Pressure transmitter, Range (-) 250 mm WC	Same as that of CNG module	Same as that of CNG Module
16.	**Fuel Supply System**	CNG Conversion Kit Make: Tomasetto Achilles,	LPG Kit, make LOVATO,	Through MPFI ECM

Table 7.3 Overview of Methodology for the Experimental Modules

Characteristics → / Module ↓	Methodology
The CNG Module	The fuel were supplied to the engine in the form of Air and CNG mixture and readings were taken at different loads/RPM, simultaneously engine exhaust emissions were measured with AVL multi gas analyser
The LPG Module	The fuel were supplied to the engine in the form of Air and LPG mixture and readings were taken at different loads/RPM, simultaneously engine exhaust emissions were measured with AVL multi gas analyser
The E-Gasoline Module	The fuel were supplied to the engine in the form of Ethanol-Gasoline blends (at 5,10 and 15%) and Air mixture and readings were taken at different loads/RPM, simultaneously engine exhaust emissions were measured with AVL multi gas analyser

7.5 Discussion on Performance and Emissions with Gasoline/CNG/LPG

The data from the experimental observations for the performance parameters were recorded with 'enginesoft' programe while various emissions data were recorded and curves are drawn with the help of Microsofat Exel.

7.5.1 Comparative Performance & Emissions Curves for Petrol /CNG/LPG

CNG or LPG use in gasoline engine can favourably impact mobile source emissions in five main air quality areas these areas are fine particulate matter (PM), carbon monoxide, toxics, ozone, and global warming.

Here in this performance evaluation test we are showing different curves b/w load (kilo Watt) Vs. thermal efficiency (%), Bsfc kg/kWhr, CO (%), HC(ppm) and NO_x in ppm.

The various performance and emissions curves for Gasoline, CNG, and LPG are shown in Figure 7.7 to 7.10.

Following observations are made from these curves:

- The results of Thermal Efficiency Vs. Power, Figure 7.7 show that gasoline gives the most optimum thermal efficiency, especially at higher power, closely followed by CNG and LPG. Therefore for engines designed to run on gasoline, LPG and CNG can be close substitutes but cannot achieve the same level of thermal efficiency across the power range. As the test rig engine i.e. Wagon R, in line engine was basically a gasoline engine, thermal efficiency showed the above mentioned trend. Though efficiency can be improved by increasing the compression ratio for the CNG or LPG module keeping in consideration that their higher knocking resistance. Further it can be seen that, the present engine with CNG or LPG cannot produce the same maximum power, as it suffers a power loss as compared to the gasoline mode. However the trend of BSFC Vs. Powershow that for the three fuels it is observed that CNG gives the lowest BSFC vis-à-vis gasoline and LPG even when used to run an engine designed for gasoline, although it increases somewhat at very high power. This observation reinforces the fact that optimum BSFC is achieved by using CNG even in an unmodified gasoline engine.

- Use of CNG and LPG in Gasoline engines reduces the CO emissions (this may be attributed to better mixing of air and fuel) vis-à-vis gasoline but at higher loads this drop in emissions is not realised, this can be seen from Figure 7.8

- There is a slight gain in HC emissions reduction throughout the power range in case of CNG and LPG as compared to gasoline as it is evident from Figure 7.9. But this gain is reduced at higher loads.

- There is no considerable difference w. r. t. NO_x emission when the engine was run on gasoline, CNG and LPG and ethanol blends as clear from Figure 7.10. In some cases there is a little increase in NOx emissions with CNG and LPG. Therefore the gains of low NO_x emissions cannot be achieved by using the alternate fuels in an engine designed for gasoline. Other technological options must be incorporated for NOx control.

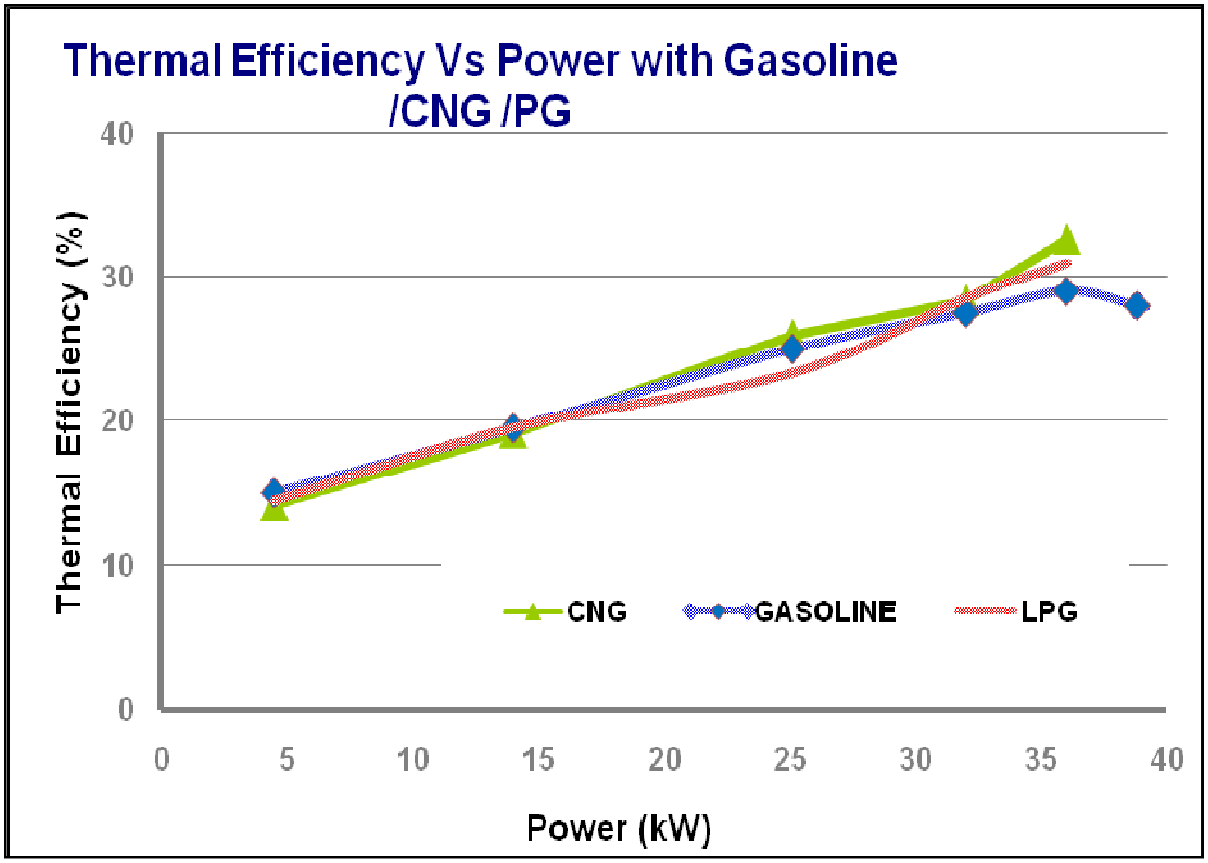


Figure-7.7: Curve b/w Thermal Efficiency v/s Power

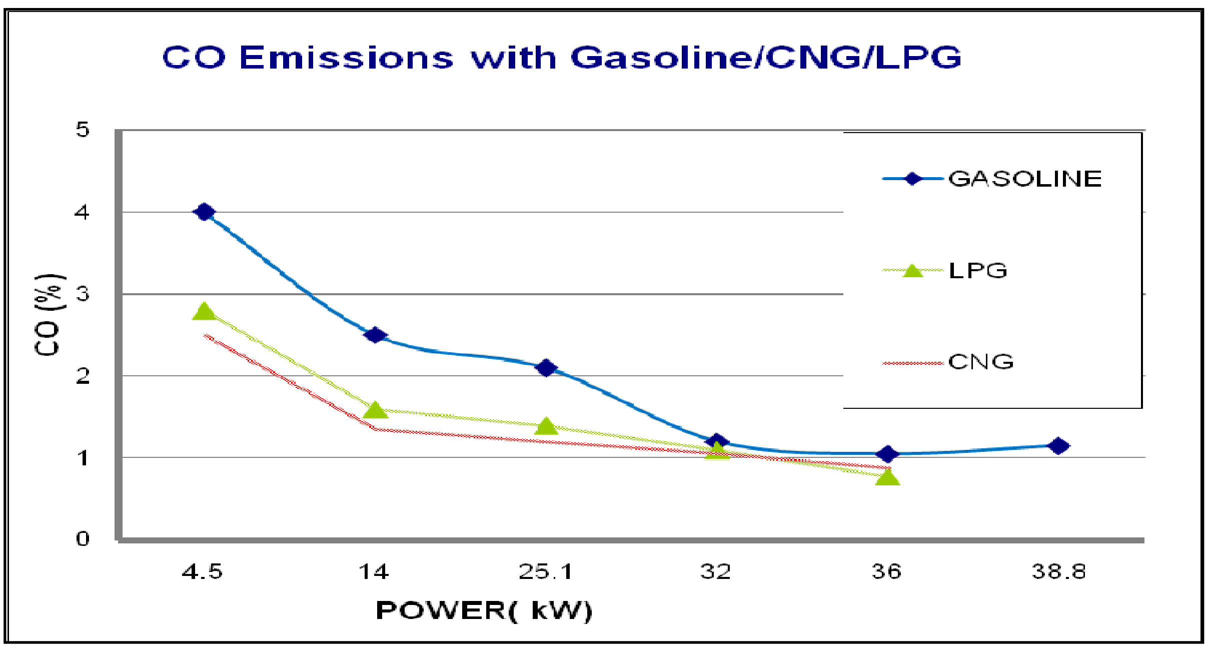


Figure-7.8: Curve b/w CO v/s Power for Gasoline, CNG & LPG

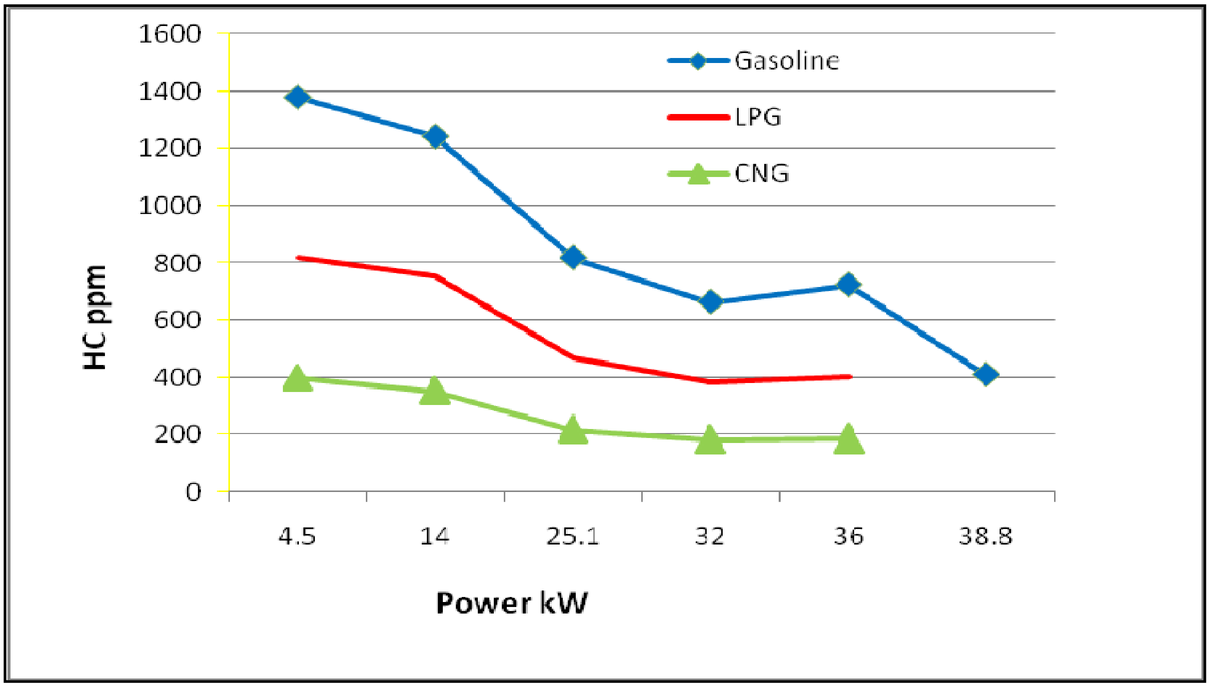


Figure-7.9: Curve b/w HC v/s Power for Gasoline, CNG & LPG

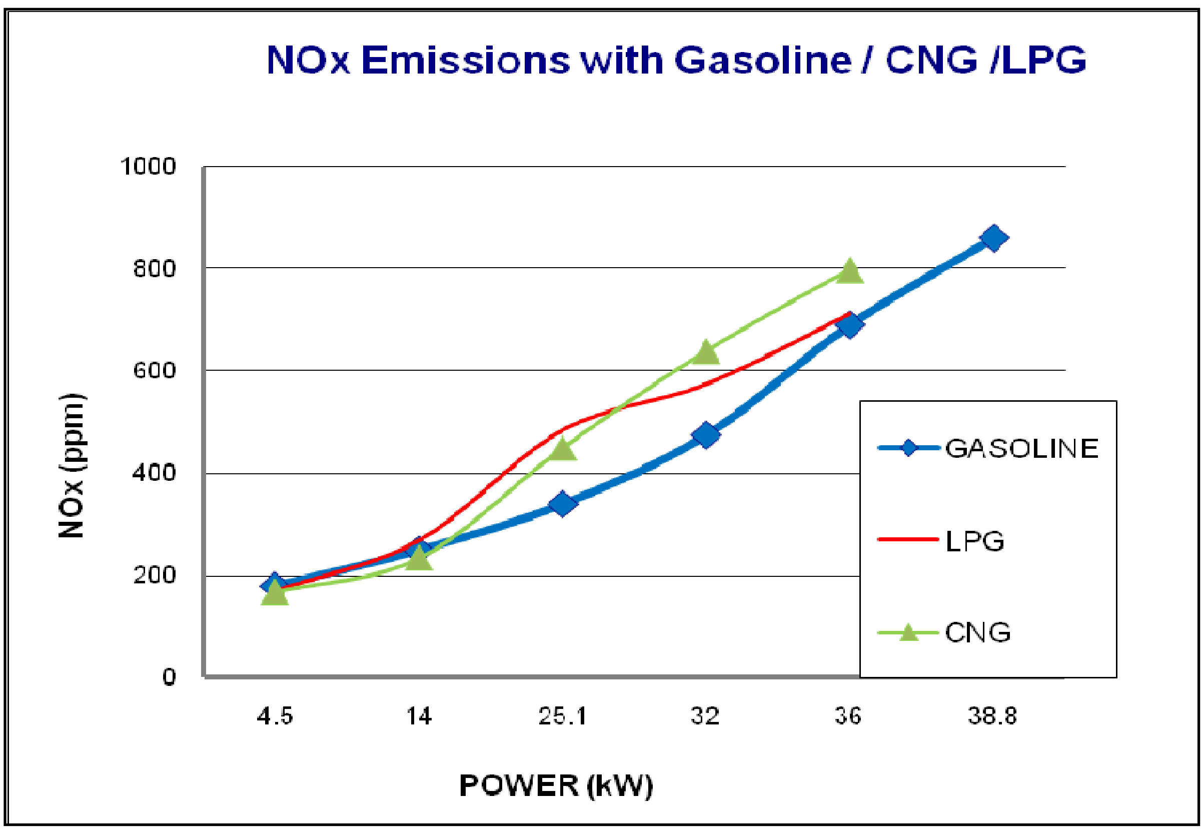


Figure-7.10: Curve b/w NOx v/s Power for Gasoline, CNG & LPG

7.5.2 Comparative Performance and Emissions Curves for Gasoline & Ethanol Blends

Using ethanol blend in gasoline engine can favourably reduce fine particulate matter (PM), carbon monoxide, toxics, ozone, and global warming. Here in this performance evaluation test we are showing different curves b/w load (kilo Watt) Vs. thermal efficiency (%), Bsfc kg/kWhr, CO (%), HC(ppm) and NO_x in ppm.

The various performance and emissions curves for Gasoline and ethanol blends from E5 to E15 are shown in Figure 7.12 to 7.16.

Following observations are made from these curves:

- The results of thermal efficiency Vs. power, Figure 7.12 show that ethanol blends of 7.5 to 12.5% gives the most optimum thermal efficiency, especially at higher power, the gains are more. Still the gain in absolute are small and a higher compression ratio is need to be investigated to utilise the anti knock characteristics of ethanol blends. Also an increase in the power may be attributed to the increased volumetric efficiency of the engine due to the higher latent heat of vapourisation of ethanol of 207 Kcal/kg as compared to 70-100 Kcal/kg of gasoline. Also due to the higher latent heat of vapourisation the combustion temperatures for the blended ethanol fuel decreases and the amount of thermal load on the engine is also decreased. Therefore for engines designed to run on gasoline, marginal thermal efficiency improvement can be obtained.

- Considering the trend of bsfc Vs. power, Figure 7.13 show that for all the ethanol blends the combustion efficiency improves but at higher blends bsfc increases slightly due to lower specific heat of the ethanol and this increase is significant at higher power. We have though found an increase in bsfc with ethanol blends over gasoline when the engine was run at higher loads and this further increased with increase in blend % of ethanol.

- The addition of ethanol to gasoline causes an increase in the oxygen available for combustion in the intake charge thereby making the air fuel mixture lean in an unmodified engine, hence the charge burns more completely Use of ethanol blends in gasoline engines reduces the CO emissions vis-à-vis gasoline also at higher loads the drop in CO emissions is higher, this can be seen from Figure 7.14.

- The HC emissions reduction is observed throughout the power range in case of ethanol blends as compared to gasoline as it is evident from Figure 7.15. This shows a decrease in HC emissions with gasohol. Since the entry of the fuel vapour to the crevices, flame quenching and absorption by the oil layer would be more or less similar for all the ethanol blends. The difference in the unburnt hydrocarbon emissions may be attributed to following statements.

- There is no considerable difference w. r. t. NO_x emission when the engine was run on gasoline, CNG and LPG and ethanol blends as clear from Figure 7.16. In some cases there is a little decrease in NOx emissions with the ethanol blends. But significantly low NO_x emissions cannot be achieved by using the alternate fuels in an engine designed for gasoline. Other technological options must be incorporated for NOx control.

- Also since the flame speed of ethanol is 49 cm/s as compared to 45 cm/s for gasoline the air fuel charge combustion with E10 and above are completed much earlier during the expansion stroke, thereby decreasing the probability of CO emissions due to flame quenching caused by downward movement of the piston. NOx emissions with E10 and above were observed to be lower as compared to gasoline with the engine equivalence ratio maintained in the range of 0.85-0.95 by the engine lambda sensor. It is found that as the blend percentage is increased the maximum NOx emissions take place at higher value of equivalence ratio i.e. at much richer mixtures than stochiometric because of the inherent oxygen content in ethanol. Lower NOx emissions with the ethanol blends are attributed to the lower flame temperature of ethanol fuel of 2197 K as compared to 2266 K for gasoline.

- Hence for the ethanol gasoline blends the tendency of nitrogen to oxidize to NO and NO_2 will be lesser as compared to gasoline. Also ethanol flame's lower luminosity reduces the heat loss by radiation and leads to lower NOx emission from the engine.

Exhaust gas temperature is found to be on the higher side with the increase in the percentage content of ethanol in gasoline and CNG and LPG operations. This may be attributed to a more complete combustion under lean burning conditions with the ethanol gasoline blends and lean air fuel mixture content increasing the value of the ratio of specific heats (γ) leading to an increased exhaust gas temperature. Normally at higher value of RPM exceeding 3000 RPM maintaining a constant throttle opening and at higher values of load, exhaust temperature are slightly higher. However at lower engine rpm the exhaust gas temperature with E10 and higher found to be lower.

Pressure v/s Crank Angle Variation

It can be seen easily from the graphical variation of cylinder pressure with the crank angle for the fuels gasoline, E10 and E15 that the peak cylinder pressure in higher in case of the oxygenated fuels i.e. E10 and E15 because the excess oxygen in the ethanol molecule allows the mixture to burn lean thereby providing a cylinder atmosphere for complete combustion as compared to gasoline. Also the noticeable difference in the peak pressures using the three test fuels is attributed to the increase in the volumetric efficiency of the engine caused due to higher latent heat of vapourisation of the blend as compared to pure gasoline. However it is primarily noticed that the peak cylinder pressure for the ethanol gasoline blends is reached earlier after TDC as compared to gasoline. This may be attributed to higher flame velocity of 48 cm/s of ethanol as compared to gasoline whose is 45 cm/s.

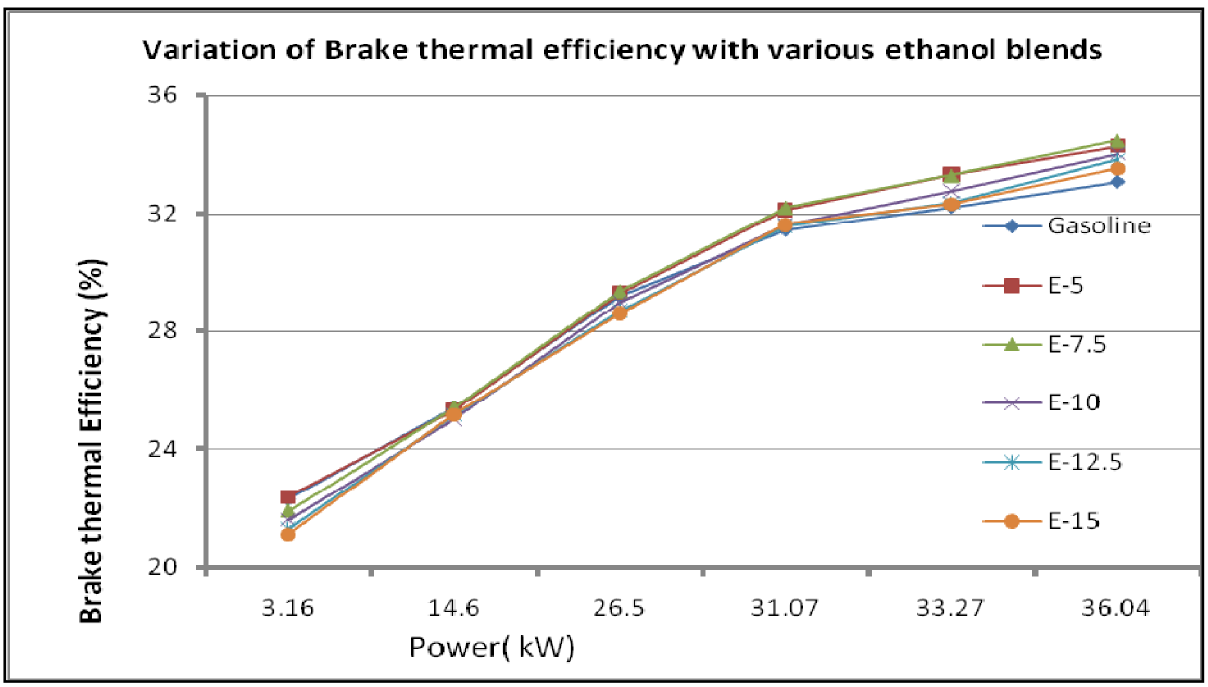


Figure 7.11 Variation of Brake Thermal Efficiency with Various Ethanol Blends

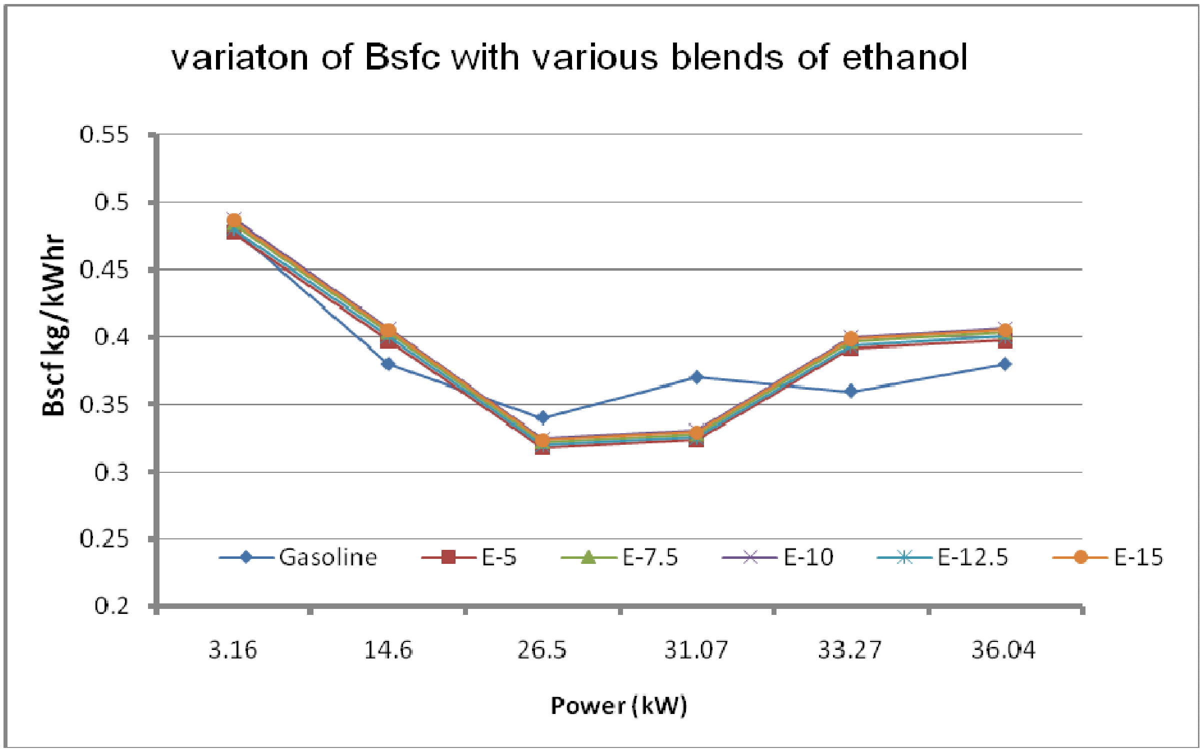


Figure-7.12: Curve b/w Bsfc v/s Power for Gasoline Ethanol Blends

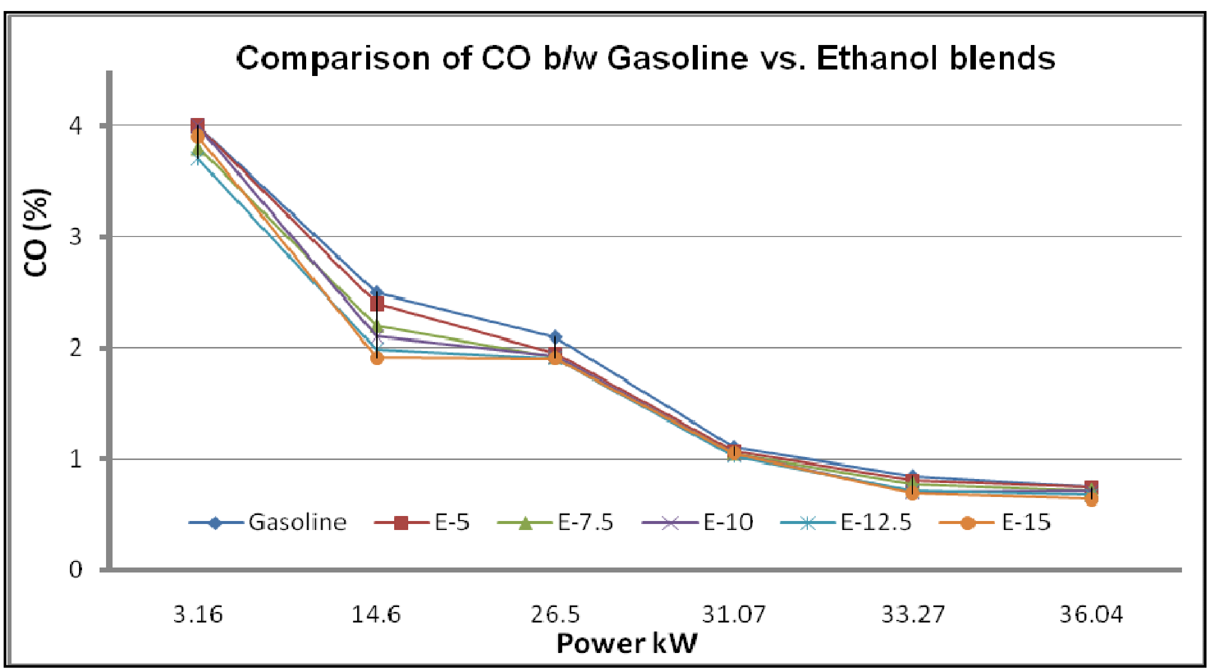


Figure-7.13: Curve b/w CO v/s Power for Gasoline Ethanol Blends

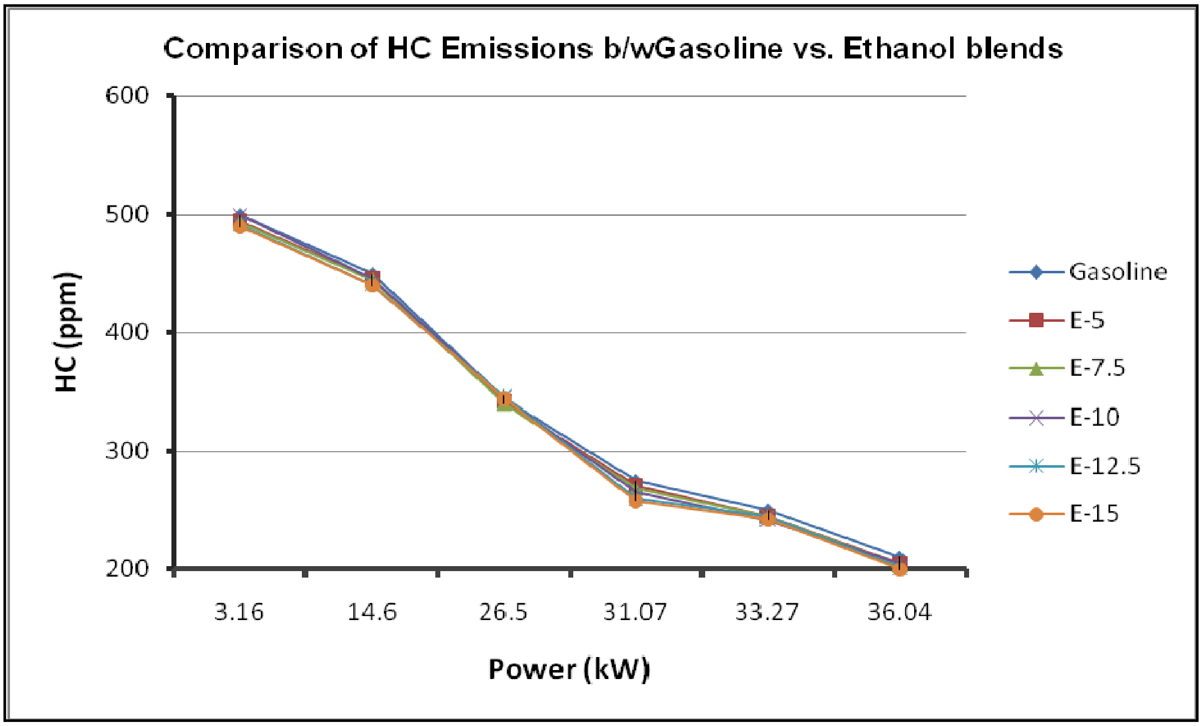


Figure-7.14: Curve b/w HC v/s Power for Gasoline Ethanol Blends

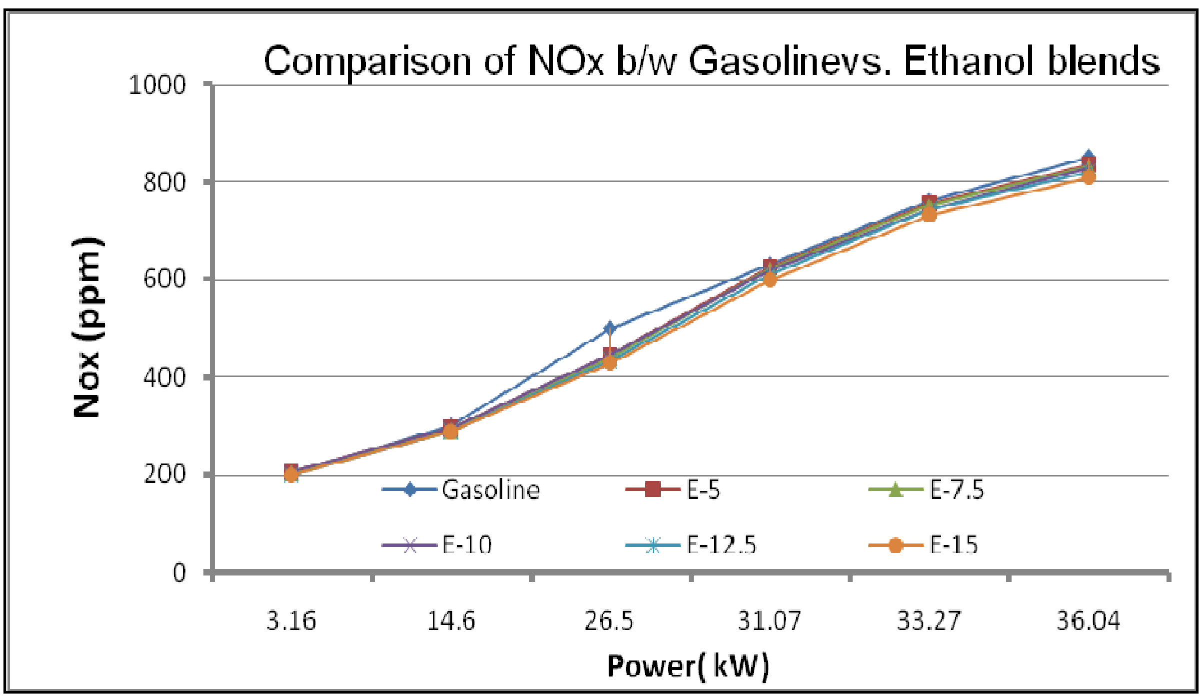


Figure-7.15: Curve b/w NOx v/s Power for Gasoline Ethanol Blends

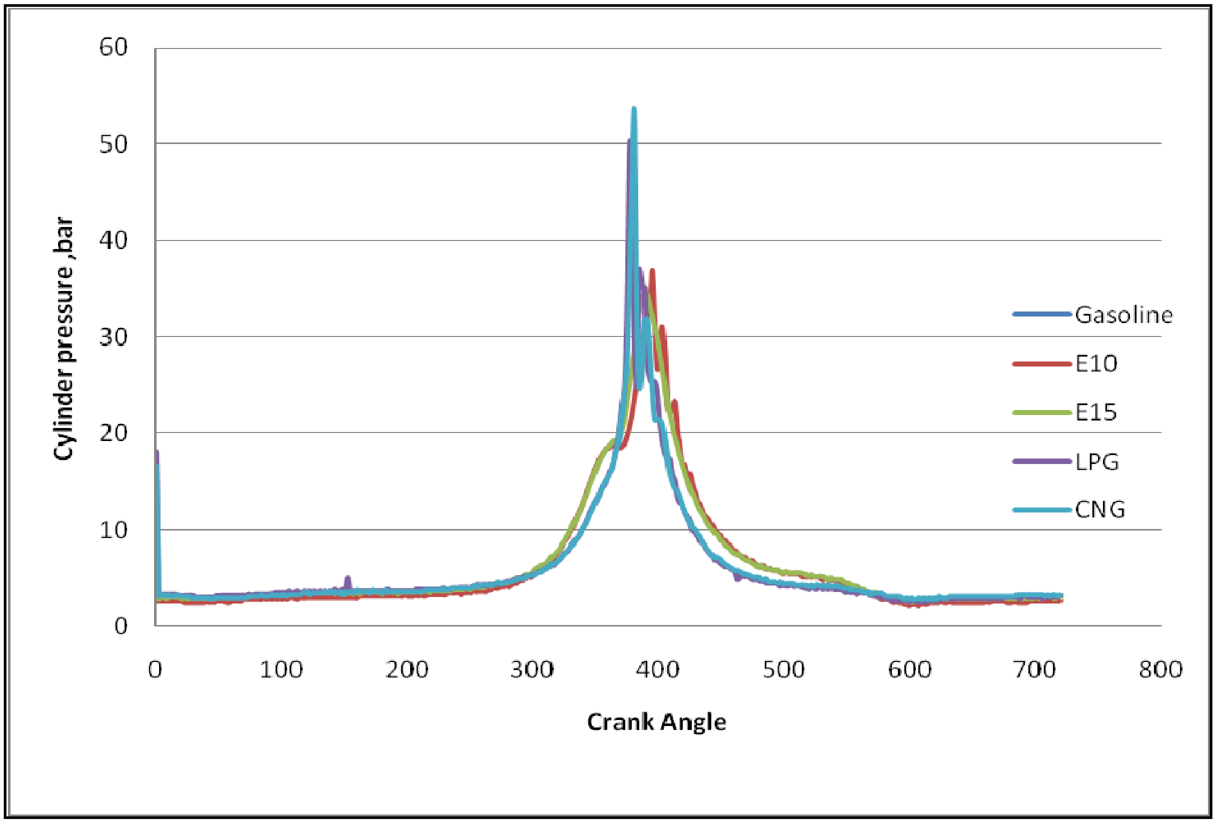


Figure-7.16: p-θ Curve for Gasoline CNG/LPG Ethanol Blends at 3000RPM

7.6 CONCLUDING REMARKS

The benefits of CNG and LPG as alternate automotive fuels may not be realized by simply using them in an unmodified petrol engine. As the test results indicate, the energy content of CNG and LPG is the most limiting factor in acceptance for fuel economy and performance reasons. Optimum performance is achieved by using gasoline but alternate fuels i.e. LPG and CNG aid in emissions reduction in terms of CO and HC emissions but still in terms of NO_x emissions no considerable difference is noticed.

- The results of Thermal Efficiency Vs Power show that gasoline gives the most optimum thermal efficiency closely followed by LPG and CNG. Therefore for engines designed to run on gasoline, LPG and CNG can be close substitutes but cannot achieve the same level of thermal efficiency. As the test rig engine i.e.

Wagon–R, 4 cylinder, in line engine was basically a gasoline engine, thermal efficiency showed the above mentioned trend.

- Considering the trend of BSFC Vs. Power for the three fuels it is again reiterated that LPG and CNG give a higher BSFC vis-à-vis Gasoline when used to run an engine designed for gasoline. The fact is reinforced that optimum BSFC is achieved by using gasoline in an unmodified engine.
- Use of CNG and LPG in gasoline engines reduces the CO emissions vis-à-vis gasoline but at higher loads this drop in emissions is not realized.
- Drop in HC emissions is consistent throughout the power range in case of CNG and LPG as compared to gasoline.
- There is no considerable difference with reference to NOx emission when the engine was run on gasoline, CNG and LPG. Therefore the gains of low NO_x emissions cannot be achieved by using the alternate fuels in an engine designed for gasoline.

After completing this experimental work it was decided to gather the public/experts opinion on future transportation policy guidelines, which are discussed in next chapter.

CHAPTER 8.

LIKELY FUTURE SCENARIO OF THE VEHICULAR EMISSIONS BASED ON EMPIRICAL INVESTIGTIONS

8.1 INTRODUCTION

Optimization of the vehicular emissions of a metro city public transportation system cannot be done either by experimental investigations alone or by processing any amount of statistical data through some very intelligent software. Any honest approach for it needs to incorporate the judgment, critical comments and suggestions by the people who use these systems and who also know the technical aspects of these systems. This is also in consonance with the social obligations enshrined in our constitution which declares our country as a Sovereign Democratic Republic and where such systems directly relate to the welfare of our people.

It is therefore, in addition to experimental work and statistical data collection; it was decided to conduct a survey to obtain the feedback and the suggestions of the people, mainly belonging to technical background, about the present and future transportation system. When various techniques have been studied for future planning and conflict resolution, it was decided to commission the Delphi methodology for the present problem. The Delphi methodology enables one to incorporate the opinions of a large number of experts/participants, about the present public transportation system and their preferences, without creating any conflict or wide disagreements.

8.2 THE DELPHI VERSUS OTHER STATISTICAL PROCEDURES

The average estimate of Delphi panellists on the first round – prior to iteration or feedback – is equivalent to that from a statistical sized group. Comparing a final round Delphi aggregate to that of the first round is thus, effectively, a within-subjects comparison of techniques (Delphi versus statistical sized group). Although the comparison of round averages should be possible in every study considering Delphi accuracy/quality, a number of evaluative studies have omitted to report round differences [Fischer (1981) and Riggs (1983)]. Many studies have reported significant increase in accuracy over Delphi rounds [Erffmeyer et al. (1986), and Rowe & Wright (1996)]. Some other studies have reported Delphi to be better than statistical or first round aggregates more often than not, or to a degree that does not reach statistical significance [Dalkey et al. (1963), Brockhoff (1975) and Rohrbaugh (1979)].

8.3 THE DELPHI TECHNIQUE

Delphi is one of the most widely used techniques for creative exploration of ideas for the production of suitable information for the decision making or future planning applications. The Delphi study or technique was used to determine if there are emerging patterns or consensus on leadership practices and information technologies used in leading virtual teams. The purpose of the Delphi technique is to elicit information and judgments from participants to facilitate problem-solving, planning, and decision-making. Why Delphi was used in this study is explained in the chapter 3 on the selection of the research methodology.

8.4 THE HISTORY OF DELPHI

The Delphi technique was developed during the 1950s by the workers at the RAND Corporation while operating on a U.S. Air Force sponsored project. The aim of the project was the application of expert opinion to the selection – from the point of view of a Soviet strategic planner – of an optimal U.S. industrial target system, with a corresponding estimation of the number of atomic bombs required to reduce armaments output by a prescribed amount. More generally, the technique is seen as a procedure to ‘‘obtain the most reliable consensus of opinion of a group of experts by a series of intensive questionnaires interspersed with controlled opinion feedback’’ (Dalkey & Helmer, 1963). In particular, the structure of the technique is intended to allow access to the positive attributes of interacting groups (knowledge from a variety of sources, creative synthesis, etc.), while pre-empting their negative aspects (attributable to social, personal and political conflicts etc.), from a practical perspective, the method allows input from a larger number of participants that could feasibly be included in a group or committee meeting and from members who are geographically dispersed.

Delphi is not a procedure intended to challenge statistical or model-based procedures, against which human judgment is generally shown to be inferior. It is intended for use in judgment and forecasting situations in which pure model-based statistical methods are not practical or possible because of the lack of appropriate historical / economic / technical data, and thus where some form of human judgmental input is necessary (Wright et al., 1996). Such input needs to be used as efficiently as possible, and for this purpose the Delphi technique might serve a role.

Four key features may be regarded as necessary for defining a procedure as a 'Delphi'. These are: Anonymity, Iteration, Controlled feedback, and Statistical aggregation of group response.

Anonymity is achieved through the use of questionnaires. By allowing the individual group members an opportunity to express their opinions and judgments privately, undue social pressures – as from dominant or dogmatic individuals or from a majority – should be avoided. Ideally, this should allow the individual group members to consider each idea on the basis of merit alone, rather than on the basis of potentially invalid criteria (such as the status of an idea's proponent).

Furthermore, with the **iteration** of the questionnaire over a number of rounds, the individuals are given the opportunity to change their opinions and judgements without fear of losing face in the eyes of the others in the group.

Between questionnaire iterations, **controlled feedback** is provided, through which the group members are informed of the opinions of their anonymous colleagues. Often feedback is presented as a simple statistical summary of the group response, usually comprising a mean or median value, such as the average 'group' estimate of the date by when an event is forecast to occur.

Occasionally, additional information may also be provided, such as arguments from individuals whose judgments fall outside certain pre specified limits. In this manner, feedback comprises the opinions and judgments of all group members and not just the most vocal. At the end of the polling of participants (i.e., after several rounds of questionnaire iteration), the group judgment is taken as the **statistical average** (mean / median) of the panellists' estimates on the final round.

The above four characteristics are necessary defining attributes of a Delphi procedure, although there are numerous ways in which they may be applied. The first round of the classical Delphi procedure (Martino, 1983) is unstructured, allowing the individual experts relatively free scope to identify, and elaborate on, those issues they see as important. These individual factors are then consolidated into a single set by the monitor team, who produce a structured questionnaire from which the views, opinions and judgments of the Delphi panellists may be elicited in a quantitative manner on subsequent rounds.

After each of these rounds, responses are analysed and statistically summarised (usually into medians plus upper and lower quartiles), which are then presented to the panellists for further consideration, if panellists' assessments fall outside the upper or lower quartiles, they may be asked to give reasons, why they believe their selections are correct against the majority opinion? This procedure continues until stability in panellists' responses is achieved. The forecast or assessment for each item in the questionnaire is typically represented by the median on the final round. An important point to note here is that variations from the above Delphi model do exist (Martino, 1983). Most commonly round one is structured in order to make the application of the procedure simpler for the monitor team and panellists; the number of rounds is variable, though seldom goes beyond one or two iterations (during which time most change in panellists' responses generally occurs).

Often, panellists may be asked for just a single statistic – such as the date by when an event has a 50% likelihood of occurring – rather than for multiple figures or dates representing degrees of confidence or likelihood (e.g., the 10% and 90% likelihood dates), or for written justifications of extreme opinions or judgments. These simplifications are particularly common in laboratory studies and have important consequences for the generalise ability of research endings.

One of the aims of using Delphi is to achieve greater consensus amongst panellists. Empirically, consensus has been determined by measuring the variance in responses of Delphi panellists over rounds, with a reduction in variance being taken to indicate that greater consensus has been achieved. Results from empirical studies seem to suggest that variance reduction is typical, although claims tend to be simply reported unanalysed (Dalkey & Helmer, 1963), rather than supported by analysis (Jolson & Rossow, 1971). Indeed, the trend of reduced variance is so typical that the phenomenon of increased 'consensus', per se, no longer appears to be an issue of experimental interest. Where some controversy does exist, however, it is in whether a reduction in variance over rounds reflects true consensus (reasoned acceptance of a position).

Delphi has, after all, been advocated as a method of reducing group pressures to conform (Martino, 1983) and both increased consensus and increased conformity will be evident as a convergence of panellist's estimates over rounds (i.e., these factors are confounded). It is seen in the literature that reduced variance has been interpreted according to the position on Delphi held by the particular author/s, with proponents of Delphi arguing that results demonstrate consensus, while critics have argued that the 'consensus' is often only 'apparent', and that the convergence of responses is mainly attributable to other social-psychological factors leading to conformity (Stewart, 1987).

Clearly, if panellists are being drawn towards a central value for reasons other than a genuine acceptance of the rationale behind that position, then inefficient process-loss factors are still present in the technique. Alternative measures of consensus have been taken, such as 'post-group consensus. This concerns the extent to which individuals – after the Delphi process has been completed – individually agree with the final group aggregate, their own final round estimates, or the estimates of other panellists.

Rohrbaugh (1979) compared individuals' post-group responses to their aggregate group responses, and seemed to show that reduction in 'disagreement' in Delphi groups was significantly less than the reduction achieved with an alternative technique (Social Judgment

Analysis). Furthermore, he found that there was little increase in agreement in the Delphi groups. This latter finding seems to suggest that panellists were simply altering their estimates in order to conform to the group without actually changing their opinions (i.e., implying conformity rather than genuine consensus).

An alternative slant on this issue has been provided by Bardecki (1984), who reported – in a study not fully described – experts with more extreme views were more likely to drop out of a Delphi procedure than those with more moderate views (i.e., nearer to the group average). This suggests that consensus may be due – at least in part – to attrition. Further empirical work is needed to determine the extent to which the convergence of those who do not (or cannot) drop out of a Delphi procedure are due to either true consensus or to conformity pressures.

8.5 APPLICATION OF DELPHI TO THE PUBLIC TRANSPORTATION SYSTEM OF DELHI

Although evidence suggests that Delphi does generally lead to improved judgments over statistical sized groups and unstructured interacting groups, it is clearly of interest to see how Delphi performs in comparison to groups using other structured procedures. The Delphi survey conducted in this research work included the people chosen mainly from technical background such as:

Transportation Planning related Departments like Delhi Transport Corporation (DTC), Department of Science and Technology (DST), Defense Research and Development Organization (DRDO), State Transport Authority (STA), Central Road Research Institute (CRRI), Delhi Metro Rail Corporation (DMRC) etc.

Automobile manufacturers like Maruti Udyoog Limited, Hyundai Motors, Ashok Leyland, Honda and their vendors.

Indian fuel refinery personals from Indian Oil Corporation (IOCL), Bharat Petroleum Corporation Limited (BPCL), Hindustan Petroleum Corporation Limited (HPCL), Indraprastha Gas India Limited (IGIL)

Engineering academicians from Delhi College of Engineering (DCE), Indian Institute of Technology Delhi (IITD), Maharaja Agrasen Institute of Technology (MAIT), Delhi, Directorate of Training and Technical education (DTTE) Delhi and Engineering students from DCE, NSIT, MAIT etc.

The Delphi questionnaire was designed using guidelines of Sharma (2000) and Pal (2004), included a wide spectrum of different modes of transportation, beginning with bicycles and cycle rickshaws, encompassing all the prevalent modes being used of automobiles, and extending up to electric and solar powered vehicles, including advanced forms of fuel cells, hybrid vehicles etc. for planning an appropriate strategy to optimize the vehicular emissions of the capital city of Delhi. The experts have been asked to rate the suggested strategies for the reduction of the vehicular emissions from the transport system of the city of Delhi on a scale of 10 and they were also been asked to give their narrative suggestion and remarks to control the vehicular emissions.

In the first round of Delphi, about 300 participants were approached, roughly fifty plus from each category i.e. Automobile industry, Petroleum oil industry, Transport Department, Engineering Academia's and Engineering Students, out of which 138 responded, spending on an average of 30 to 45 minutes of their precious and rationed time.

8. 6 INVESTIGATIONS OF THE DELPHI STUDY

Methods used to contact the experts for the survey are illustrated in Figure 8.1 and 8.2. Maximum experts were contacted personally. A sizable number of experts were contacted through various other means of communications such as internet, post/courier, phone calls etc. The respondent’s work experience and stay in Delhi are illustrated in figure 8.3 and 8.4, for experience groups average is more than 8 years which is reasonably good (Assigning the experience of one year to all the students as most of them were already graduate i.e. Post Graduate students), whereas the group’s average for experts stay in Delhi is about 10 years.

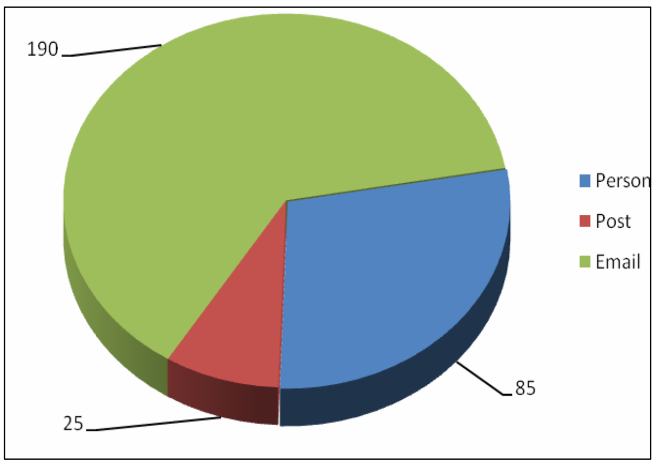


Figure 8.1: Various means used to contact the experts

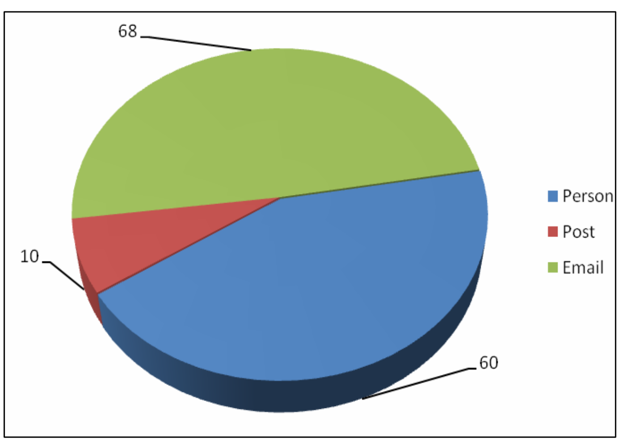


Figure 8.2: Various means successful in contacting the experts

Figure 8.5 shows the variation of group's annual income, here for students their family income is considered and only final year engineering students (both full time and part time) are approached for the study. The group's average annual income is more than rupees two lakh. Figure 8.4 shows the survey experts stay duration in Delhi. It is also taken care of that the experts have reasonable stay duration in Delhi, so as to ensure that they are fully aware of the transportation problem of Delhi. The groups average stay duration in Delhi is more than 8 years.

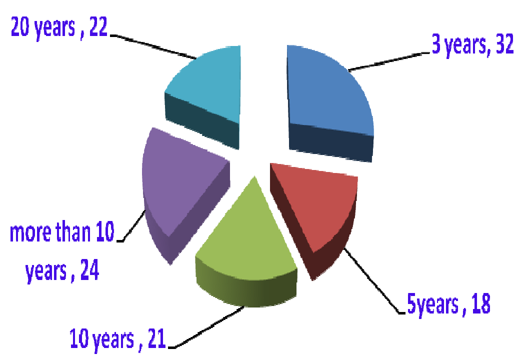


Figure 8.3: Work Experience of the Experts in Delhi.

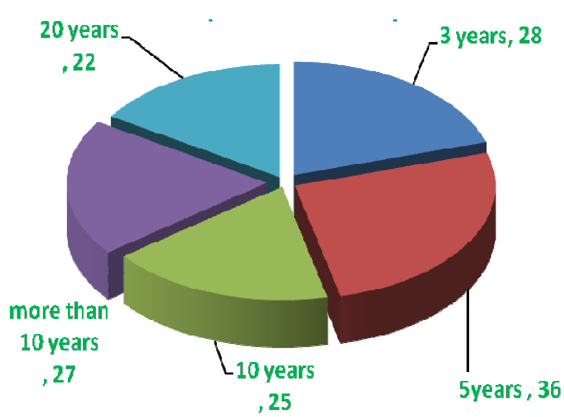


Figure 8.4: Experts Stay Duration in Delhi.

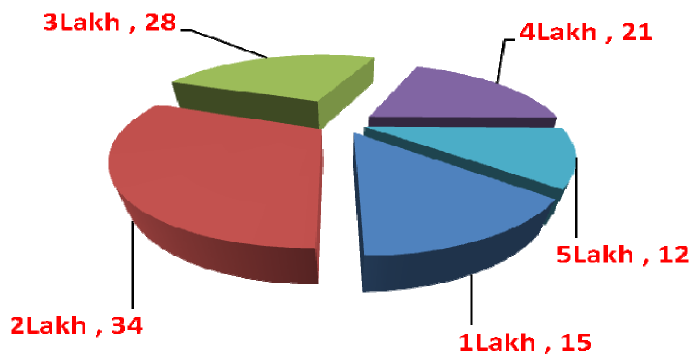


Figure: 8.5: Economic Backgrounds of the Experts.

The responses of above questionnaire were analyzed using statistical tools and processed with MATLAB programme. The STATISTICALLY ACCEPTABLE RANGE followed here to ascertain the agreement of majority of the group, for Delphi first and second round are as following:

RANGE (Higher /Lower) = AVERAGE ± 1.5 STDV, IF STDV d≤2.0,

RANGE (Higher /Lower) = AVERAGE ± 1.5 STDV, IF STDV >2.0

The responses of 36 experts were found to be out of acceptable range; they were again contacted and requested to participate in the second round, with a view to arrive at a consensus worthy of framing a feasible solution/policy framework. All the responses of second round were within statistical limits. Further their replies to some specific questions on how to control the vehicular emissions, suitability of the alternative fuels, how to improve the Public Transportation System, steps to control the number of vehicles and their awareness level on alternative propulsion systems are presented in the form of bar chart in figure 8.6 to 8.10.

It is worth to mention that all the experts have rated our suggested measures more than 6. The opinion of the participants is given due consideration in proposing the future emission control strategies. It is observed that they have given a very high rating (i.e. about 8-10) to the practically feasible options like improvement in fuel quality, augmentation of Delhi metro, promoting CNG as fuel, augmentation of PTS, enforcement of strict emission norms etc., while control actions such as removing the encroachment from roads, improving the infrastructure, adding the hydrogen in CNG fuel, strengthening the ring rail, restructuring the tax on vehicles taxes, among others were rated low because their implementation is not practically easy.

Experts reply were also analyzed with MATLAB software, various statistical parameters like average, coefficient of variance, standard deviation etc were determined and they are represented in graphical images in Figure 8.9 to 8.13. Different coloured lines are used for different experts groups (such as Engg. Acamadiations-ACAD-dark blue, Engg. Students-STUD-blue, Automobile engineers-AIE-green, Transport officials- TRPS-orange, Oil industry personals-OIE-red, group averages are also shown in different column heights. These graphs show the various statistical parameters for the survey data such as standard deviation (SD), mean, coefficient of variance (CV), inter quartile range (IQR) etc. with different types and coloured lines with the reply of the different expert groups for various questionnaire entries.

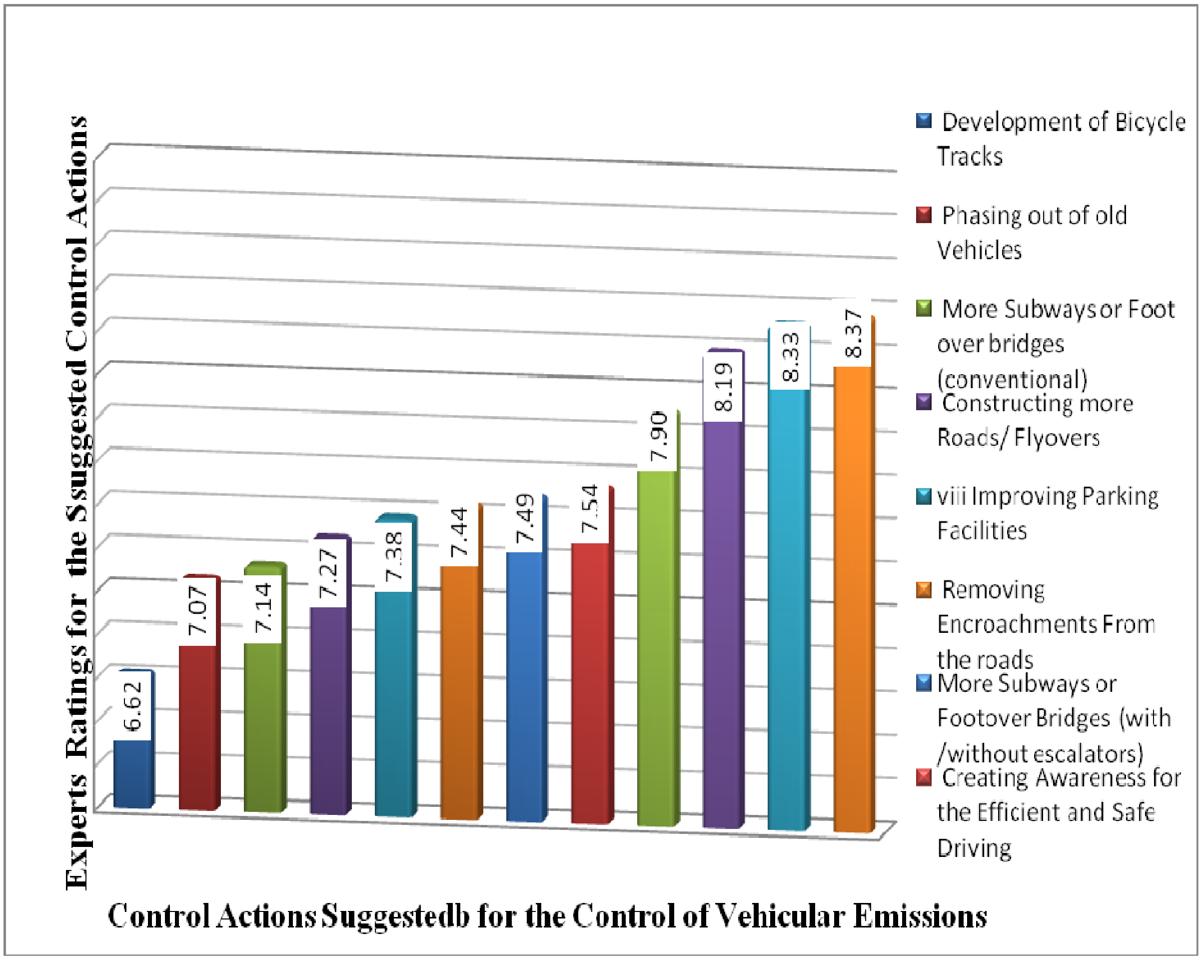


Figure: 8.6 Experts Preferences to Control Vehicle Emissions

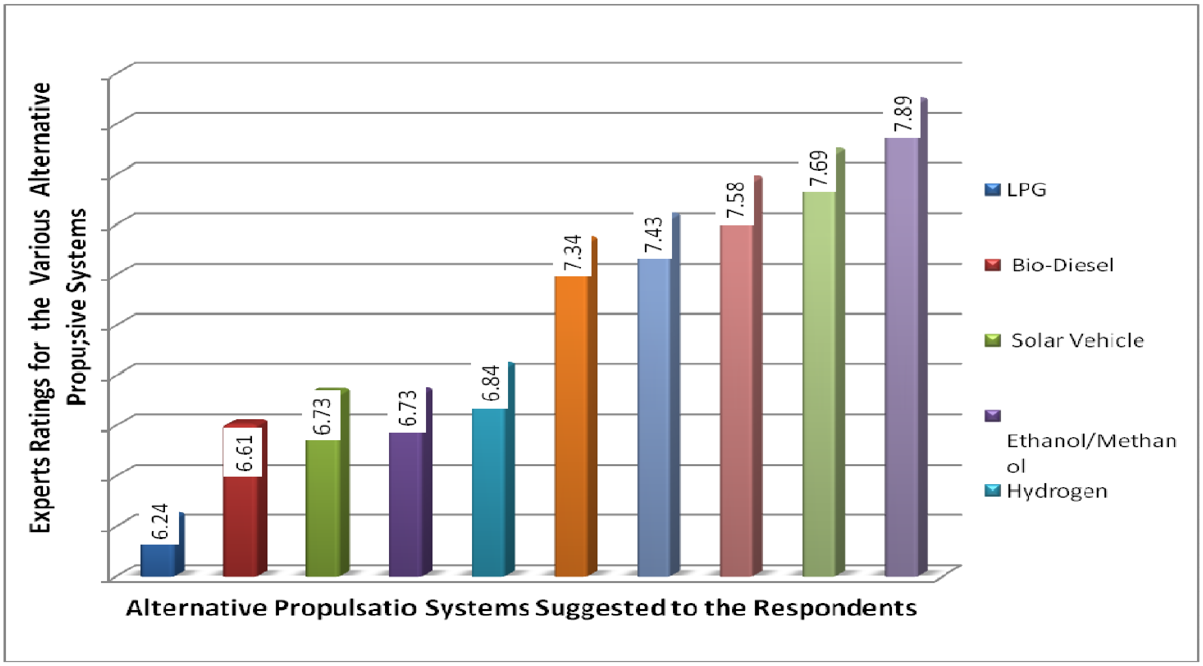


Figure 8.7: Experts preferences for the Alternative Fuels

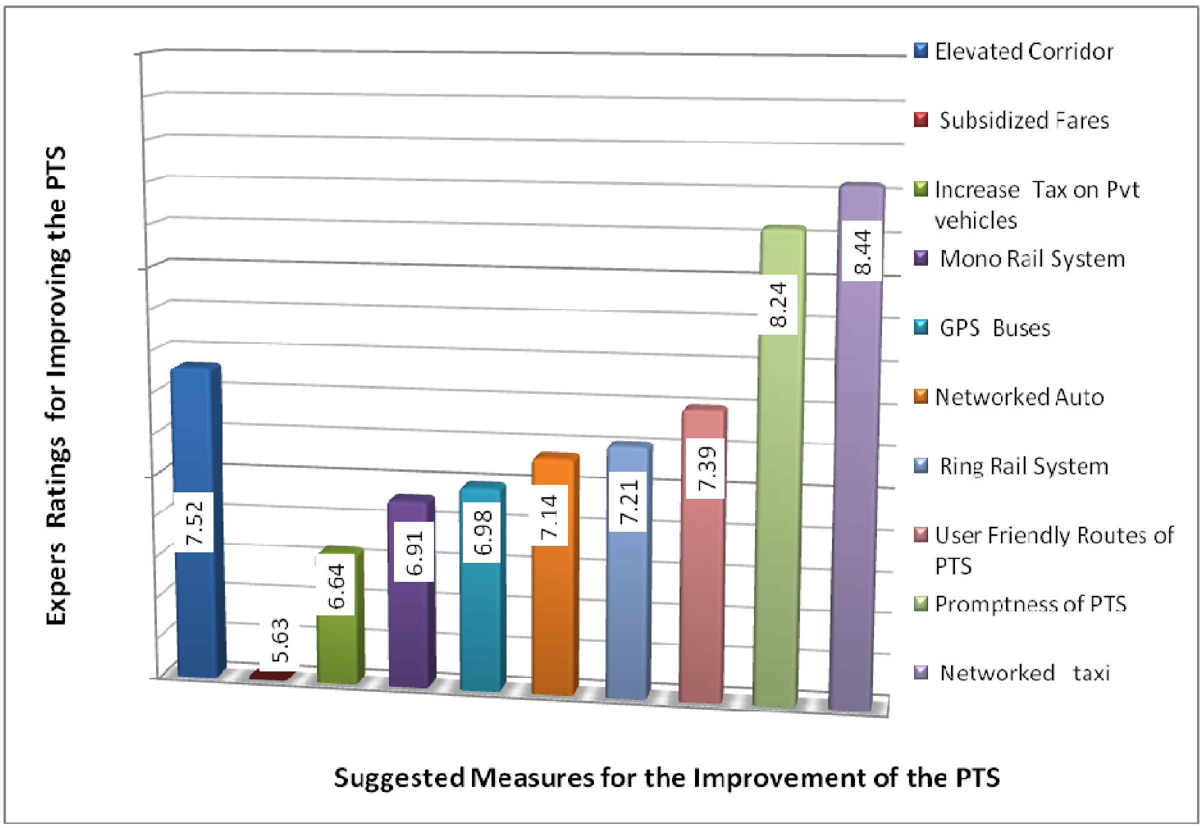


Figure 8.8: Experts Suggestions to Improve Public Transport

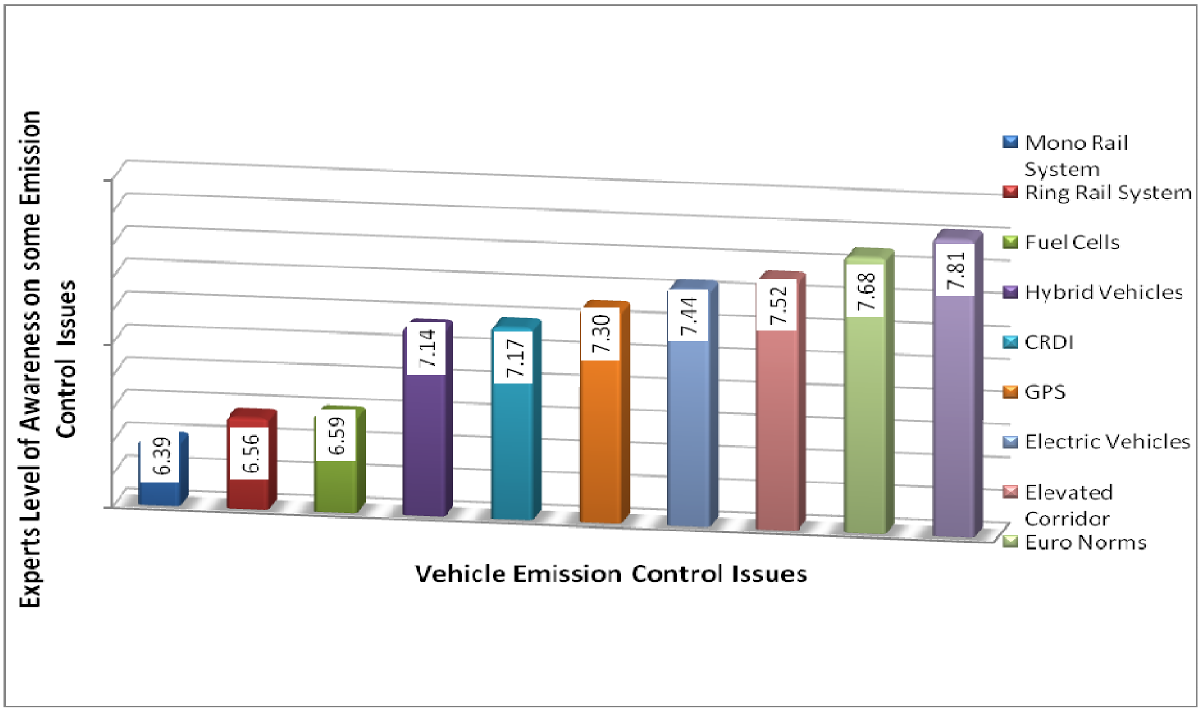


Figure: 8.9: Experts' Level of Awareness about Alternative Propulsion Systems

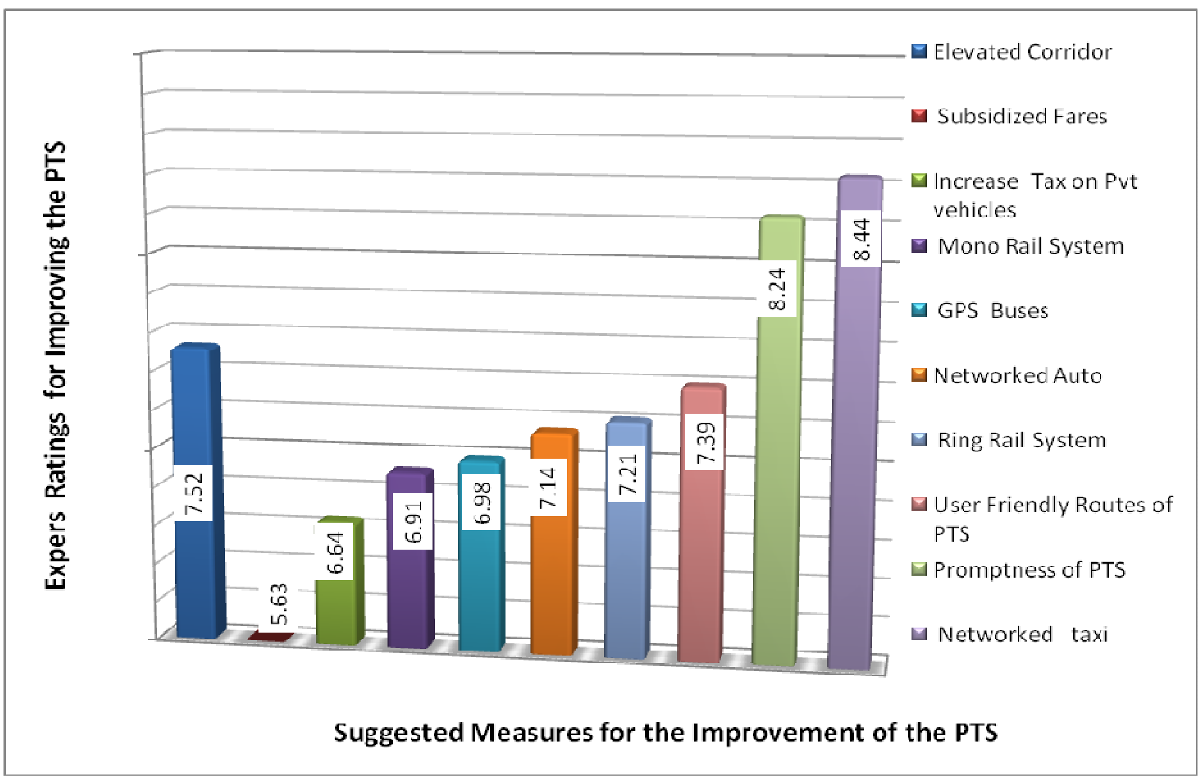
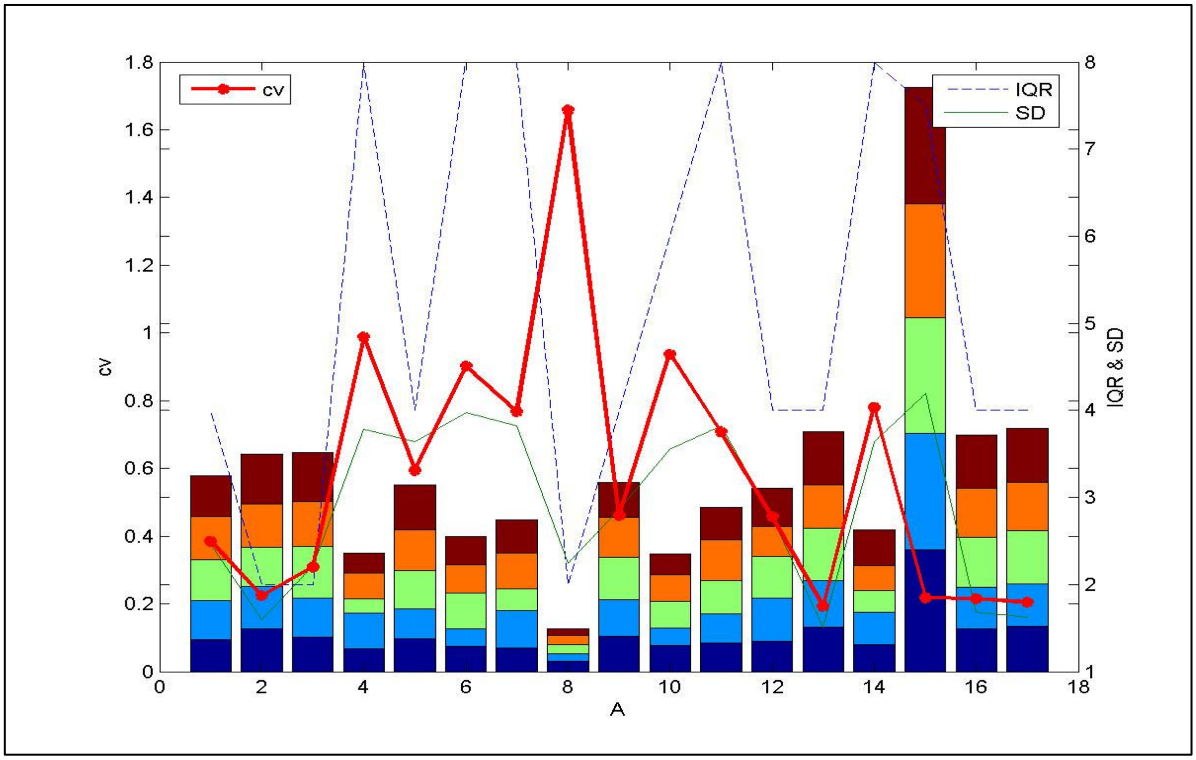


Figure: 8.10: Experts' Suggestions to Control the Number of Vehicles



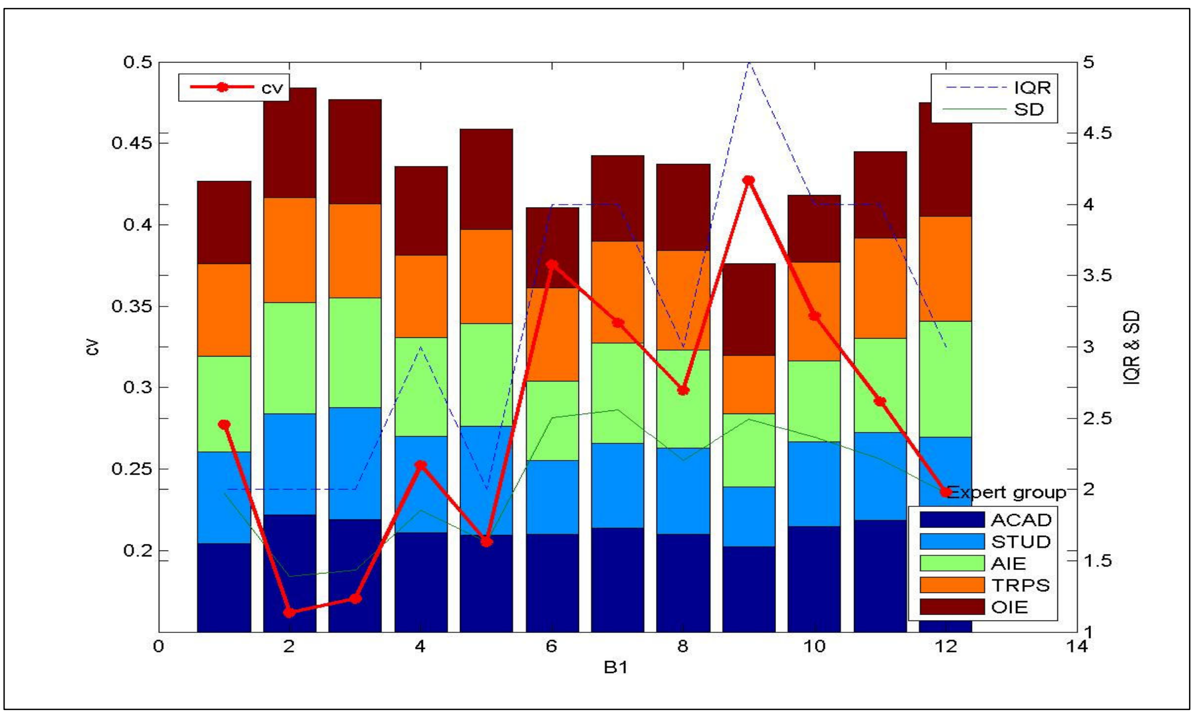


Figure: 8.11: MATLAB Statistical Results for the Survey Section A & B1

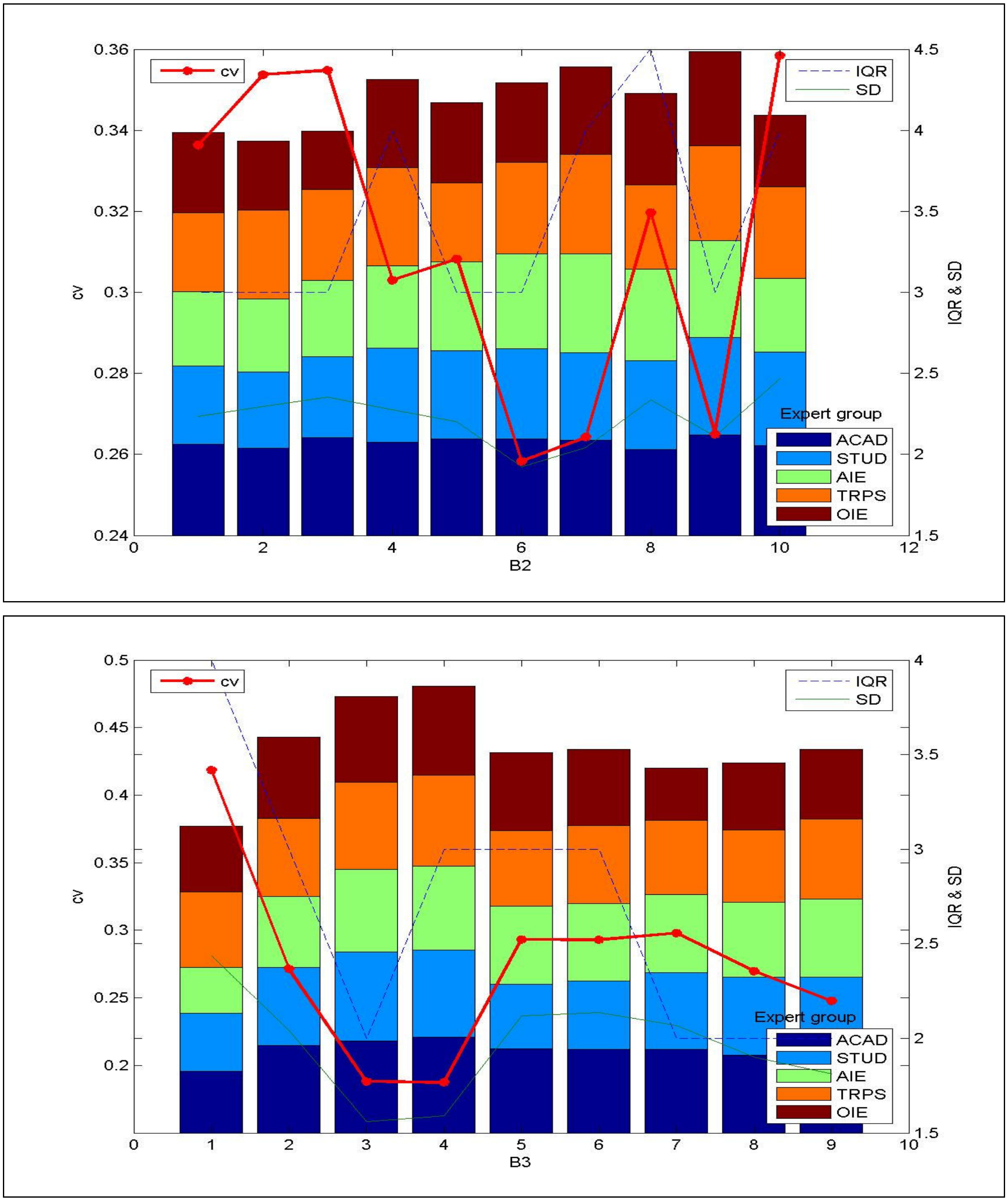
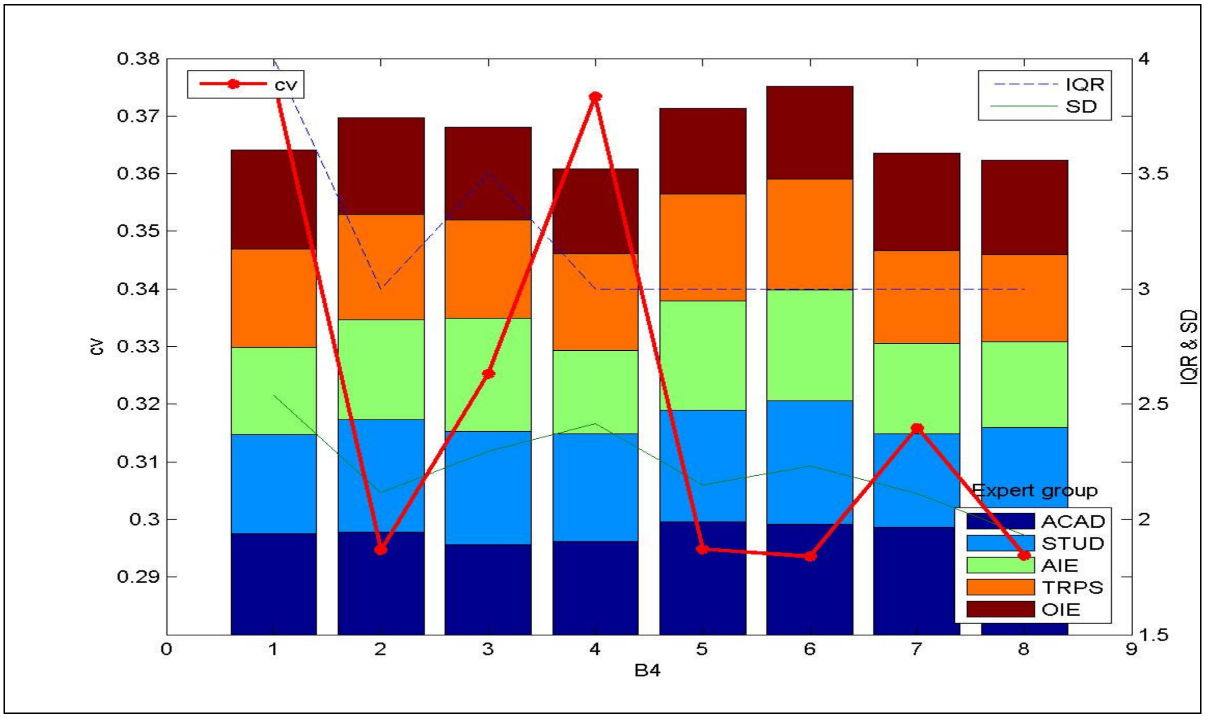


Figure: 8.12: MATLAB Statistical Results for the Survey Section B2 (Experts' Level of Awareness on Related Topics) and B3 (Experts' Preferences to Control the Growth of Private Vehicles)



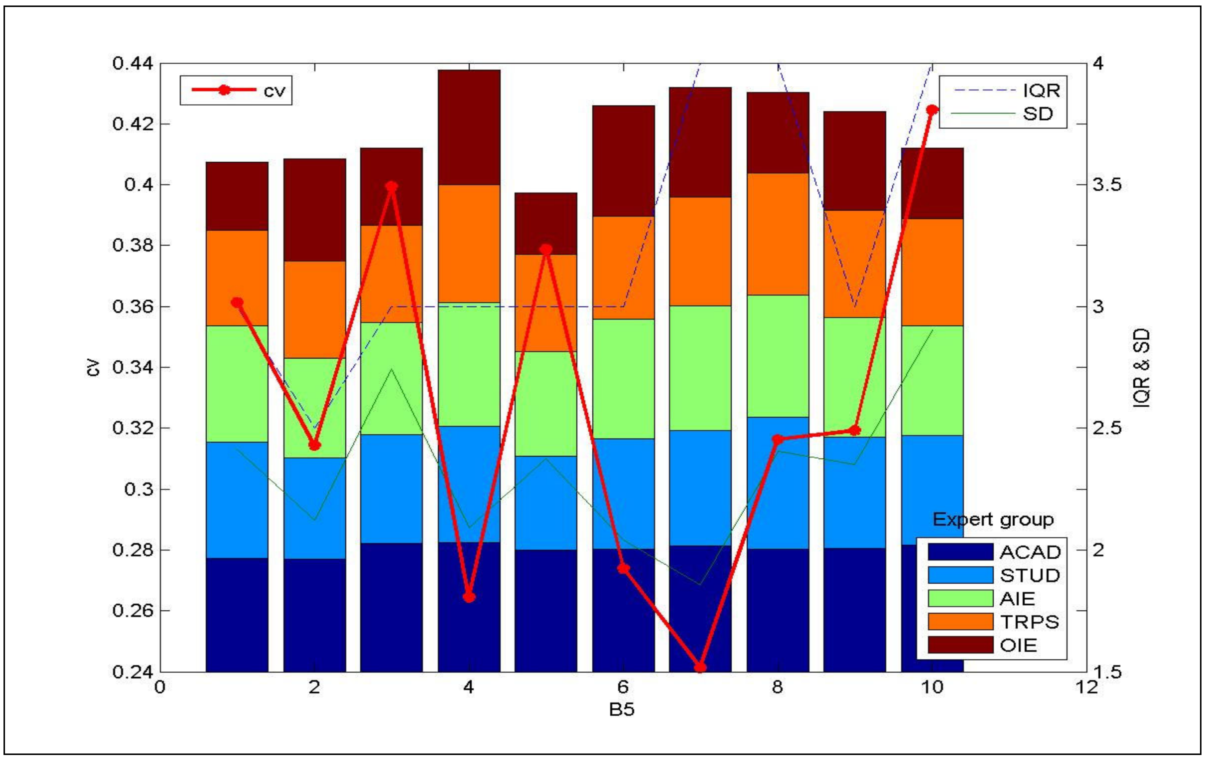


Figure: 8.13: MATLAB Statistical Results for the Survey Section B4 (Experts' Opinion on Vehicle Taxation) and B5 (Experts' Opinion on Various Alternative Fuels/Technology)

8.6 CONCLUDING REMARKS

The survey results shown above are an indication that though people are well aware about the advanced alternatives like Hydrogen, Hybrid, Solar and Fuel Cell etc. but as their success history is not proven thus they are ranked, marginally lower than that of well established and familiar alternative fuels like CNG/LPG/Ethanol and Bio-diesel etc. We noticed some very much important and interesting suggestion from the experts. Some of them valuable to be referred are:

- There should be a system in which or a method has to be developed so that only a particular lot of vehicle (like odd or even numbered) can operate on some decided day of work.
- Strict rule for no use of private vehicles, for at least one day /week
- Advanced and classified PTS for different section of people
- Campaign on public awareness for lane driving to avoid traffic jams
- Endorse employee car pool as a part of corporate social responsibility
- To control higher fuel consumption and aldehyde emission
- Hydrogen technology is in nascent stage.
- For CNG safety aspects need to be taken care of.
- Motor vehicle licensing system should be strict and linked to awareness for emission control and driving training, and advance driver licensing system like graduated licensing system must be promoted.
- Create a phool (ideates) lane for fast movers, let live us.
- Reliable integration of different modes of public transport.
- Tax Free, State owned buses, to subsidize public transport.
- Making turbocharger mandatory in standard design in diesel engine.
- Delhi metro should be linked possibly by small PTS vehicle under one ticket scheme.

- Amendment should be made in Central Motor Vehicle Rule (CMVR) to restrict entry of other state private vehicle in Delhi. Otherwise due to heavy tax in Delhi people are lured top get their vehicles registered outside Delhi and use in Delhi.
- Substantially subsidized fare passes of PTS for the School/College/Office goers.
- Incentive for accident /challenge free vehicle
- Public walk way (footpath to be made encroachment free) elevated, made to cater up to 1km walk
- Limiting the number of vehicle per family, and enforcing higher tax for the subsequent vehicles.
- Tax to the number of vehicle per floor of a house.
- Heavy duty vehicle should not be allowed from 6AM to 11PM.
- Public Transport Systems routes should be increased connecting residential and industrial area.
- High penalty for environment enemy vehicle.

A large majority of experts were in favour of improving and subsidizing the public transportation system, enhancing the traffic management and accelerating the infra-structure projects. The preferences of the experts were given due consideration while proposing the future emission control strategies and making the estimates of the vehicle emissions in the next chapter.

CHAPTER 9.

ESTIMATION OF EMISSIONS AND FUTURE PROJECTIONS

9.1 INTRODUCTION

After completing the experimental investigations on C.I. and S.I. engines for various potential alternative fuels and Delphi survey work to obtain the feedback and suggestion of the experts our next target is to estimate the present vehicular emissions of Delhi transportation system and to predict the future scenario for next two decade. For this we have used the earlier results in proposing the future emission modification factors

9.2 THE EMISSION FACTORS

As it is commonly perceived, a properly compiled emission inventory is the fundamental building block of any air quality management system in a country and two essential building blocks required for compiling emission inventory are the emission factors and the activity data. Emission factors (gm/km) for different vehicles types as presented by [Bose (1998), Mittal and Sharma (2003a), Saxena et al. (2002), and Kandlikar and Ramachandran (2000)] were used by earlier researchers. These emission factor were inadequate to accurately estimate the vehicle emissions hence further development work of emission factors is an outcome of the efforts put in by the stake holders (Oil Industry, research Organizations, academic institutions, under the aegis of MOEF (Ministry of environment and Forests), CPCB and State Pollution Control Boards (SPCB) realizing the need for an integrated air quality management in India.

The project was started as per recommendations of Dr. Mashelkar Committee report published in 2003, and in line with international experience of [Austin et al.(1993), Defries et al. (1992) and Magbuhat and Long (1995)] who have developed the emission factors for the US vehicles. The project consists of three major sub-components as following:

1. Development of emission factors for Indian vehicles

2. Vehicle source profiling
3. Ambient air quality monitoring, emission inventory and source apportionment

The highlights of the project can be summarised as following:

- In-use vehicles of different vintages (Viz, 1991-96, 1996-2000, Post 2000 and Post 2005 [Tech Matrix] were included in the test matrix to understand the effect of technology on emission factors and give appropriate representation to all kinds of vehicles plying on Indian roads
- The project involved Exhaust Emission testing of in-use 2 Wheelers, 3 Wheelers, Passenger Cars, LCVs and HCVs on Chassis dynamometer.
- After the tests with commercial fuel, maintenance was carried out at authorized service stations.
- After the maintenance, the test with commercial fuel was repeated followed by fuels with different fuel specifications to understand the effect of fuels on emissions.
- The committee decided to adopt the Indian Driving cycle for 2-W, 3-W and Pre-2000, 4W.
- Modified Indian Driving cycle was used for testing for post-2000, 4W. For comparative purpose, post -2000, 4W were also tested on IDC.
- As there is no standard test procedure and driving cycle for HCV category for chassis dynamometer tests as the HCV engines are tested on the engine dynamometer for regulatory tests. Thus ARAI developed overall Bus Driving cycle for HCV category as it was the best available driving cycle for that category which is based on the average driving pattern of HCV vehicles in the four metro cities (Mumbai, Delhi, Kolkata and Chennai).

Different inertia settings were used depending on the vehicle category as follows:

- 2-wheelers: ULW (Unladen Weight) + 75 kg
- 3-wheelers gasoline: 225 kg (3 passengersX75)
- 3-wheeler diesel: GVW
- Passenger cars: ULW+225 kg(3 passengers *75 kg)
- Multi Utility Vehicles: ULW+450 kg (6 passengers *75kg)
- Bus: ULW + 1500 kg(equivalent to 20 passengers of 75 kg weight each)

- Trucks: GVW (as specified by the vehicle manufacturer)
- Bus – ULW + 4500 kg (equivalent to 60 passengers of 75 kg each)
- Trucks – GVW (to be limited to 20 ton max. for GVW > 20 tons.

(In case GVW is less than 20 tons, Inertia is set to the maximum specified GVW)

- The particulate matter was chemically characterized into SOF (Oil and fuel fraction) and IOF (Sulphate, Nitrate, H_2O, Carbon Soot, and Metal Oxides).
- The particulate size distribution in terms of number, size and mass was also measured by ELPI and MOUDI instruments.
- The idle and constant speed mass emissions were also measured and expressed in g/min.

The study generated huge amount of data by testing of 89 numbers of vehicles for approximately 450 tests. However one of limitations of the project is that sample size in most of the categories of vehicles is less even to the extent of only one vehicle for some categories. An expert group on emission factors was constituted by CPCB to critically analyze the data collected under the project and after numerous deliberations the emission factors were evolved on the following basis as agreed upon by all the members of the expert group.

1. While reporting the emission factors, it has been attempted to optimize the number of emission factors subject to vehicle category, vintage and cc. The averages of the emission results of before and after maintenance are reported as emission factors.

2. In case of technology matrix, mass emission results of Euro-III fuel were considered as emission factors.

3. CNG/LPG vehicles were tested for after maintenance tests and after maintenance results are considered as Emission Factors.

4. MIDC results were considered as emission factors for post 2000 passenger cars and MUV's.

Thus a total of 62 emission factors have been worked out depending on vehicle categories, vintages and engine cubic capacities out of the total 89 numbers of vehicles tested under the project for 450 numbers of emission tests. The emission factors reported in this study are based on prevailing driving cycles. However, the driving pattern of one city may not be same as the other cities due to the reasons mentioned above. Use of city specific Driving Cycle will lead us to closer EF to real world scenario.

9.3 ESTIMATION OF PRESENT VEHICLE EMISSIONS

Present Estimated Emissions from Delhi Vehicles Exhaust are estimated by classifying all the Transport vehicles in Delhi, age wise like

1. Vehicles registered between 1991-1995
2. Vehicles registered between 1996-2000
3. Vehicles registered between 2001-2005
4. Vehicles registered between 2005-2008

First of all the vehicles of Delhi's transportation System were segregated (for this reference data were obtained by various transport agencies) as above, **then** to estimate a particular type of Vehicle Emissions the no. of vehicles in a particular category were multiplied by the **Emission Factor** for that category of Vehicle and the product were **further** multiplied by the average km traveled by that category of vehicle per day [John Roger, 2000].

An illustrative calculation is as given below

CO Emissions of goods vehicles registered between 2001-05 are estimated as

$CO_{2001\text{-}05,\ GV}$=45900* 1.9* 82, comes out as 7.151 TPD

Where 45,900 is the no. of goods vehicles registered, 1.9 is the CO emission factor in gm/km and 82 is the average distance travelled per day. Similarly other emissions from different category of vehicles were estimated. These are detailed out in the following Table 9.1

Table 9.1 Estimation of Present Vehicle Emission Load

Year	Type of Vehicle	No.of vehicles Registerd	Avg. km.Travelled perday	CO Emission Factor g/km	CO Emission tonnes./Day	HC Emission Factor g/km	HC Emission tonnes./Day	NOx Emission Factor g/km	NOx Emission tonnes./Day	PM Emission Factor g/km	PM Emission tonnes./Day
Two Wheelers											
1	2-W-2S>80cc	0	27	2.2	0	2.13	0	0.1	0	0.1	0
2005-07	2-W -4S	347834	27	1.4	13.3	0.7	6.7	0.3	2.9	0.1	0.6
1991-95	2-W -2S>80cc	466884	27	6.5	83.1	3.9	50	0	0.4	0.2	2.9
1991-95	2-W-4S	37610	27	3	3.09	0.8	0.8	0.3	0.3	0.1	0.1
1996-00	2-W-2S>80cc	503000	27	4	55.1	3.3	45	0.1	0.8	0.1	1.4
1996-00	2-W-4S	127825	27	2.6	9.11	0.7	2.5	0.3	1.1	0.1	0.2
2000-05	2-W-2S>80cc	114625	27	2.2	6.91	2.13	6.7	0.1	0.2	0.1	0.2
2000-05	2-W-4S	622836	27	1.4	23.9	0.7	0	0.3	5.1	0.1	1
SUM		**2220614**			**203**		**136**		**8.7**		**6.3**
Taxies- Rickshaws(All CNG)											
1996-00	Taxies	5464	89	0.9	0.41	0.79	0.4	0.5	0.3	0.001	0
1996-00	Rikshaw	19694	110	1	2.16	0.26	0.6	0.5	1.1	0.015	0.03
2000-05	Taxies	14245	89	0.6	0.76	0.36	0.5	0	0	0.002	0
2000-05	Rikshaw	22468	110	0.7	1.7	2.06	0	0.2	0.5	0.118	0.29
2005-07	Taxies	7628	89	0.6	0.41	0.36	0	0	0	0.002	0
2005-07	Rikshaw	11734	110	0.7	0.89	2.06	2.6	0.2	0.2	0.118	0.15
SUM		**81233**			**6.33**		**4.1**		**2.1**		**0.48**

Table 9.1 Estimation of Present Vehicle Emission Load…contd

Year	Type of Vehicle	NO.of vehicles Registerd	Avg. km.Travelled perday	CO Emission Factor g/km	CO Emission tonnes./Day	HC Emission Factor g/km	HC Emission tonnes./Day	NOX Emission Factor g/km	NOX Emission tonnes./Day	PM Emission Factor g/km	PM Emission tonnes./Day
Goods vehicles											
1996-00	goods veh	27987	82	1.4	3.17	1.39	3.2	0.7	1.5	0.6	1.3
2001-05	goods veh	45900	82	1.9	7.15	0.28	1.1	2.5	9.4	0.5	1.9
2005-07	goods veh	57528	82	2	9.34	0.13	0.6	0.2	0.9	0	0.1
SUM		131415	-	-	19.7	-	4.9		12	-	3.3
Buses											
2001-05	CNG buses	13147	164	3.6	0.78	0.87	0.2	13	2.7	0.6	0.1
	Cng RTV	5750	110	1.8	0.11	0.43	0	6.3	0.4	0.3	0
2006-07	CNG buses	4500	164	3.2	0.24	0.87	0.1	11	0.8	0.2	0
	Cng RTV	2850	110	1.6	0.05	0.43	0	5.5	0.2	0.1	0
SUM		26247			1.18		0.3		4.1		0.2

Table 9.1 Estimation of Present Vehicle Emission Load…contd

year	Type of Vehicle	NO.of vehicles Registerd	Avg. km.Travelled perday	CO Emission Factor g/km	CO Emission tonnes./Day	HC Emission Factor g/km	HC Emission tonnes./Day	NOX Emission Factor g/km	NOX Emission tonnes./Day	PM Emission Factor g/km	PM Emission tonnes./Day
CAR AND JEEPS											
1991-95	CAR-G	215007	41	9.8	86.4	1.7	15	1.8	16	0.1	0.5
1991-95	CAR-D	600	41	7.3	0.18	0.37	0	2.8	0.1	0.8	0
1996-00	CAR-G	354488	41	3.9	56.7	0.8	12	1.1	16	0.1	0.7
1996-00	CAR-D	10087	41	1.2	0.5	0.37	0.2	0.7	0.3	0.4	0.2
2001-2005	CAR-G	577325	41	2	46.9	0.25	5.9	0.2	4.7	0	0.7
2001-2005	CAR-D	20939	41	0.9	0.77	0.13	0.1	0.5	0.4	0.1	0.1
2001-2005	CAR-CNG	4260	41	0.9	0.15	0.79	0.1	0.5	0.1	0	0
2001-2005	CARLPG	2750	41	6.8	0.76	0.85	0.1	0.5	0.1	0	0
2006-07	CAR-G	383521	41	6	94.3	3	47	10	162	0.1	1.4
2006-07	CAR-D	64721	41	0.1	0.16	0.08	0.2	0.3	0.7	0	0
2006-07	CAR-CNG	4750	41	0.9	0.17	0.79	0.2	0.5	0.1	0	0
2006-07	CAR-LPG	2360	41	2.7	0.26	0.23	0	0.2	0	0	0
SUM		1640808			**287**		**81**		**200**		**3.7**
CAR-G : Gasoline fueled cars, CAR-D : diesel fueled cars CAR-CNG : CNG fueled cars, CAR-LPG : LPG fueled cars											

The components of the vehicular emissions of Delhi are shown in figure 9.1, highest is CO which is about 53% followed by NOx and HC which are 23% each. Historic trend for the vehicle emission sources are depicted in figure 9.2

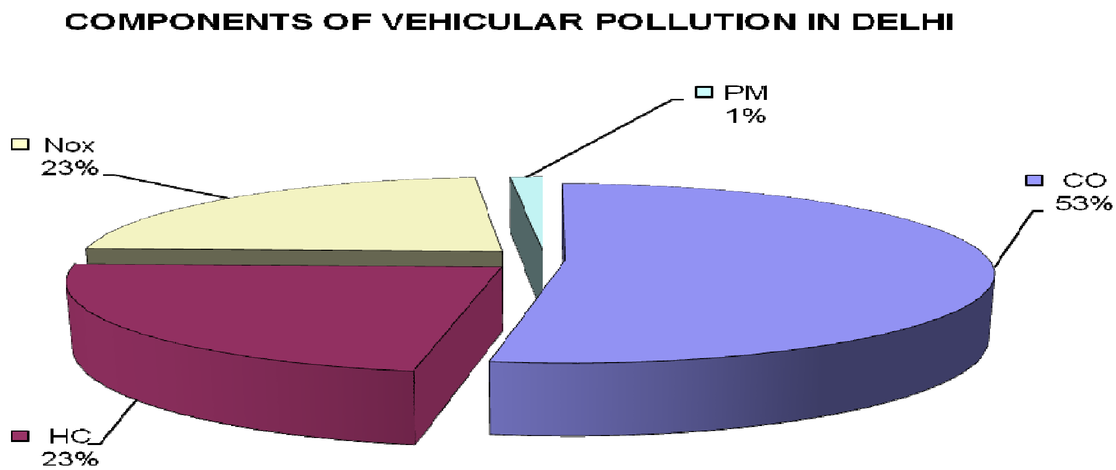


Figure 9.1: Components of Vehicular Pollution in Delhi

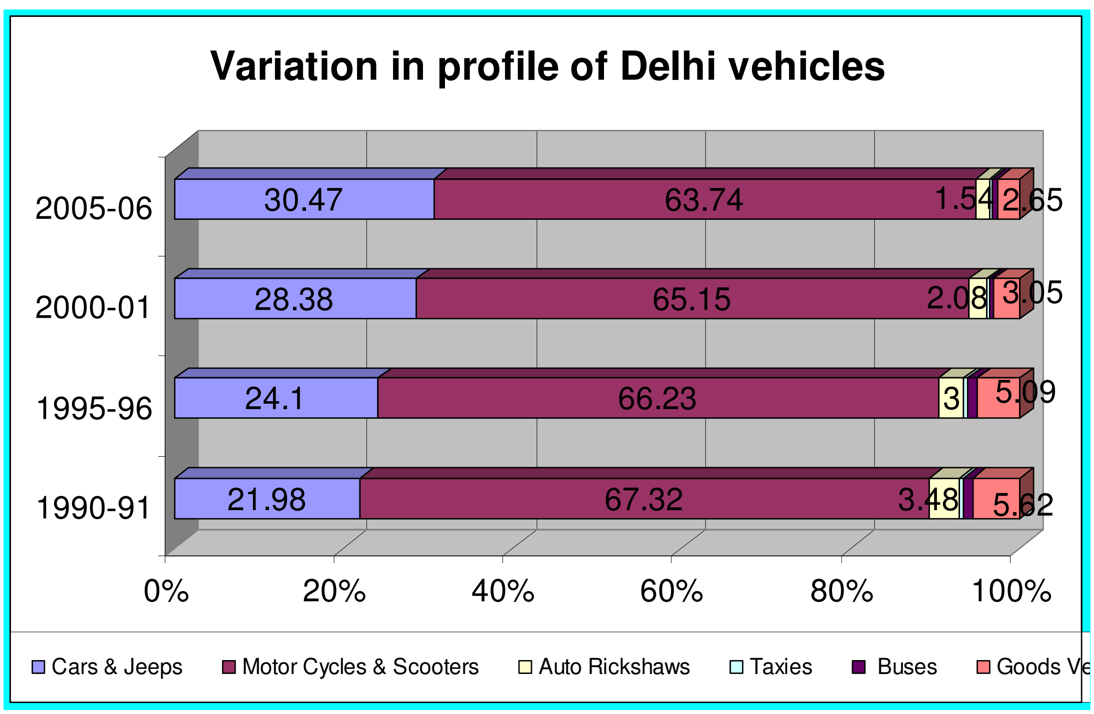


Figure 9.2: History of Variation in Profile of Delhi Vehicles

Figure 9.3 to 9.6 show the various sources of vehicular pollution for CO, HC, NOx and PM, where for all types two wheelers are majority contributor, except for car and jeeps which are the majority contributor for the NOx

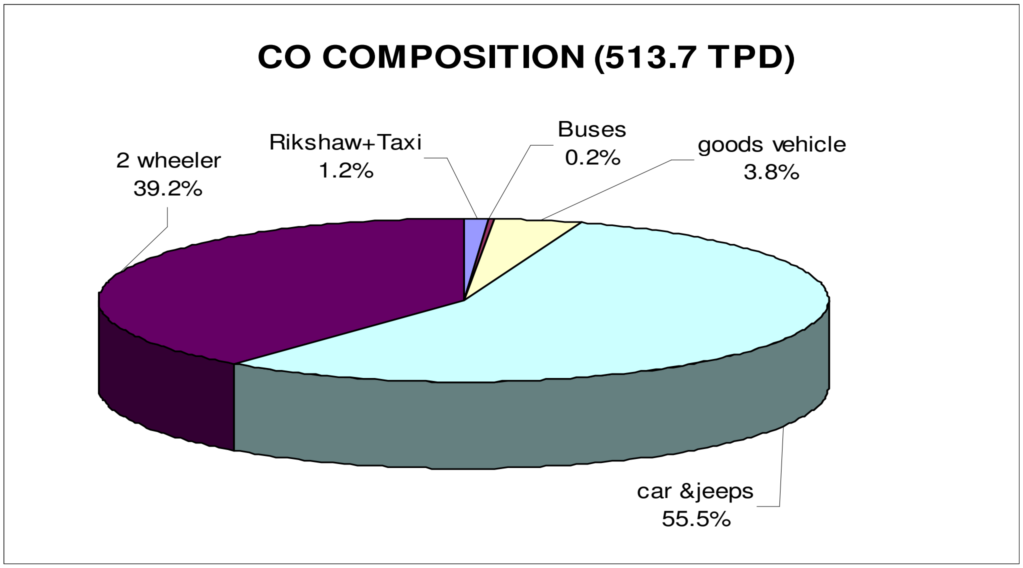


Figure 9.3: Composition of Vehicular Carbon Monoxide Pollution in Delhi

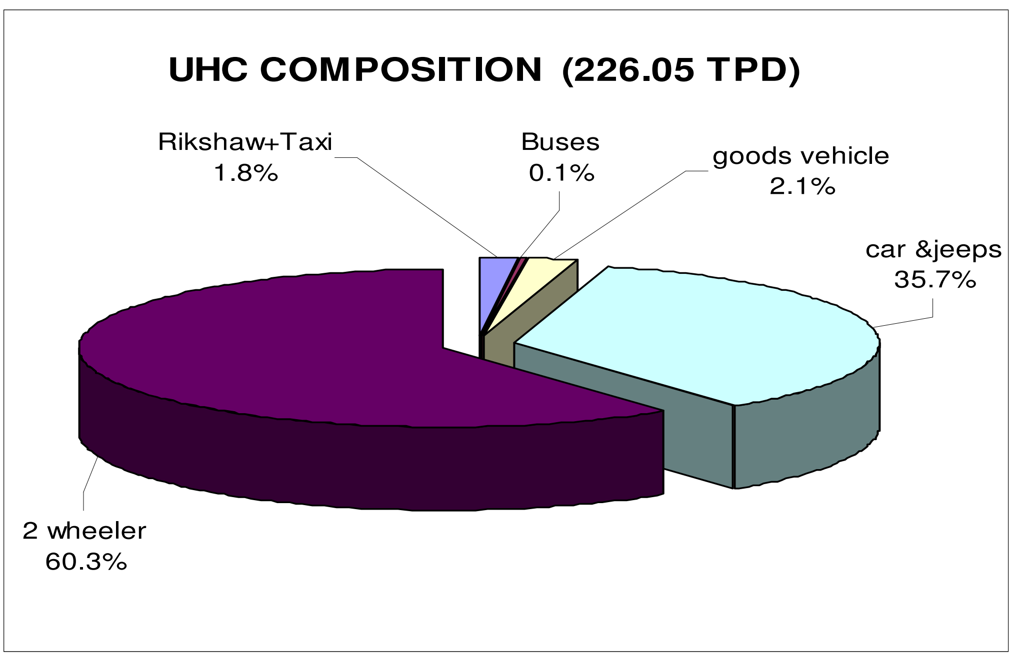


Figure 9.4: Composition of Vehicular Unburnt Hydrocarbon Pollution in Delhi

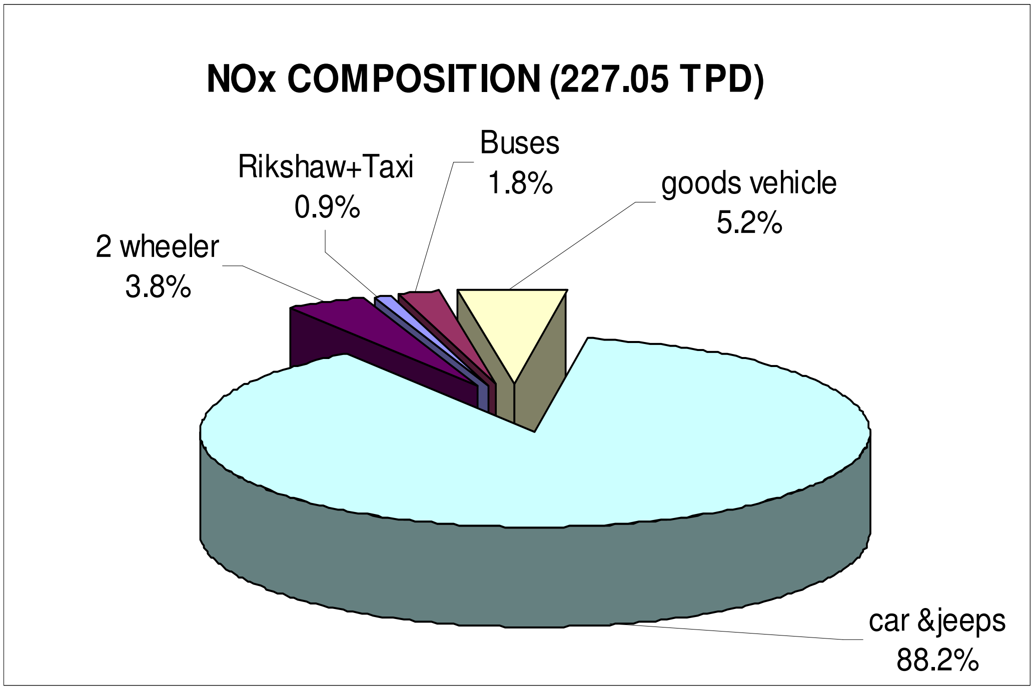


Figure 9.5: Composition of Vehicular Nitrogen Oxides Pollution in Delhi

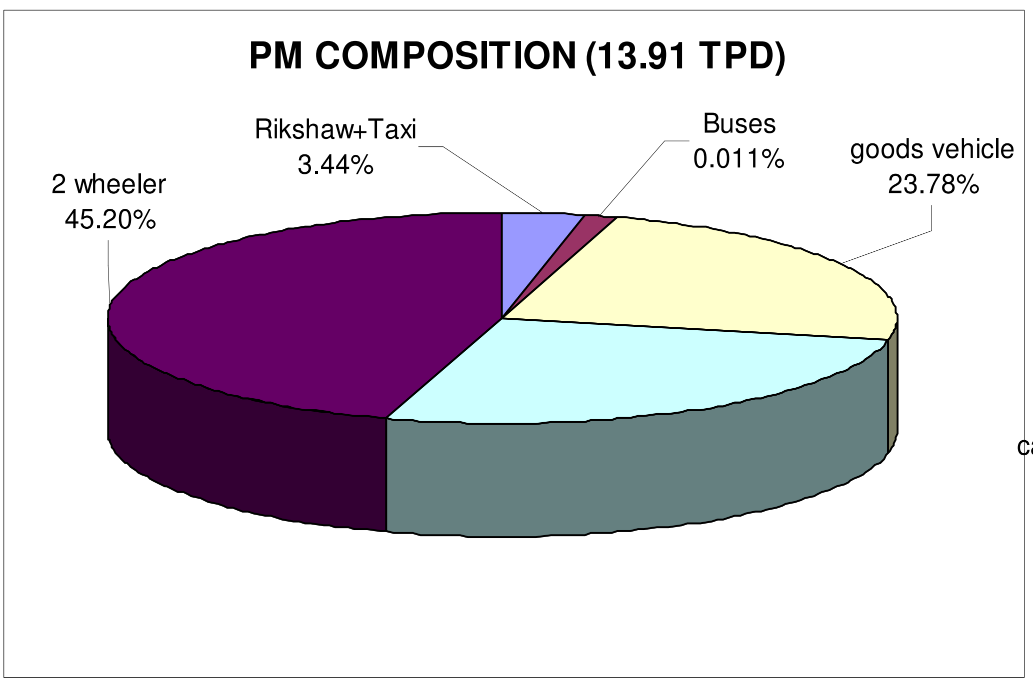


Figure 9.6: Composition of Vehicular Particulate Matter Pollution in Delhi

9.4 PROJECTED EMISSIONS FOR THE FUTURE

Projected Emissions for a specific type of Vehicles are calculated with the following relation, applying five different multiplying factors

Projected Emissions = [Constant (Mfvcc) $*M_{f1}*M_{f2}*M_{f3}*M_{f4}$]

Where Constant (Mfvcc) is a constant for the specific type of Emissions and Vehicle Combination, we have chosen this as present emission as estimated in Table 9.1 below:

M_{f1}-Another constant for a particular type of vehicles, Growth factor as per historic trend

M_{f2}- Change in growth for a particular type of vehicles, after proposed measures

M_{f3}-factor for the Impact of Fuel Quality Improvements

M_{f4}- factor for the Impact of Advanced Vehicle Technologies

(These emission modification factors are detailed in Table 9.2.)

Like CO from two wheelers in 2030 as per Action Plan 8

CO 2W, $_{2030,\ AP\text{-}8}$=202.92*3.651 *0.6 *0.7 *0.75 comes out as 233.375TPD

Total Emissions =Σ_1^5 CO + Σ_1^5HC+ Σ_1^5 NOx + Σ_1^5 PM

Where 1…5→1-Two Wheelers, 2-Car & Jeeps, 3-Bus, 4-Taxi & Auto-Rickshaws, 5-Goods Vehicles

9.5 ESTIMATION OF FUTURE EMISSIONS

In present work vehicular emission load of the capital city of Delhi is estimated based on the present vehicle population, its composition and the emissions factors specified by ARAI, then future emission load is estimated incorporating the proposed changes and their possible effect as per the modifying factors for the Vehicle growth, Fuel Quality and the vehicle technology advancement. For different possibilities of the proposed strategies the future scenario for the year 2010, 2020 and 2030 emission estimates are predicted. At the same time a Business as usual scenario is also estimated. And a comparison of different control actions is presented.

Table 9.2(1/4): Modifying Factor for Growth of Vehicles as per History – M_{f1}

S. No.	Year	For Private Vehicles 2 wheeler@5.6% yearly	For Private vehicles Car and Jeeps @8.6% yearly	For Public Vehicles Taxi & Auto @2% & Goods Vehicles @1% yearly	For Public Vehicles/ BUS @4% yearly
1	2010	1.168	1.259	1.06/1	1.12
2	2010	2.067	2.851	1.272/1	1.568
3	2030	3.659	6.389	1.152/1	2.195

Table 9.2 (2/4): Modifying Factors for No. of Vehicles - M_{f2}

S. No.	Year	Control Action	Private Vehicles		Public Vehicles	
			Two wheeler	Car & jeep	Taxi & Auto Rickshaw and Bus	Goods Vehicle
1	2010	Improved PTS, as usual growth of Metro and DTC, BRT routes, higher subsidies for PTS	.90	.95	1.06	1
	2020	Augmentation of Metro, , Electric 2 Wheelers and improved parking, Metro with Higher number of DTC buses	.80	.85	1.272	1
	2030	Mono rail, Electric Buses	.70	.75	1.52	1
1’	2010	High price rise of Petroleum fuels, improved public transport, & Augmentation of Delhi Metro,	.80	0.9	1.09	1
	2020	Reorganization of ring rail, Effective parking, GPS enabled, reliable A/c Buses, Rickshaw & taxies	.70	0.8	1.417	1
	2030	Improved and congestion free traffic, Mono rail, dedicated high speed metro	.6	0.7	1.842	1

Table 9.2(3/4): Modifying Factors for Fuel Quality Improvements M_{f3}

S.No.	Year	Control Action	For Private Vehicles	For Public Vehicles
1	2010	Low sulphur fuel, E-5 and B-5 Gasoline, Diesel blends	0.95	0.98
	2020	and Reduction of benzene, Ultra Low sulphuer diesel and use of LPG, B-10 & E-10 & Hythen 5-10%	0.85	0.93
	2030	Blends and Hythen 20% (CNG- H2 Blends), B-20 and E-20 Gasoline and Ethanol Blends	0.75	0.88
1'	2010	Improvement of octane and cetane no., use of E-10 & B-10 %,	0. 90	0.98
	2020	Incorporation of E-20, B-20 %, Hythen 10% (CNG- H2 Blends),	0.80	0.90
	2030	Bio-Fuels / Hydrogen as IC Engine fuel / Hythen 15-30 %(CNG- H2 Blends)	0.70	0.82

Table 9.2(4/4): Modifying Factors for Technology Advancement M_{f4}

S.No.	Year	Control Action	For Private Vehicles		For Public Vehicles
			Two wheeler	Car & Jeeps	
1	2010	CRDI,MPFI	.98	.98	0.98
	2020	Advanced MPFI,VVT, Advanced Cat Converters	.91	.91	0.91
	2030	Hybrid Vehicles Fuel Cell Vehicles	.85	.85	0.85
1'	2010	Diesel –CNG Duel Fuel,	.95	.95	0.90
	2020	Gasoline Direct Injection/ Ceramic Catalytic converters	.85	.85	0.80
	2030	Mini Turbines /Hydrogen/ Hybrid / Solar/Fuel Cell	.75	.75	0.7

9.6 Different Control Action Plans

Using the possibility of different plans and amount of success and sincerity in their implementation, Future emissions are projected s with following equations:

CONTROL ACTION PLAN-1 = $[Mfvcc *M_{f1}*M_{f2}*M_{f3}*M_{f4}]$

CONTROL ACTION PLAN-2 = $[Mfvcc *M_{f1}*M_{f2}*M_{f3}'*M_{f4}]$

CONTROL ACTION PLAN-3 = $[Mfvcc *M_{f1}*M_{f2}*M_{f3}*M_{f4'}]$

CONTROL ACTION PLAN-4 = $[Mfvcc *M_{f1}*M_{f2}*M_{f3'}*M_{f4'}]$

CONTROL ACTION PLAN-5 = $[Mfvcc *M_{f1}*M_{f2'}*M_{f3}*M_{f4}]$

CONTROL ACTION PLAN-6 = $[Mfvcc *M_{f1}*M_{f2'}*M_{f3'}*M_{f4}]$

CONTROL ACTION PLAN-7= $[Mfvcc *M_{f1}*M_{f2'}*M_{f3}*M_{f4'}]$

CONTROL ACTION PLAN-8 = $[Mfvcc *M_{f1}*M_{f2'}*M_{f3'}*M_{f4'}]$

Where Mfvcc is a constant for each different category of vehicle.

Computation results of vehicle emission for various action plans are detailed out in the following Table 9.3, in 4 parts, while detailed calculations used for the prediction of emissions for future are given in Appendix VI which shows the emissions for the BAU scenario as well as for the above eight control action plans.

Table 9.3 Projected Emissions for the Different Action Plans

Business as Usual Scenario, Projected Emissions in TPD						
Pollutant - Year	**Two Wheeler**	**Car & Jeeps**	**Bus**	**Taxi & Auto Rickshaw**	**Goods Vehicles**	**By All**
CO 2010	235.39	361.69	1.25	6.90	20.84	**626.06**
HC 2010	158.00	101.49	0.31	4.43	5.15	**269.38**
NOx 2010	10.12	252.28	4.35	2.25	12.52	**281.52**
PM 2010	7.29	4.63	0.17	0.52	3.51	**16.12**
SUM	**410.80**	**720.08**	**6.08**	**14.10**	**42.01**	**1193.08**
CO 2020	416.72	818.91	1.41	8.96	25.01	**1271.02**
HC 2020	279.71	229.79	0.35	5.76	6.18	**521.79**
NOx 20210	17.91	571.19	4.93	2.93	15.02	**611.98**
PM 2020	12.91	10.48	0.19	0.68	4.21	**28.47**
SUM	**727.26**	**1630.37**	**6.88**	**18.33**	**50.41**	**2433.26**
CO 2030	740.87	1835.15	1.71	11.65	30.00	**2619.38**
HC2030	497.28	514.95	0.42	7.49	7.41	**1027.55**
NOx 2030	31.85	1280.02	5.95	3.81	18.02	**1339.65**
PM 2030	22.96	23.49	0.23	0.88	5.05	**52.61**
SUM	**1292.96**	**3653.61**	**8.32**	**23.83**	**60.48**	**5039.19**

Control Action Plan-1, Projected Emissions in TPD						
Pollutant - Year	**Two Wheeler**	**Car & Jeeps**	**Bus**	**Taxi & Auto Rickshaw**	**Goods Vehicles**	**By All**
CO 2010	197.23	319.89	1.10	6.82	20.01	**545.07**
HC 2010	132.38	89.76	0.27	4.38	4.94	**231.75**
NOx 2010	8.48	223.13	3.85	2.23	12.02	**249.70**
PM 2010	6.11	4.09	0.15	0.52	3.37	**14.24**
SUM	**344.21**	**636.88**	**5.38**	**13.95**	**40.35**	**1040.76**
CO 2020	257.87	538.41	0.97	8.76	21.63	**827.64**
HC 2020	173.08	151.08	0.24	5.63	5.34	**335.38**
NOx 2020	11.09	375.54	3.38	2.86	12.99	**405.86**
PM 2020	7.99	6.89	0.13	0.66	3.64	**19.32**
SUM	**450.03**	**1071.93**	**4.73**	**17.92**	**43.60**	**1588.20**
CO 2030	330.61	877.43	0.86	12.36	23.23	**1244.50**
HC 2030	221.91	246.21	0.22	7.94	5.74	**482.02**
NOx 2030	14.21	612.01	3.01	4.04	13.95	**647.23**
PM 2030	10.25	11.23	0.12	0.94	3.91	**26.44**
SUM	**576.98**	**1746.88**	**4.21**	**25.29**	**46.83**	**2400.19**

Control Action Plan-2, Projected Emissions in TPD						
Pollutant - Year	**Two Wheeler**	**Car & Jeeps**	**Bus**	**Taxi & Auto Rickshaw**	**Goods Vehicles**	**By All**
CO 2010	175.32	319.89	1.08	7.02	20.01	**523.32**
HC 2010	117.68	89.76	0.27	4.51	4.94	**217.16**
NOx 2010	7.54	223.13	3.75	2.30	12.02	**248.73**
PM 2010	5.43	4.09	0.15	0.53	3.37	**13.57**
SUM	**305.96**	**636.88**	**5.24**	**14.36**	**40.35**	**1002.78**
CO 2020	225.63	538.41	0.99	9.86	21.63	**796.53**
HC 2020	151.45	151.08	0.25	6.34	5.34	**314.46**
NOx 2020	9.70	375.54	3.45	3.22	12.99	**404.91**
PM 2020	6.99	6.89	0.13	0.75	3.64	**18.40**
SUM	**393.77**	**1071.93**	**4.82**	**20.17**	**43.60**	**1534.29**
CO 2030	308.57	877.43	0.95	13.77	23.23	**1223.95**
HC2030	207.12	246.21	0.24	8.85	5.74	**468.15**
NOx2030	13.27	612.01	3.30	4.50	13.95	**647.03**
PM2030	9.56	11.23	0.13	1.04	3.91	**25.87**
SUM	**538.52**	**1746.88**	**4.61**	**28.16**	**46.83**	**2365.00**

Control Action Plan-3, Projected Emissions in TPD						
Pollutant - Year	**Two Wheeler**	**Car & Jeeps**	**Bus**	**Taxi & Auto Rickshaw**	**Goods Vehicles**	**By All**
CO 2010	186.85	303.06	1.05	6.82	20.01	**517.79**
HC2010	125.42	85.04	0.26	4.38	4.94	**220.04**
NOx2010	8.03	211.38	3.65	2.23	12.02	**237.32**
PM2010	5.79	3.88	0.14	0.52	3.37	**13.70**
SUM	**326.09**	**603.36**	**5.10**	**13.95**	**40.35**	**988.85**
CO 2020	242.70	506.74	1.04	8.48	20.93	**779.89**
HC2020	162.90	142.19	0.25	5.45	5.17	**315.96**
NOx2020	10.43	353.45	3.49	2.77	12.57	**382.72**
PM2020	7.52	6.49	0.14	0.64	3.52	**18.31**
SUM	**423.56**	**1008.87**	**4.92**	**17.34**	**42.19**	**1496.88**
CO 2030	308.57	818.93	1.04	11.52	21.65	**1161.71**
HC2030	207.12	229.80	0.26	7.40	5.35	**449.92**
NOx2030	9.56	571.21	3.62	3.77	13.00	**601.16**
PM2030	10.25	10.48	0.14	0.87	3.64	**25.38**
SUM	**535.50**	**1630.42**	**5.06**	**23.56**	**43.64**	**2238.18**

Control Action Plan-4, Projected Emissions in TPD						
Pollutant - Year	**Two Wheeler**	**Car & Jeeps**	**Bus**	**Taxi & Auto Rickshaw**	**Goods Vehicles**	**By All**
CO 2010	181.13	293.78	1.02	6.82	20.01	**502.76**
HC2010	121.58	82.44	0.25	4.38	4.94	**213.59**
NOx2010	7.79	204.91	3.54	2.23	12.02	**230.49**
PM2010	5.61	3.76	0.14	0.52	3.37	**13.40**
SUM	**316.11**	**584.89**	**4.94**	**13.95**	**40.35**	**960.24**
CO 2020	226.70	473.33	0.95	8.20	20.25	**729.44**
HC2020	152.16	132.82	0.24	5.27	5.00	**295.49**
NOx2020	11.70	330.15	3.31	2.68	12.17	**360.01**
PM2020	7.02	6.06	0.11	0.62	3.41	**17.22**
SUM	**397.59**	**942.35**	**4.60**	**16.78**	**40.83**	**1402.16**
CO 2030	272.27	722.59	0.92	10.73	20.17	**1026.69**
HC2030	182.75	202.76	0.23	6.90	4.98	**397.62**
NOx2030	11.70	504.01	3.22	3.51	12.11	**534.56**
PM2030	8.44	9.25	0.11	0.81	3.39	**22.00**
SUM	**475.16**	**1438.61**	**4.48**	**21.95**	**40.66**	**1980.87**

Control Action Plan-5, Projected Emissions in TPD						
Pollutant - Year	**Two Wheeler**	**Car & Jeeps**	**Bus**	**Taxi & Auto Rickshaw**	**Goods Vehicles**	**By All**
CO 2010	191.20	293.78	1.14	6.82	20.01	**512.95**
HC2010	128.33	82.44	0.28	4.38	4.94	**220.38**
NOx2010	8.22	204.91	3.96	2.23	12.02	**231.34**
PM2010	5.92	3.76	0.15	0.52	3.37	**13.72**
SUM	**333.67**	**584.89**	**5.53**	**13.95**	**40.35**	**978.39**
CO 2020	291.72	473.33	1.07	8.48	20.93	**795.53**
HC2020	161.67	132.82	0.27	5.45	5.17	**305.37**
NOx2020	10.35	330.15	3.73	2.77	12.57	**359.57**
PM2020	7.46	6.06	0.15	0.64	3.52	**17.83**
SUM	**471.21**	**942.35**	**5.21**	**17.34**	**42.19**	**1478.31**
CO 2030	312.56	722.59	3.74	11.52	21.65	**1072.05**
HC2030	195.80	202.76	0.27	7.40	5.35	**411.58**
NOx2030	12.54	504.01	3.74	3.77	13.00	**537.06**
PM2030	9.04	9.25	0.15	0.87	3.64	**22.95**
SUM	**529.94**	**1438.61**	**7.90**	**23.56**	**43.64**	**2043.64**

Control Action Plan-6, Projected Emissions in TPD						
Pollutant - Year	**Two Wheeler**	**Car & Jeeps**	**Bus**	**Taxi & Auto Rickshaw**	**Goods Vehicles**	**By All**
CO 2010	169.95	293.78	1.14	7.02	20.01	**491.90**
HC2010	114.07	80.16	0.28	4.51	4.94	**203.97**
NOx2010	5.27	199.26	3.96	2.30	12.02	**222.79**
PM2010	5.92	3.66	0.15	0.53	3.37	**13.63**
SUM	**295.22**	**576.85**	**4.39**	**14.36**	**40.35**	**931.17**
CO 2020	210.76	473.33	1.07	9.54	20.93	**715.63**
HC2020	141.46	101.65	0.27	6.13	6.58	**256.09**
NOx2020	9.06	252.67	3.73	3.12	12.57	**281.15**
PM2020	6.53	4.64	0.15	0.72	3.52	**15.56**
SUM	**367.81**	**832.29**	**5.21**	**19.52**	**43.60**	**1268.43**
CO 2030	250.04	722.59	1.07	12.83	21.65	**1008.19**
HC2030	167.83	124.15	0.27	8.25	8.16	**308.65**
NOx2030	10.75	308.59	3.74	4.20	13.00	**340.28**
PM2030	7.75	5.66	0.15	0.97	3.64	**18.17**
SUM	**436.37**	**1160.98**	**5.23**	**26.24**	**46.45**	**1675.28**

Control Action Plan-7, Projected Emissions in TPD						
Pollutant - Year	**Two Wheeler**	**Car & Jeeps**	**Bus**	**Taxi & Auto Rickshaw**	**Goods Vehicles**	**By All**
CO 2010	166.09	287.11	1.14	6.82	21.21	**482.37**
HC2010	111.48	80.56	0.28	4.38	4.94	**201.66**
NOx2010	9.13	200.26	3.96	2.23	12.02	**227.59**
PM2010	5.15	3.67	0.15	0.64	3.37	**12.99**
SUM	**291.85**	**571.60**	**5.53**	**14.08**	**41.55**	**924.60**
CO 2020	212.36	476.93	1.07	8.48	26.62	**725.47**
HC2020	142.54	133.83	0.27	5.45	5.17	**287.25**
NOx2020	11.37	332.66	3.73	2.77	12.57	**363.10**
PM2020	6.58	6.10	0.15	0.64	3.52	**16.99**
SUM	**372.85**	**949.53**	**5.21**	**17.34**	**47.89**	**1392.82**
CO 2030	264.49	764.34	1.07	11.52	33.03	**1074.46**
HC2030	177.53	214.48	0.27	7.40	5.35	**405.02**
NOx2030	13.27	533.13	3.74	3.77	13.00	**566.90**
PM2030	8.20	9.78	0.15	0.87	3.64	**22.64**
SUM	**463.48**	**1521.73**	**5.23**	**23.56**	**55.03**	**2069.02**

Control Action Plan -8, Projected Emissions in TPD						
Pollutant - Year	**Two Wheeler**	**Car & Jeeps**	**Bus**	**Taxi & Auto Rickshaw**	**Goods Vehicles**	**By All**
CO 2010	161.01	278.32	1.14	6.82	20.01	**467.29**
HC2010	108.07	78.10	0.28	4.38	4.94	**195.78**
NOx2010	6.92	194.13	3.96	2.23	12.02	**219.26**
PM2010	4.99	3.56	0.15	0.52	3.37	**12.59**
SUM	**280.99**	**554.10**	**5.53**	**13.95**	**40.35**	**894.92**
CO 2020	198.36	445.49	1.07	8.48	20.25	**673.65**
HC2020	133.14	125.01	0.27	5.45	5.00	**268.87**
NOx20210	8.53	310.73	3.73	2.77	12.17	**337.92**
PM2020	6.15	5.70	0.15	0.64	3.41	**16.04**
SUM	**346.17**	**886.92**	**5.21**	**17.34**	**40.83**	**1296.48**
CO 2030	233.38	674.42	1.07	11.52	20.17	**940.56**
HC2030	156.64	189.24	0.27	7.40	4.98	**358.54**
NOx2030	11.70	470.41	3.74	3.77	12.11	**501.73**
PM2030	7.23	8.63	0.15	0.87	3.39	**20.28**
SUM	**408.95**	**1342.70**	**5.23**	**23.56**	**40.66**	**1821.11**

Figure 9.7(a,b) shows the growth of different category of vehicles since 2005 to the future projections up to the year 2030. Point to be noticed is a very high growth rate for the personnel vehicles i.e. both two wheelers and car and jeeps.

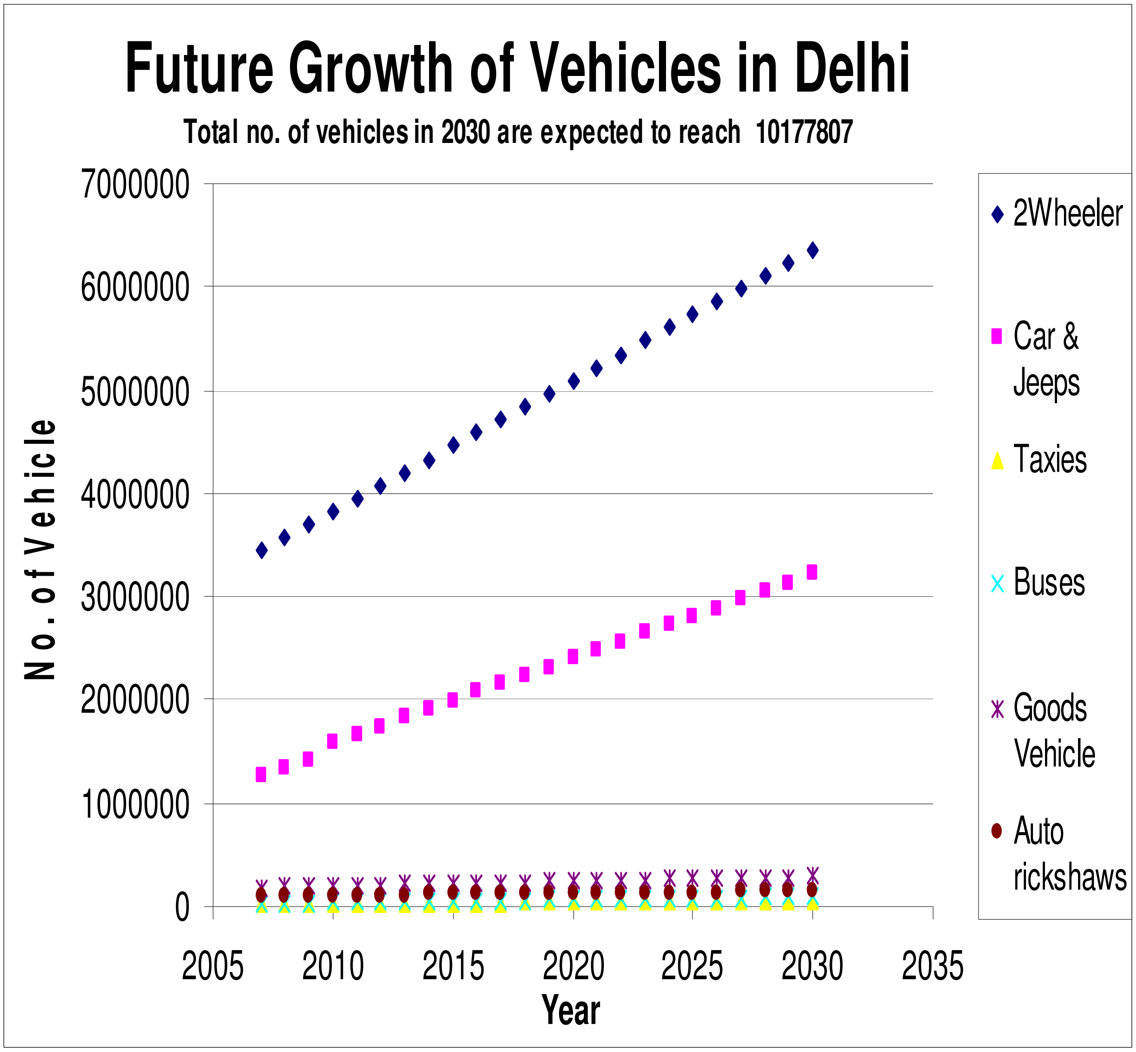


Figure 9.7: Expected Future Growth of Vehicle (Business as Usual Scenario)

Various emissions CO, HC, NOx, PM and total of these, their prediction estimated for BAU and other control actions for the year 2010 are shown graphically in following figure 8.8 to figure 8.12. Detailed calculation for these is given in appendix VI. It can be seen that a15%-30% reduction, as compared to BAU projections, can be obtained through the implementation of various control action planes.

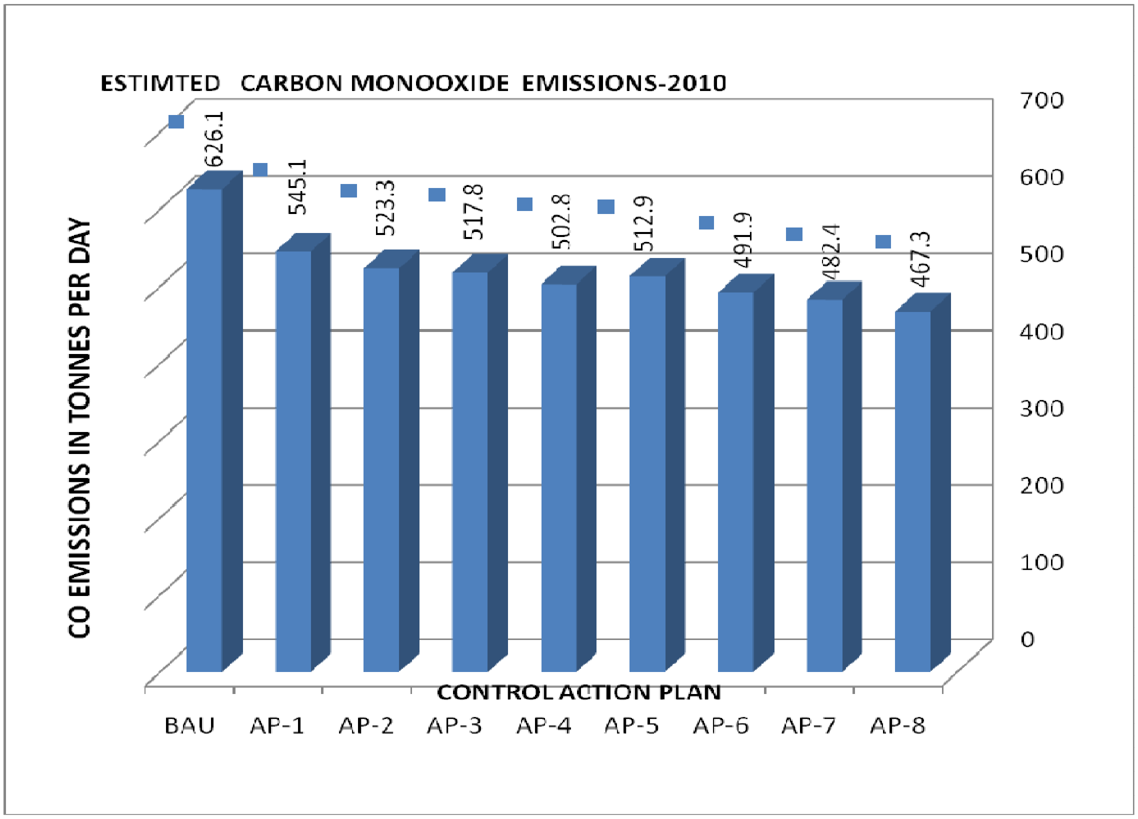


Figure 9.8: Estimated Carbon Monoxide Emissions from Different Control Action Plans 2010

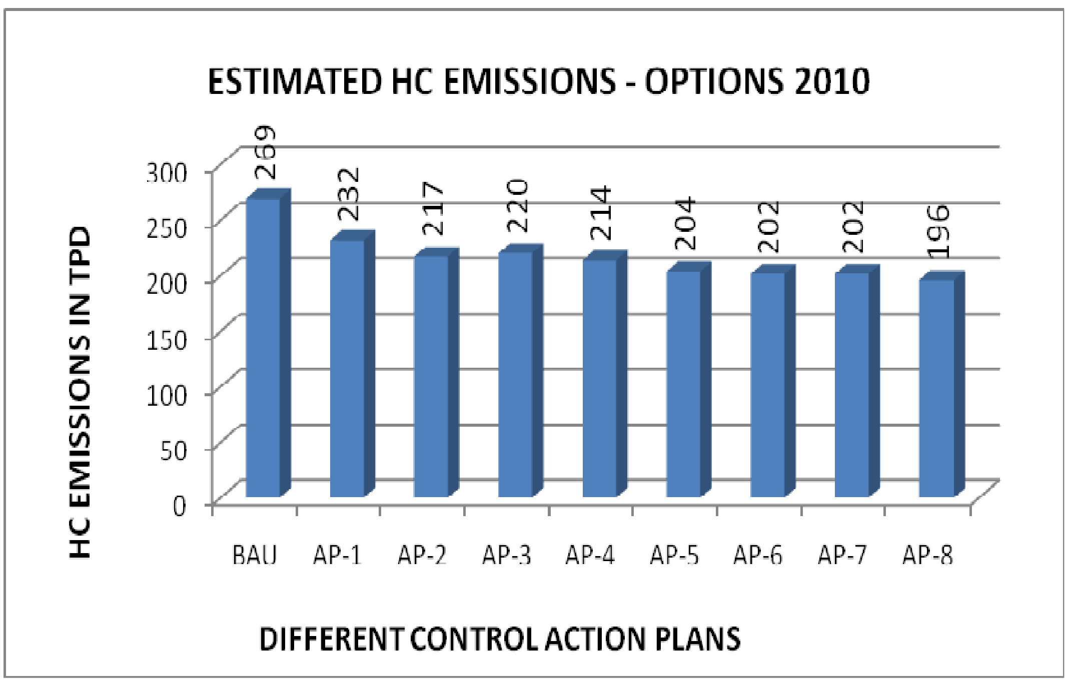


Figure 9.9: Estimated Unburnt HC Emissions from Different Control Action Plans 2010

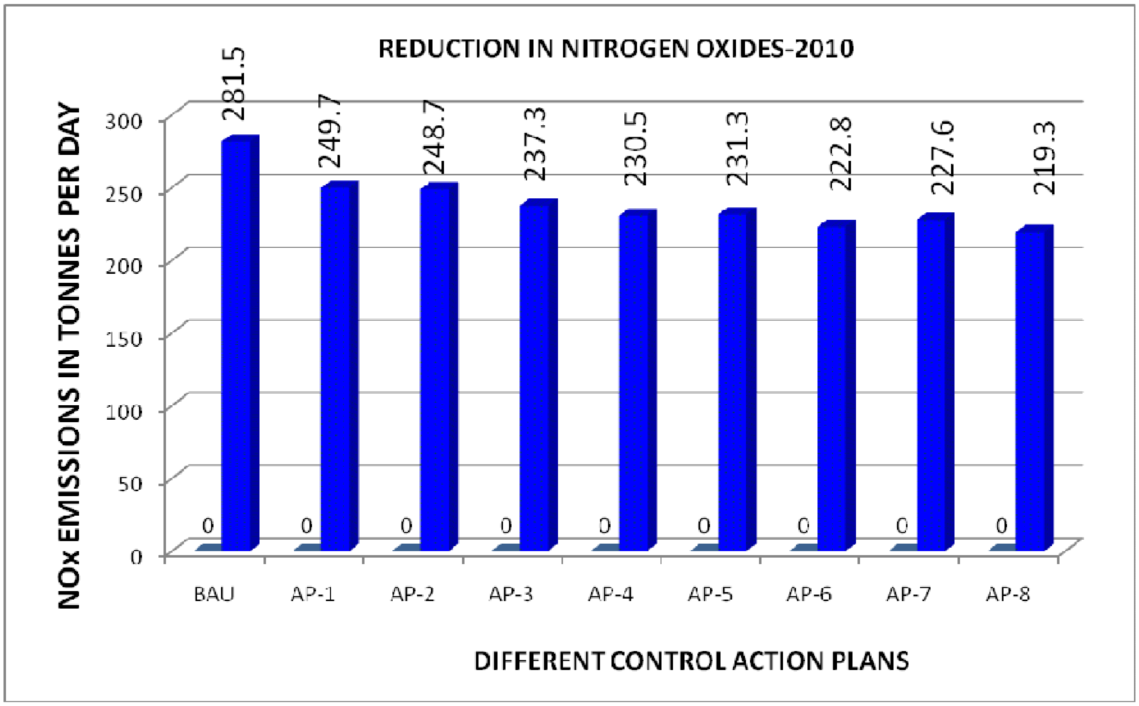


Figure 9.10: Estimated Nitrogen Oxides Emissions from Different Control Action Plans 2010

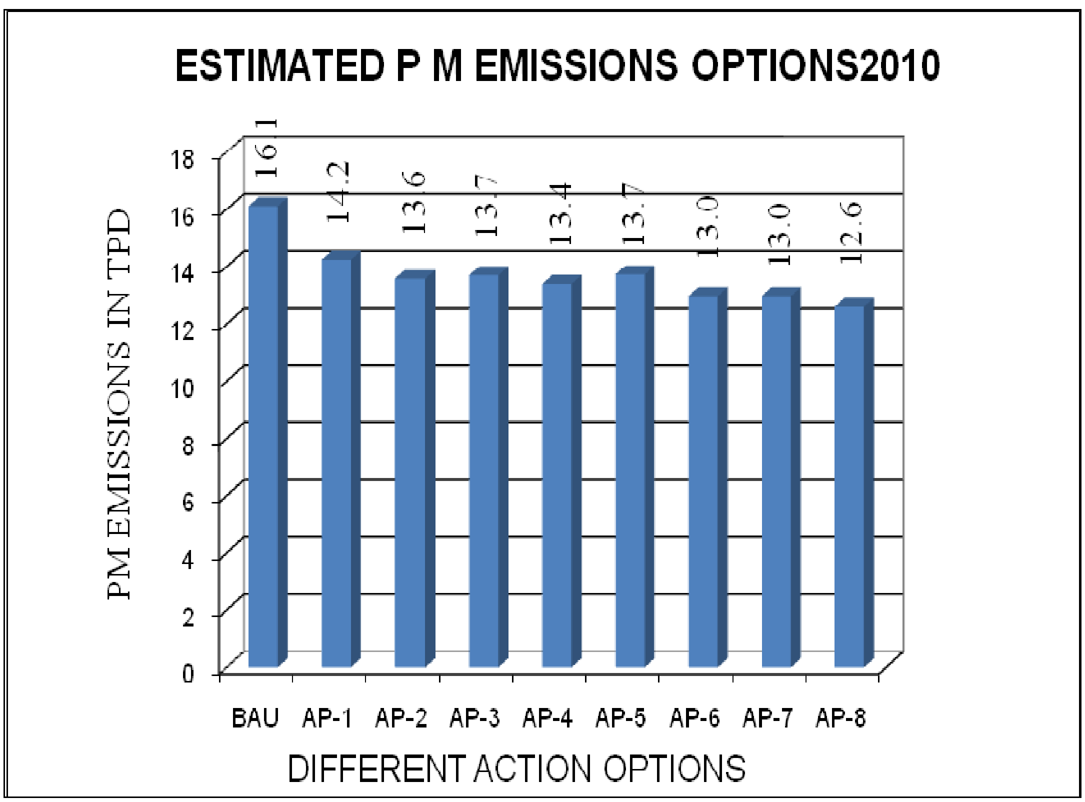


Figure 9.11: Estimated Particulate Matter Emissions from Different Control Action Plans 2010

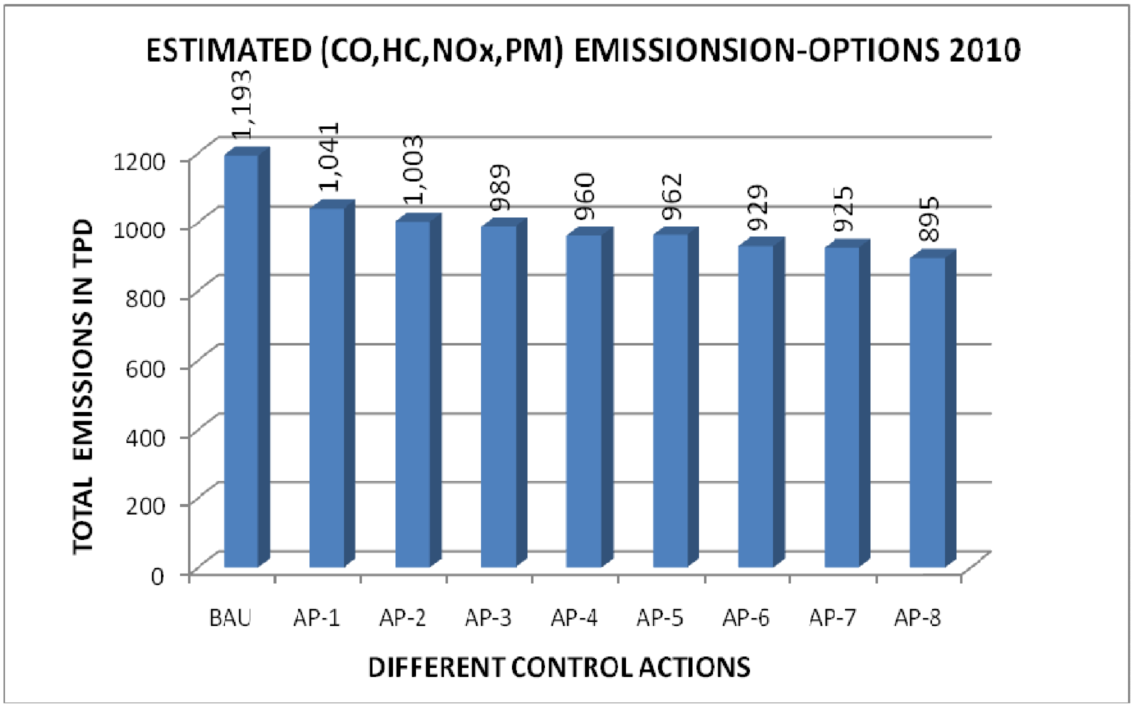


Figure 9.12: Estimated Vehicular Emissions (CO+HC+NOx+PM) from Different Control Action Plans 2010

Various emissions CO,HC,NOx,PM and total of these estimated for BAU and other control actions for the year 2020 are shown graphically in following figure 8.13 to figure 8.17. Detailed calculation for these is given in appendix VI. It can be seen that a 33%-50% reduction, as compared to BAU projections, can be obtained through the implementation of various control action planes.

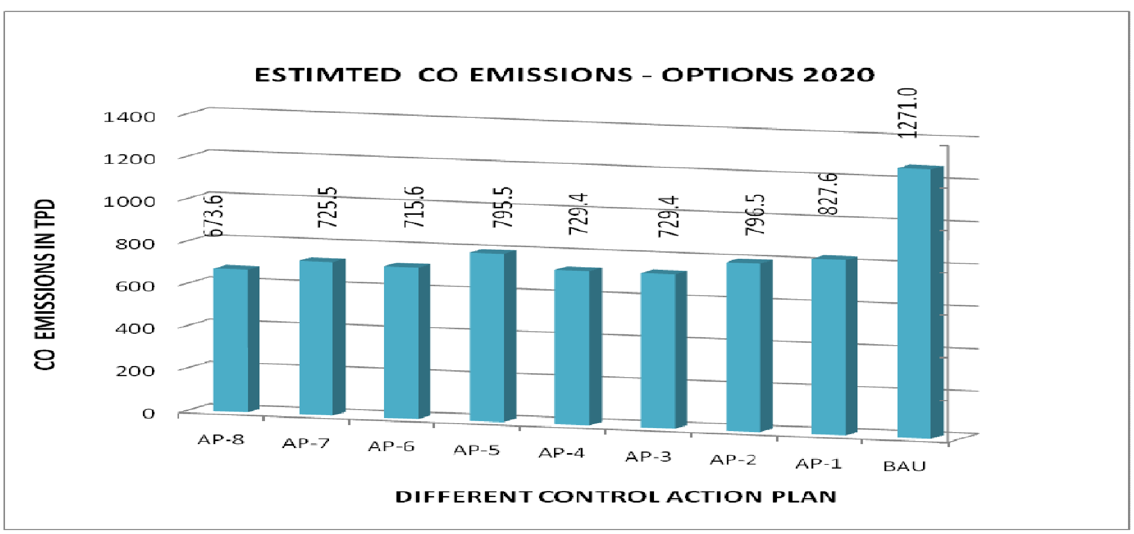


Figure 9.13: Estimated CO Emissions from Different Control Action Plans 2020

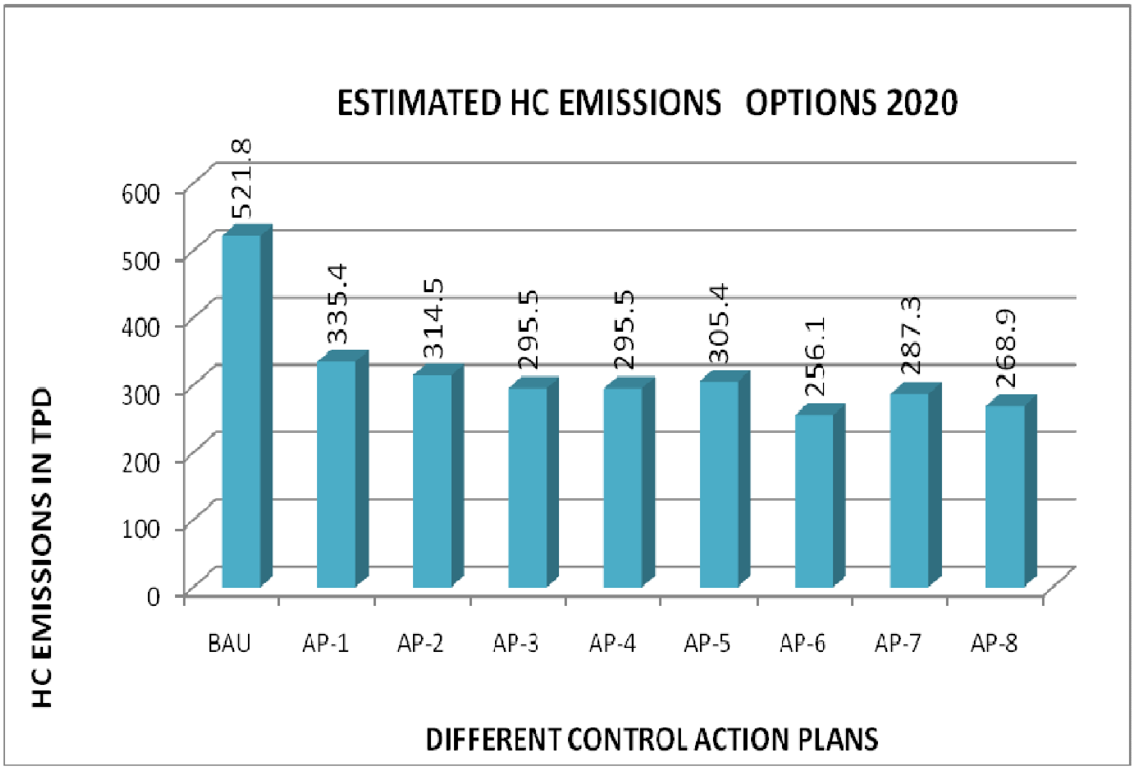


Figure 9.14: Estimated Unburnt Hydrocarbon Emissions from Different Control Action Plans 2020

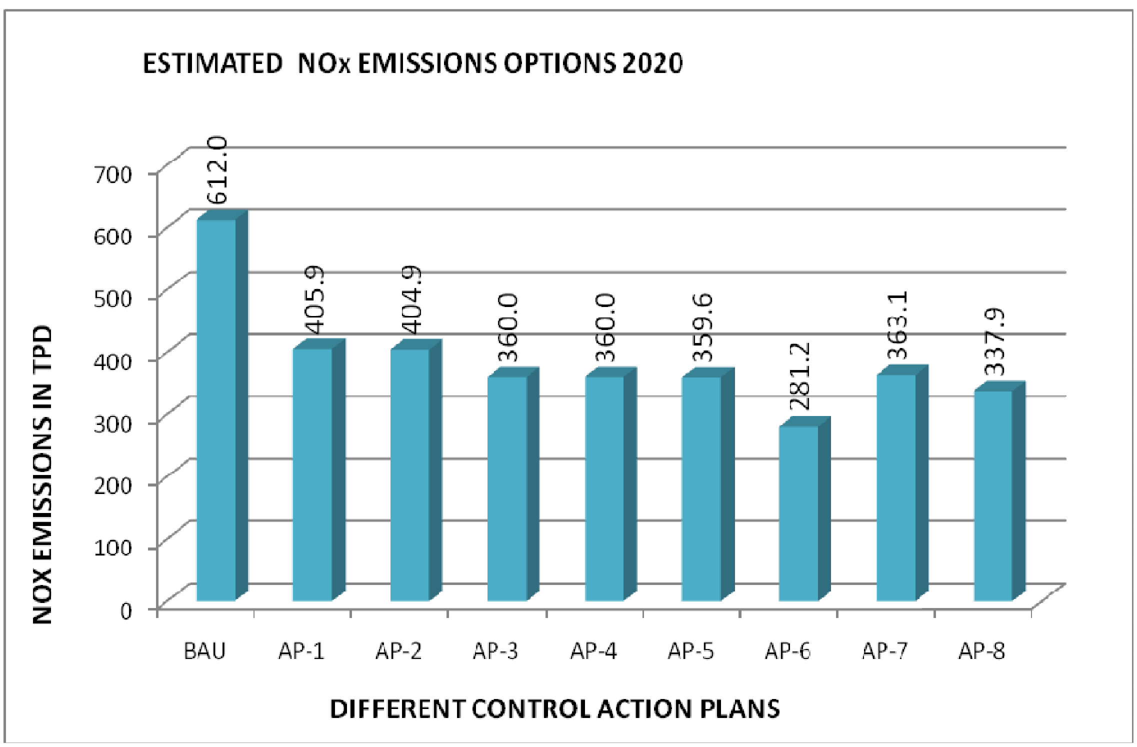


Figure 9.15: Estimated Nitrogen Oxides Emissions from Different Control Action Plans 2020

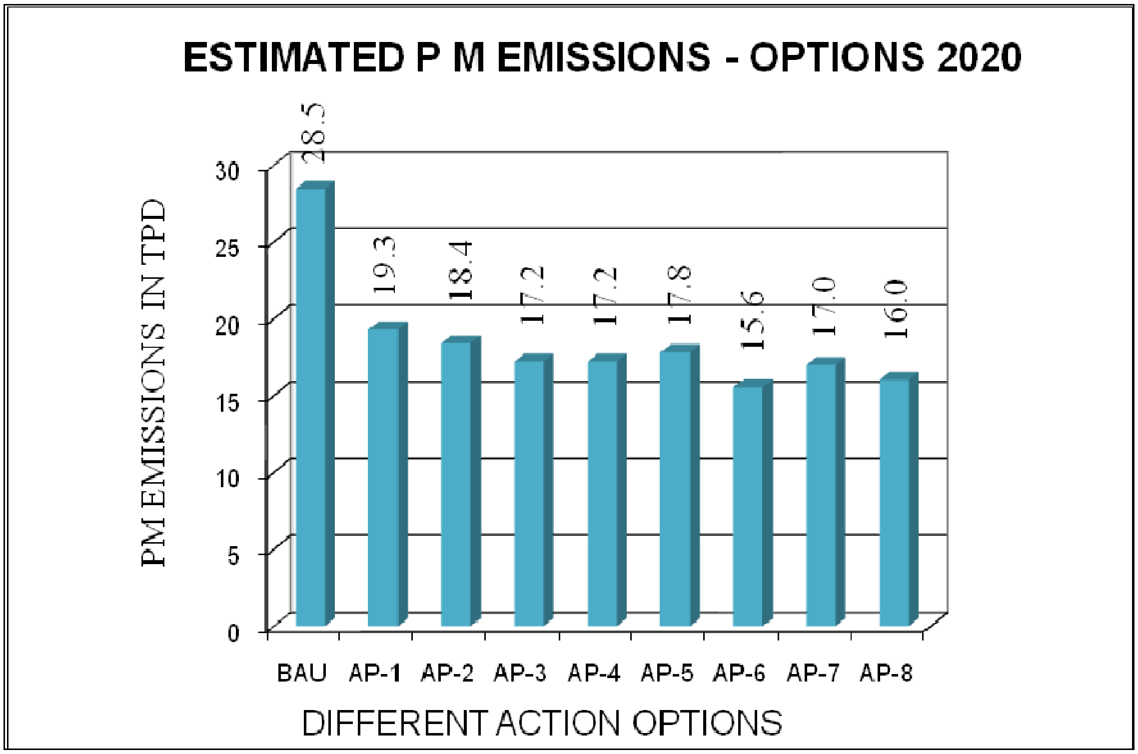


Figure 9.16: Estimated Particulate Matter Emissions from Different Control Action Plans 2020

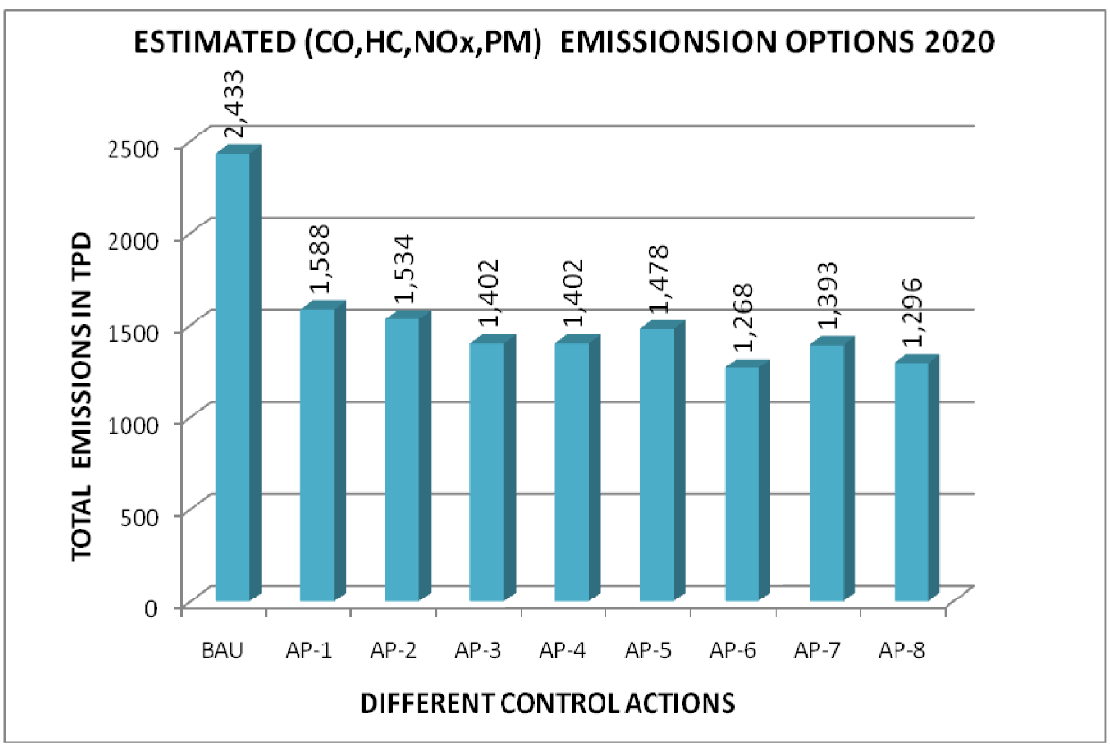


Figure 9.17: Estimated Total Vehicular Emissions (CO+HC+NOx+PM)
from Different Control Action 2020

Various emissions CO, HC, NOx, PM and total of these estimated for BAU and other control actions for the year 2030 are shown graphically in following figure 9.18 to figure 9.22. Detailed calculation for these is given in appendix VI. It can be seen that a45%-70% reduction, as compared to BAU projections, can be obtained through the implementation of various control action planes.

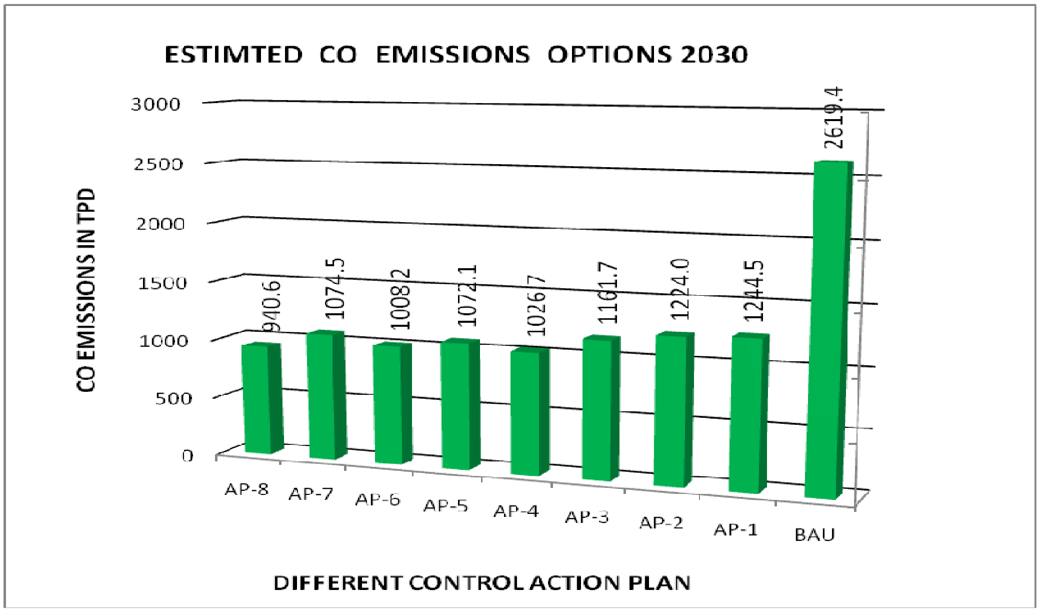


Figure 9.18: Estimated Carbon Monoxide Emissions from Different Control Action Plans 2030

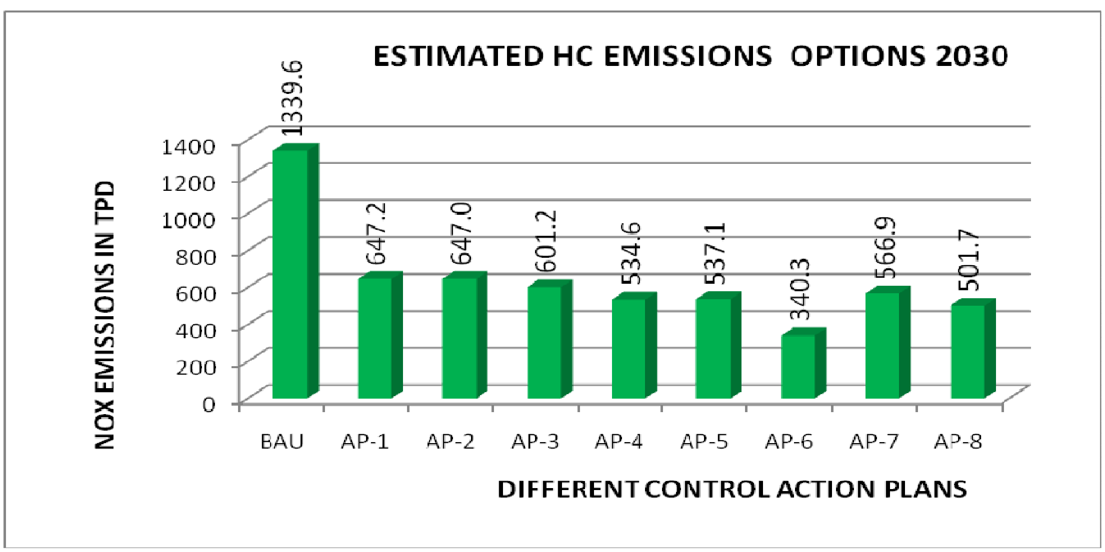


Figure 9.19: Estimated Unbrunt HC Emissions from Different Control Action Plans 2030

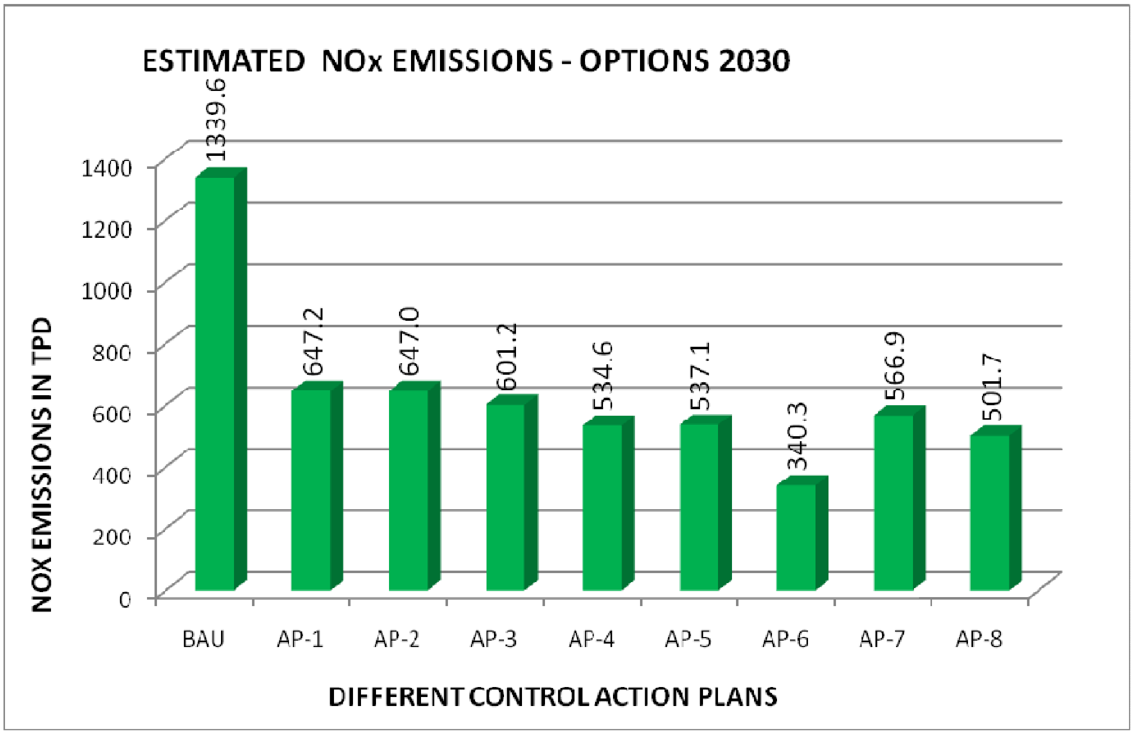


Figure 9.20: Estimated Nitrogen Oxides Emissions from Different Control Action Plans 2030

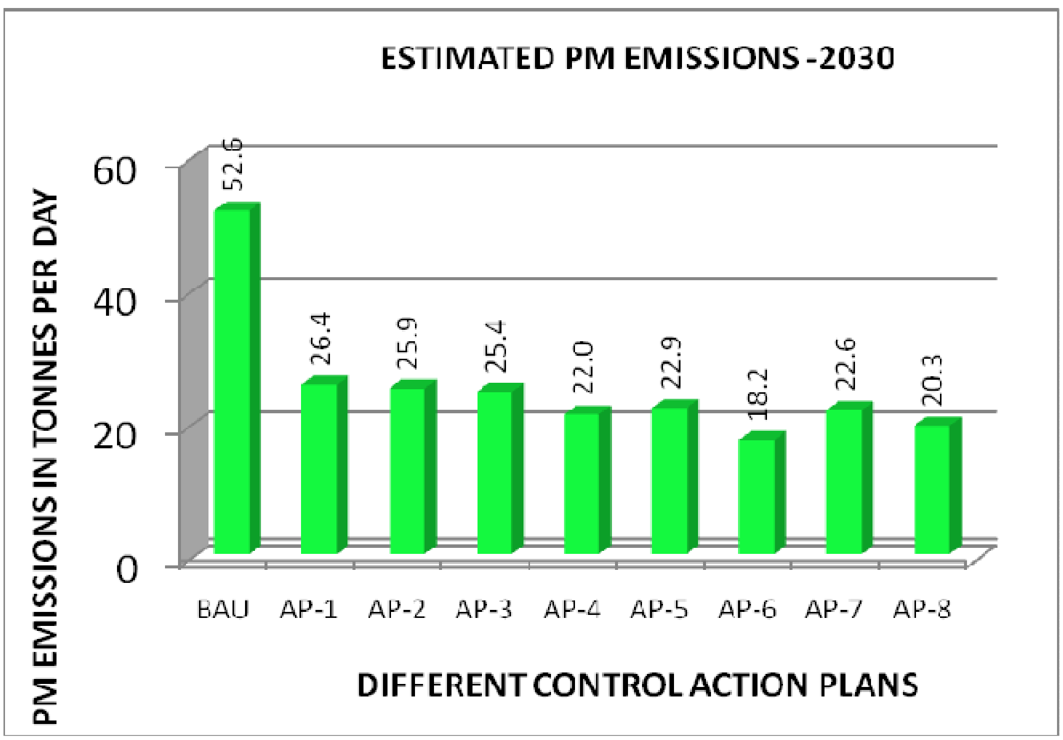


Figure 9.21: Estimated Particulate Matter Emissions from Different Control Action Plans 2030

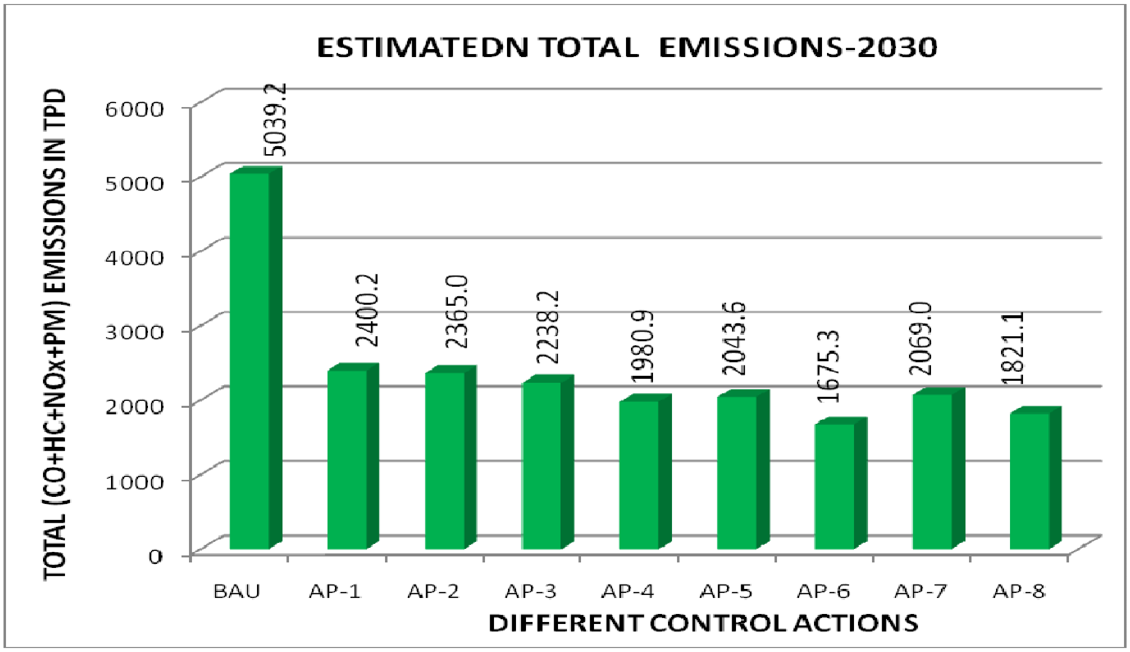


Figure 9.22: Estimated Total Vehicular Emissions (CO+HC+Nox+PM) from Different Control Action 2030

Various emissions (CO,HC,NOx,PM and total of these estimated for BAU and other control actions for the year 2010/2020 and 2030 are shown graphically in following figure 9.23 to figure 9.27. It can be seen that most of the effect of the control actions will give quite significant reduction in 2020 and 2030, as compared to BAU projections.

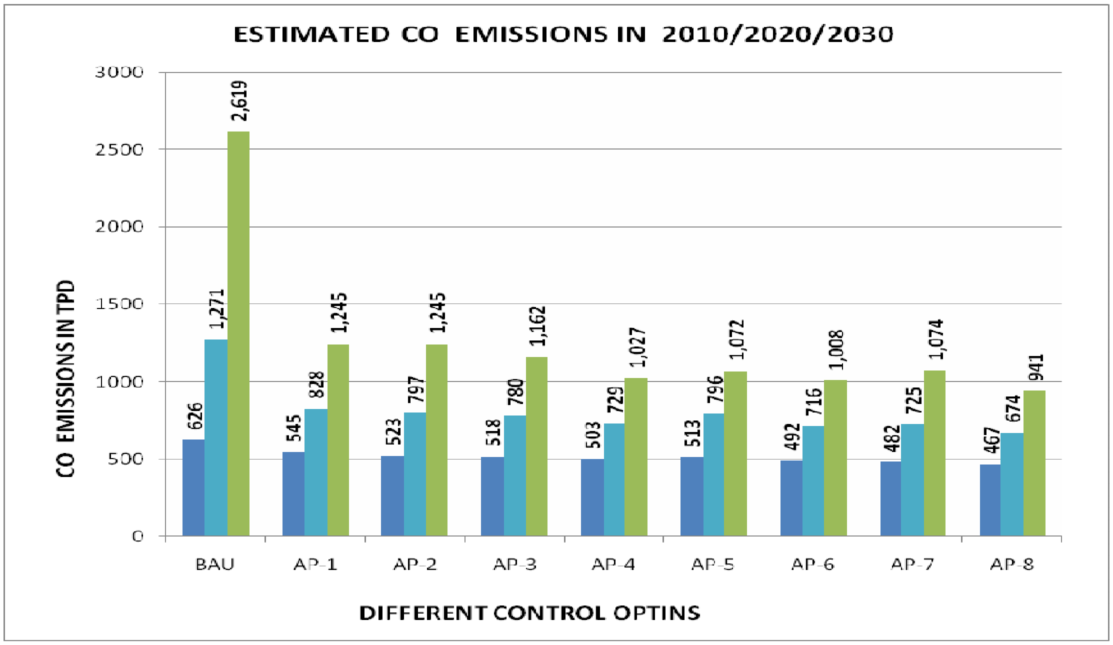


Figure 9.23: Estimated Carbon Monoxide Emissions Comparison of 2010/2020/2030

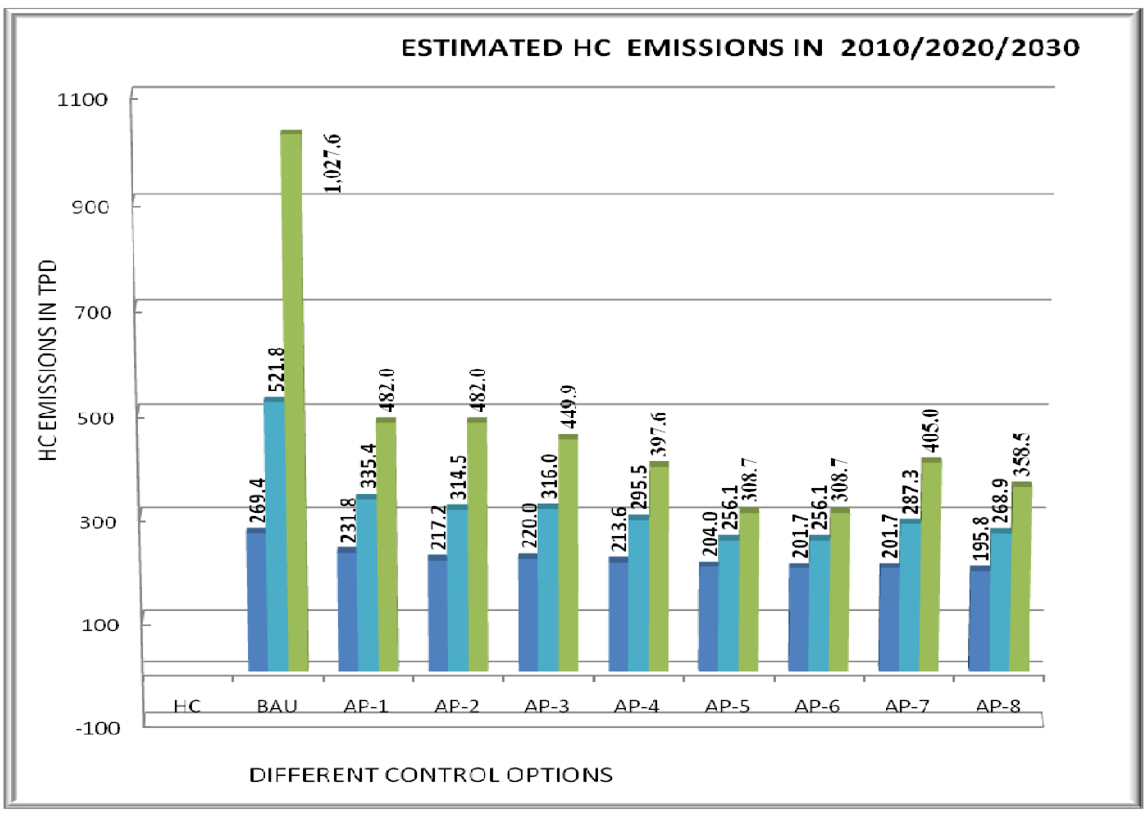


Figure 9.24: Estimated Unburnt Hydrocarbon Emissions Comparison of 2010/2020/2030

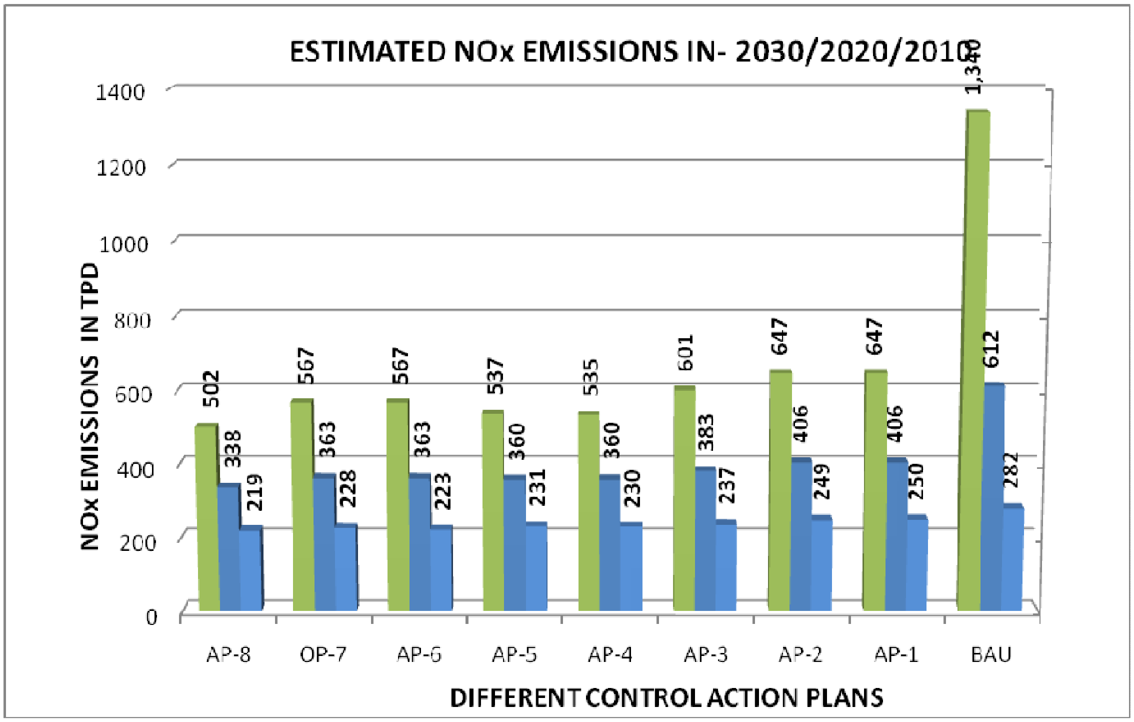


Figure 9.25: Estimated Nitrogen Oxides Emissions Comparison of 2010/2020/2030

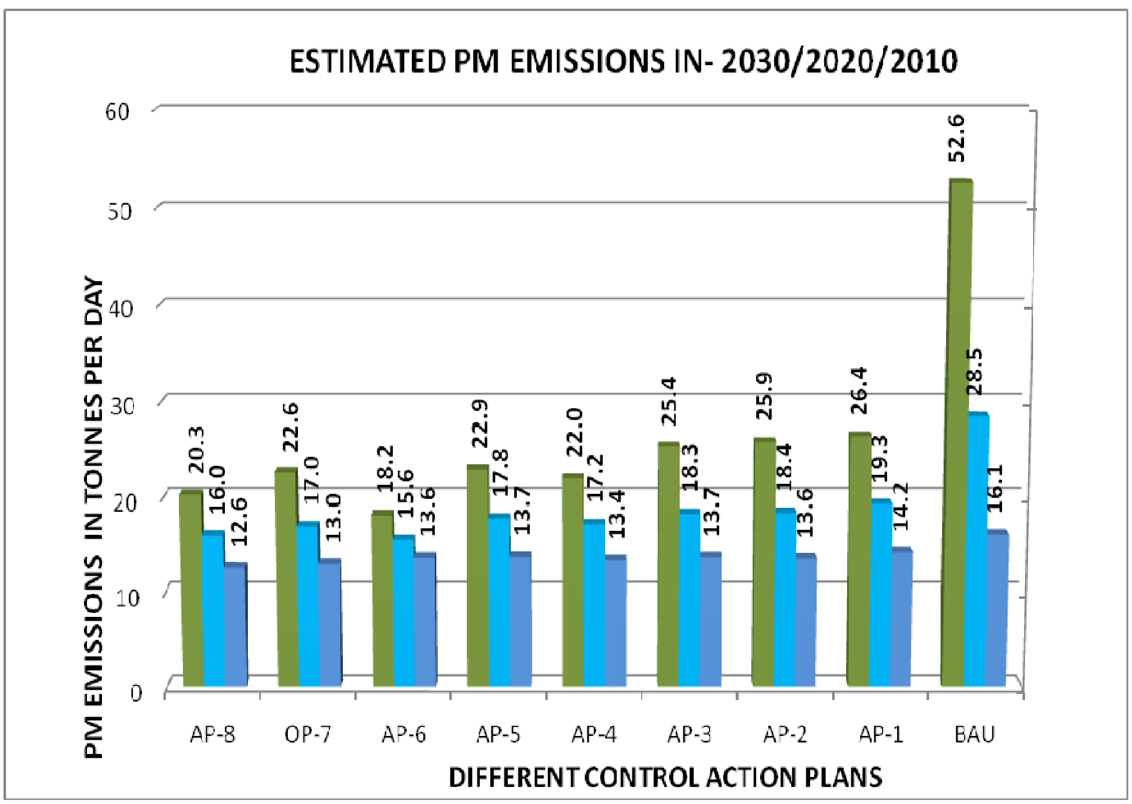


Figure 9.26: Estimated Particulate Matter Emissions Comparison of 2010/2020/2030

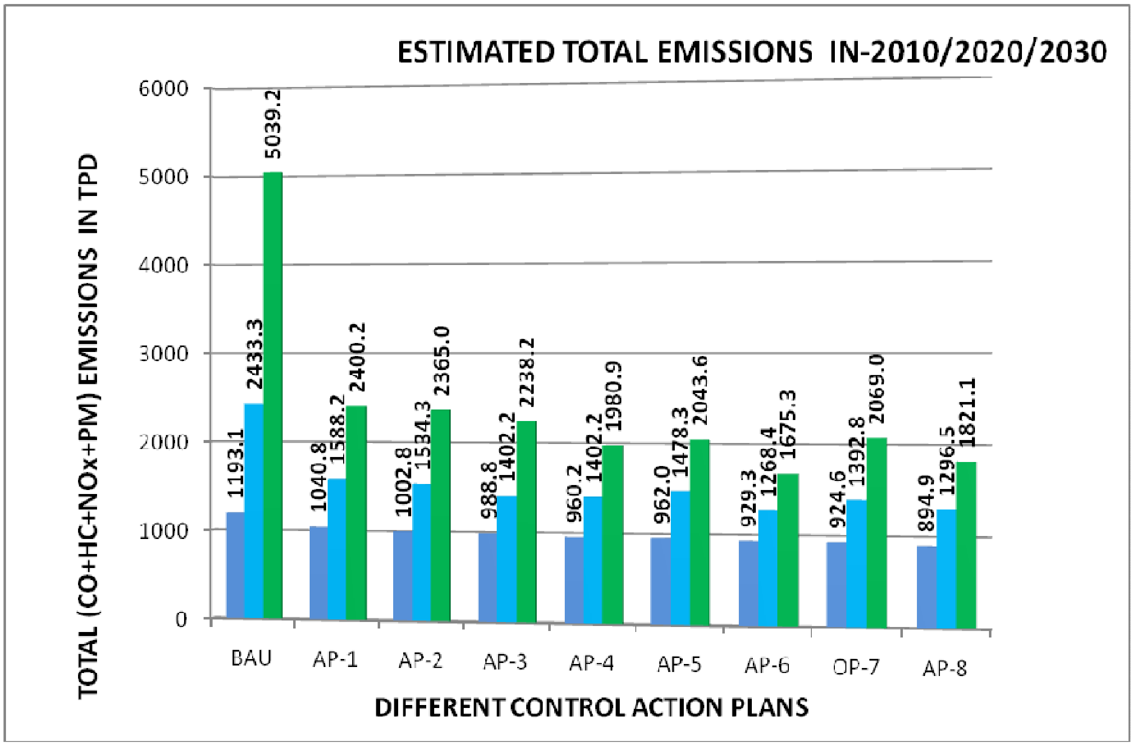


Figure 9.27: Estimated Total (CO+HC+Nox+PM) Emissions Comparison of 2010/2020/2030

9.7 COMPARISON OF THE RESULTS WITH REFERENCES

The results of the present study are compared with previous references and a comparison is shown in Table 9.4. It is seen that for the CO and PM emissions results are matching to a large extent about 10-15% higher than the earlier predictions whereas HC and NOx emissions are very high as compared to earlier references, one of the reason for these may be to the adoption of CNG in Delhi transportation system which resulted in higher NOx and lower PM emissions. It can also be seen that the earlier researchers had under estimated the vehicle growth in Delhi, as the number of vehicles registered today in Delhi are much more than their earlier predictions. Hence it can be said that the results of the present study are very much close to the realistic values with variations within 10-15 %.

Table 9.4: Comparison of the Results with References

CARBON MONOXIDE (CO)				
S.NO.	**REFERENCE**	**2005**	**2010**	**2020**
1	Das and Parikh	203	127	182
2	TERI	198	206	-
3	Bose	191.91	200.62	-
4	Present study	202.93(2007)	235.39(BAU) 161.01(AP-8)	416.72(BAU) 198.36(AP-8)
HYDRO CARBON(HC)				
1	Das and Parikh	76	66	81
2	TERI	81	82	-
3	Bose	80.63	82.48	-
4	Present Study	136.20(2007)	158(BAU) 108.07(AP-8)	279.71(BAU) 133.14(AP-8) Cont……

S.NO.	REFERENCE	2005	2010	2020
NITROGN OXIDE(NO_X)				
1	Das and Parikh	39	40	52
2	TERI	61	74	-
3	Bose	50.42	65.56	-
4	Present Study	226(2007)	281(BAU) 219.26(AP-8)	611.98(BAU) 33719.2(AP-8)
PARTICULATE MATTER(PM)				
1	Das and Parikh	5.4	2.8	3.2
2	TERI	12	11	-
3	Bose	11.59	13.39	-
4	Present Study	6.28(2007)	7.29(BAU) 4.99(AP-8)	12.91(BAU) 6.19(AP-8)
Number of Vehicles				
1	Das and Parikh	3508371	4796766	8854421
2	TERI	-	-	-
3	Bose	2591019(2000)	27,86016	
4	Present Study	52,8000(2007)	61,9000(BAU) 49,90000(AP-8)	83,77807(BAU) 61,9000(AP-8)

9.6 CONCLUDING REMARKS

In this work computation were made for finding the exact level of the vehicle emissions and finally an estimate were prepared about the total vehicular exhaust emissions and projected emission estimates were computed for the next two decades considering different pollution control actions. For future prediction various emission modification factors were proposed on the basis of the survey and the experimental results and the literature review. Presented estimates show an overview of the possible future scenarios for the year 1010, 2020 and 2030. The specific recommendations for the reduction of vehicle emissions are discussed in the next chapter.

CHAPTER 10.

CONCLUSIONS AND RECOMMENDATIONS

10.1 INTRODUCTION

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In this chapter the outcome of the present research is presented. All the aspects associated with the vehicle exhaust emissions from the transportation system of the metropolitan city of Delhi have been looked into. At the end of this research work the strategies that have been contemplated include the following:

i. Improvement of public transport system (PTS), by making it cheaper, comfortable, reliable, efficient and available within walkable distances.

ii. Optimization of traffic flow, improvement in traffic management (e.g., area traffic control system, no-traffic zones, green corridors, removal of encroachment on roads, strict regulation for construction activities and digging of roads etc.)

iii. Comprehensive inspection and certification system for Inspection and Maintenance (I&M) of on-road vehicles; emission warranty by manufacturers/ authorized service providers, which should not be just for the first few years but for the whole legally usable life of the vehicle.

iv. Phasing out of grossly polluting units or mandatory technological up-gradation.

v. Fuel quality improvements (e.g., benzene and aromatics reduction in Petrol, reformulated Gasoline with oxygenates/additives, reduction of sulfur in Diesel etc.).

vi. Accelerate the research on environment friendly alternative fuels such as Ethanol. Bio-diesel, Hydrogen etc. and laying their quality standards and ensuring their availability in the market with satisfactory quality at affordable price and to provide necessary subsidy wherever necessary.

vii. Tightening of emission norms regularly with the advancement of the technology for newer vehicles.

viii. Improvement in vehicle technology. (e.g., restriction on the two-stroke engines, on-board diagnostic system, commencement of the Gasoline Direct Injection systems, Hybrid vehicles, Electric, Fuel cell etc.)

ix. Checking adulteration of fuel and training the NGO's/general public to do so and devising the advanced technologies to check adulteration automatically.

x. Checking evaporative emissions from storage tanks and fuel distribution system.

Various future projections are estimated as per the different levels of progress on these strategies and on the basis of our estimates it is seen that there will be about 30% reduction in vehicular emissions by the year 2020 and it may be almost 50% less as compared to Business As Usual Scenario by the year 2030. The conclusion arrived out of the present research work is the need of an integrated action plan, which requires a significant contribution from all the stake holders of the city transportation system.

10.2 STAKE HOLDERS OF THE TRANSPORTATION SYSTEM

The transportation system of Delhi is dependent on the Central Government of India for any major infrastructure development. While Government of Delhi collects the revenue in the form of vehicle registration fee, fuel sale tax etc., and controls the matters of city transport system. Municipal Corporation of Delhi (MCD) looks after the construction and maintenance of a large number of roads. MCD is also responsible for providing the proper parking facilities and removing the encroachment from the roads. Responsibility for construction, planning and maintenance of the major roads and flyovers lies with CPWD and Delhi state PWD. Fuel Quality and vehicle exhaust emission legislation are framed by the central government of India in consultation with the CPCB, SIAM, ARAI, PETROFED etc.

General public has also taken its stand as and when government failed to react in safeguarding the health concern of the common people. People have approached to the supreme court of India, and it has been proven that the courts are not the mute spectators of the system but they may also intervene in the public matter at crucial times. But every time the judiciary cannot be expected to intervene in such matters.

So, there is no dearth of the stake holders for the Delhi city transport system, still, there is a need for the central co-coordinating agency, which may keep a strict vigil on regular basis on the responsibility and the action of all the stake holders. At the same time, there is a need for independent regulator headed by eminent and expert citizens like Shri M. C. Mehta who can take the responsibility and are actively vigilant to check the functioning of various government agencies.

10. 3 RECOMMENDATIONS FOR THE STAKE HOLDERS

The recommendations suggested for the various stake holders for mitigation of the vehicle exhaust emission from the transportation system of Delhi, are:

10.3.1 Recommendations for the Central Government and CPCB

∗ To promote research on environment friendly alternative fuels.

∗ To promote research and development of projects on mass transportation projects like City Metro, Sub Urban Local Trains and Monorail etc.

∗ To promote research on Fuel Cells, Hydrogen and Hythane as I C engine Fuel, and Development of Solar/Electric vehicles.

∗ To enact the legislation for stringent emission norms, engine technology and fuel quality standards.

∗ To help the state governments in preparing good quality roads, flyovers and other infrastructures.

∗ Active role to be played by Pollution Control Boards (PCBs) for addressing issues of in-use vehicle management.

∗ PCBs must lead the discussions on future emission norms in the country.

10.3.2 Recommendations for the Automobile Manufacturers

* To adopt/incorporate latest engine/vehicle technologies.
* To improve passenger comfort on public transport vehicles to make them more attractive than private vehicles, as per passenger emissions are quite small in public transport system.
* To offer regular inspection and maintenance facilities after sales for the entire usable life of the vehicles at rates competitive to other market service providers.
* To provide emission warranties for the entire usable life of the vehicles.

10.3.3 Recommendations for the Oil Companies

* To upgrade the available fuel quality as per international standards.
* To keep a regular check on adulteration of the fuel and fuel products.
* To promote research on environment friendly alternative fuels.
* To support development of fuel testing laboratories at academic institutes etc.
* To organize programmers to spread awareness on the quality of fuels.

10.3.4 Recommendations for the State Government

* To control the growth of the private vehicles by well thought taxation policy/ improving the public transport facilities etc. (Detailed action for these are given in chapter 8).
* Offer subsidies to bio-fuels manufacturers.
* Ensure sufficient number of buses plying under one control to strengthen the PTS.
* To formulate policies to minimize the official travel of the working employees by devising the policies to post them in the offices, near to their residences.

10.3.5 Recommendations for the MCD/DDA/PWD

* To remove the illegal encroachments from the roads on a regular basis.
* To develop enough parking facilities required for the vehicles.

* To maintain roads in good working condition.

* To ensure the proper working of the traffic signals and make plans to upgrade them.

10.3.6 Recommendations for the Transport Dept.

* To organize frequent I &M camps.

* To monitor pollution under control (PUC) checking process.

* To penalize overloading and highly polluting vehicles instantly.

* To regularize driver training/ licensing and promote the role of driver training institutes.

* To devise policies for the modernization of government/ public transport vehicle fleet.

* To improve overall traffic management.

* Prepare flexible time planning of the public transportation system and maintain availability as per the varying demand of the passengers.

10.4 LIMITATIONS OF THE PRESENT STUDY AND SCOPE FOR THE FUTURE WORK

Due to the limited resources and various constraints present study could not investigate many important factors affecting the vehicular pollution level of the city. Thus there exists a need for further extensive studies on the subject, such as:

1. Delhi Metro has been helpful in curtailing the vehicle emissions by indirectly reducing the usage of private vehicles and other motorized public transport vehicles which are contributing significantly lower emissions but definitely not reducing to zero level as in the case of Delhi Metro. A realistic study to find the actual reduction in number of usage of private vehicles and other motorized public transport vehicles on account of switch over to Delhi Metro service is required.

2. Bharat Stage Emission norms for the automobile exhaust pollutants partially express requirements for the purpose of the control of pollutants, particularly in Indian conditions. These norms are inadequate since no consideration has been

given to the engine characteristics, expressed either in terms of the engine swept volume or the power that it generates. These aspects need to be investigated to accommodate the wide varieties of the transport engines and varying transport densities.

3. PUC certification administration in India is highly inefficient, inadequate and unreliable, so an alternative system of original equipment manufacturers (OEM) certified inspection and maintenance has to be investigated by conducting live studies.

4. Present data used for the study is gathered from various government departments which may be different from the actual number of vehicles running on the roads. So, the live projects investigating the actual number of vehicle running on the roads at different times and their actual exhaust conditions, need to be studied.

5. Due to the limited resources and various other constraints, present study could not investigate the effect of alternative fuels on transport vehicles. Still there exists a need of case studies on the use of alternative fuels for longer periods and investigate the other effects on engine and the vehicle. These studies require substantially large infrastructure and hence can only be carried out by the organizations with a sizable man power and sufficient financial resources.

6. In this work only the registered vehicle in Delhi have been considered. But the actual number of vehicles running on Delhi roads may be different. Because a number of vehicles do not come every day on the roads, there is an inflow of traffic in city boundaries and outflow of traffic outside. Therefore, a realistic analysis of the actual number of vehicles plying on Delhi roads can be taken up.

REFERENCES

(This section includes references used in the appendices.)

1. Ackoff, L. R., “The Design of Social Research”, *University of Chicago Press*, 1953.
2. Agarwal Deepak and Agarwal Avinash, “Performance and Emissions Characteristics of Jatropha Oil (Preheated And Blends) in A Direct Injection Compression Ignition Engine”, *Applied Thermal Engineering* 2007; 27: pp 2314–2323
3. Agarwal, Avinash Kumar and Das, L. M. “Biodiesel Development and Characterization for Use as A Fuel in C. I. Engine”, *Journal of Engineering for Gas Turbines and Power ASME transaction Journal 2001*; 123, number 2 pp 440-447.
4. Ajav, E. A. and Akingbehin O. A., “A Study of some Fuel Properties of Local Ethanol Blended with Diesel Fuel”, *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development March, 2002*; Vol. IV: Manuscript EE 01 003.
5. Alternative Fuel Vehicle (AFV), Harvard University, “A Fresh Look at CNG: A Comparison of Alternative Fuels”, *HGCI, UOS, Ford Motor Company and Harvard University* (2001).
6. Altuna Sehmu et al., “The Comparison of Engine Performance and Exhaust Emission Characteristics of Sesame Oil–Diesel Fuel Mixture with Diesel Fuel in A Direct Injection Diesel Engine”, *Renewable Energy* 2008; 33 pp 1791–1795.
7. Anon, “Air Quality Monitoring in Calcutta during the Period - October 1995 to October 1996”, *West Bengal Pollution Control Board Report 1996*; pp 1–11.
8. Anon, “Diesel Exhausts a Critical Analysis of Emissions, Exposure and Health Effects”, Health *Effect Institute*, Cambridge1995.
9. Arora Ashish, “Analysis of Vehicular Pollution in Delhi: Different Cases and their Impacts”, M.E. thesis, 2002; *Faculty of Technology, University of Delhi*, India.
10. Austin, T. C. and Rubenstein, G., “Gasohal: Technical, Economic and Political Panacea”, *SAE International* 1980, *Paper no.* 800891.
11. Austin, T. C. et al., “Characterization of Driving Patterns and Emissions from Light-Duty Vehicles in California”, *Final Report submitted to the California Air Resources Board from Sierra Research,* Inst., 1993; *Contract No. A932-185, Sacramento, California*.
12. Automotive Research Association of India (ARAI) report, “Emission Factor Development for Indian Vehicles-Indian Clean Air Program- revision 4”, The Air Quality Monitoring and Emission Source Apportionment Studies”, *ARAI* 2007,.
13. Babbie, E., “*The Practice of Social Research”,* Fifth Edition 1989, *Wedsworth Publishing Company*, Belmont, California.

14. Baker, Q. A., "Use of Alcohol-in-Diesel Fuel Emulsions and Solutions in a Medium-Speed Diesel Engine", *SAE International 1981, Paper no. 810254.*

15. Banapurmath. N. R, Tewari P. G. and Hosmath R. S., "*Performance and Emission Characteristics of DI Compression Engine Operated on Honge, Jatropha and Seasme oil Methyl ester*", *Renewable Energy* 2008; 33 pp 1982-1988

16. Bardecki, M. J., "Participants' Response to the Delphi Method: An Attitudinal Perspective", *Journal of Technological Forecasting and Social Change* 1984; *25* pp281–292.

17. Barnwal, B. K., Sharma, M. P., "Prospects of Biodiesel Production from Vegetable Oils in India", *Renewable and Sustainable Energy Reviews* 2005; 9 pp 363–378.

18. Bassi, A., "Natural Gas Vehicles for a Clean Environment - An Overview and the Trends for the Future in Carvallo", Christos (eds), *Clean combustion technologies* 1990; vol. 2, Part B pp 739-762.

19. Bhandari, K. et al., "Performance and Emissions of Natural Gas Fueled Internal Combustion Engine: A Review", *Journal of Scientific and Industrial research* 2005; pp333-338.

20. Bhattacharya, T. K. and Mishra, T. N., "Studies on Feasibility of using Lower Proof Ethanol-Diesel Blends as Fuel for Compression Ignition Engines", *Institution of engineers (I) Journal*–AG 2004; 84 pp 56-60.

21. Bhure Lal Committee Report, "The Recommendations of the, Environment Pollution (Prevention & Control) Authority for the National Capital Region of India", submitted to the Honourable Supreme Court of India, 2001.

22. Black, Frank, "An Overview of the Technical Implications of Methanol and Ethanol as Highway Motor Vehicle Fuels", *SAE* International 1991, Paper no. 912413.

23. Boje, D. M., and Murnighan, J. K., "Group Confidence Pressures in Iterative Decisions", *Management Science 1982;* 28 pp 1187–1196.

24. Bonai, S., Magnini, L. and Rotiorti, G., "Genetic and Environmental Factors in Changing The Incidence of Allergy", *Journal of Allergy* 1994; 49 pp 6–14.

25. Bose, R. K. and Sperling, Daniel, "Implications of Transport Policies on Local Environment & GHG Scenarios in Delhi", Workshop on Good Practices in Policies and Measures, 8-10 October 2001 Copenhagen, Institute *of Transportation Studies, University of California*, Davis, USA. http://repositories.cdlib.org/itsdavis/UCD-ITS-REP-01-13,

26. Bose, R. K. and Nesamani K. S., "Urban Transport, Energy and Environment – A Case of Delhi", *UCD-ITS-RR-00-11, Institute of Transportation Studies, University of California*, Davis, USA, September, 2000.

27. Bose, R. K., "Automotive Energy Use and Emissions Control A Simulation Model to Analyze Transport Strategies for Indian Metropolis", *Elsevier, Energy Policy* 1998; 26(13) pp1001-1016.

28. Brockhoff, K., Linstone, H A., Turoff, M., "The Performance Of Forecasting Groups in Computer Dialogue and Face-to-Face Discussion", *The Delphi Method*, Addison-Wesley, Reading, MA, (1975) ; pp291-322

29. Bruce, C. W., Stromberg, T. F., Gurton, K. P., Mozer, J. B., "Tran Spectral Absorption And Scattering of Electromagnetic Radiation by Diesel Soot", *Appl Opt*—LP1991; 30(12) pp1537–46.

30. Brusstar, M et al., "High Efficiency and Low Emissions from a Port-Injected Engine with Neat Alcohol Fuels", *Journal of the Institution of Engineers (India)* 2002; 63 pp199.

31. Bryce, D., Ladommatos, N., Xiao, Z and Zhao, H. "Investigating the Effect Of Oxygenated and Aromatic Compounds in Fuel by Comparing Laser Soot Measurements in Laminar Diffusion Flames with Diesel-Engine Emissions", *Journal of the Institution of Energy* (1999); 72 pp150–156.

32. Buttsworth, D. R. et al., "Performance and Exhaust Emissions of A Gasoline Engine with Ethanol Blended Gasoline Fuels Using Artificial Neural Network", *Journal of Applied Energy* May 2009; 86 pp 630-639

33. Central Pollution Control Board (CPCB) 2001, "Vehicular Pollution Control in Delhi-Initiatives & Impacts" a report of *Ministry of Environment & Forests, New Delhi.*

34. Central Road Research Institute (CRRI), "Losses of Petroleum Products at Traffic Intersections Due to Idling of Vehicles in Delhi", October 1998; a report submitted to the *Petroleum Conservation Research Association of India.*

35. Centre for Science and Environment *(CSE)*, "The Leapfrog Factor Clearing the air in Asian Cities" a report 2004.

36. Choudhury, S., Bose. P. K., "*Jatropha derived Biodiesel and its Suitability as C. I. Engine Fuel"*, *SAE International* 2008; paper no. 28-0040

37. Christopher A. Sharp and Thomas W. Ryan III, "Heavy Duty Diesel Engine Emission Tests Using Special Biodiesel Fuels", 2005; *SAE International2001,* paper no. *01-3671*

38. Contaldi M., Gracceva F. and Mattucci A., "Hydrogen Perspectives in Italy: Analysis of Possible Deployment Scenarios", *International Journal of Hydrogen Energy 2008; Volume 33, Issue 6, pp 1630-1642.*

39. *CPCB* "For a Breath of Fresh Air: Ten Years of Progress and Challenges in Urban Air Quality Management in India (1993–2002)", *World Bank Report* 2005; New Delhi.

40. Dalkey, N. C. and Helmer, O., "An Experimental Application of the Delphi Method to The Use of Experts", *Management Science 1963;* 9 pp 458–467.

41. Das, A. and Parikh, J., "Transport Scenarios in Two Metropolitan Cities in India: Delhi and Mumbai", *Energy Conversion and Management* 2003; 45 pp 2603–2625.

42. DAS, L. M., "Exhaust Emission Characterization of Hydrogen Operated Engine System: Nature of Pollutants and their Control Techniques", *International Journal of Hydrogen Energy* 1991; Vol. 16, No. 11, pp. 765-775,

43. Davis, G. C., "Transportation Energy Data Book", 1998; Edition 18, ORNL-6941. *Oak Ridge National Laboratory*, Oak Ridge, TN.

44. De Gooijer, B. and Gomecsys, B. V., "A Technical document", February, 2002, available at www. gomecsys.com.

45. Defries, T. H. and Kishan, S., "Light-Duty Vehicle Driving Behavior: Private Vehicle Instrumentation", Final report submitted to the *U.S. Environmental Protection Agency from Radian Corporation*, (August 24, 1992). DCN 92-254-036-90-04, Austin, Texas.

46. Demirbas A., "Progress and Recent Trends in Biodiesel Fuels", *Energy Conversion and Management* 2009; 50 pp14–34.

47. Demirbas. A., "Biodiesel Fuels from Vegetable Oils via Catalytic and Non-Catalytic Supercritical Alcohol Transesterifications and Other Methods: A Survey", *Energy Conversion and Management* 2003; 44pp 2093-2109.

48. Dennis, R. O., "Environment Factors Versus Genetic Determinants of Childhood Inhalant Allergies", Journal of Allergy 1996; 86 pp279–287.

49. Denzin,N., The Research Act, Revised Ed., (1988) McGrawHill, New York.

50. Dodge, G. et al., "Development of an Ethanol-Fueled Ultra-Low Emissions Vehicle", 1998; *SAE International 1981, Paper no. 981358.*

51. Drolet, J. Gretz, "The Euro-Québec Hydro Hydrogen Pilot Project", *Proceedings of the 14th World Hydrogen Energy Conference, Montreal (Canada),* June 2002.

52. Eckland, E. E.; R. L Bechtold; T. J. Timbario; and P. W. McCallum, "State-of-the-Art Report on the Use of Alcohols in Diesel Engines", *SAE International1984, Paper no. 840118*

53. Economic Survey of Delhi, *Planning Department, Government of NCT of Delhi*2007-08; 138-139.

54. EPCA, "Assessment and Prevention of Gas Leakage from CNG Buses", report number 15, July, 2005 in response to the Supreme Court of India, Order dated March 11, 2005 (In the matter of W. P. (C) No.13029 of 1985; M. C. Mehta v/s UOI & others).

55. EPCA, "Second Generation Reforms for Air Pollution Control in Delhi: Examination of the Issues Raised in the IA 179" submitted by the Amicus Curiae In Response to the Supreme Court of India, Order dated February 14, 2003(In the matter of W.P.(C) No.13029 of 1985; M. C. Mehta v/s UOI & others)

56. EPCA, "The Imperative of Controlling Vehicle Numbers and Increasing Access: Report On Public Transport Projects in Delhi in Response to the Supreme Court of India, Order dated January 23, 2004 (In the matter of W. P.(C) No.13029 of 1985; M. C. Mehta v/s UOI & others) July 2004.

57. Erffmeyer, R. C. Erffmeyer E. S. and Lane, I. M.,"The Delphi Technique: An Empirical Evaluation of The Optimal Number of Rounds", *Group and Organization Studies* 1986; *11*(1): 120–128.

58. Evelyn, J., Fumifugium, "Inconvenience of the AER: Smoake of London Dissipated", W. *Godbid, printer*, London, 1661

59. Fanhua, Yefu Wang, Shangfen Ding and Long Jiang, "Twenty Percent Hydrogen-Enriched Natural Gas Transient Performance Research", *International Journal of Hydrogen Energy* 2009; Volume 34, Issue 15, pp 6523-6531

60. Ferman, G. S. and Levin, J., Social Science Research :A Handbook for Students, A Schenkman Publications,(1975), *John Wiley and sons, New York*.

61. Fikret Yüksel and Bedri Yüksel, "The Use of Ethanol–Gasoline Blend as A Fuel in An SI Engine", *Renewable Energy*, June 2004; Volume 29, Issue 7: 1181-1191.

62. Fischer, G. W., "When oracles fail – a comparison of four procedures for aggregating subjective probability forecasts", *Organizational Behavior and Human Performance* 1981; 28: 96–110.

63. Fleming R. D. and Allsup J. R., "Emission Characteristics of Natural Gas As An Alternative Fuel", *SAE International 1971, Paper* No. 710833.

64. Gangwar, Harish Kumar and Agarwal, Avinash Kumar, "Emission and Combustion Characteristics of Vegetable Oil Blends in an Indirect Ignition Transportation Engine*",* 2008. *SAE International2008, Paper no. 2008-28-0034.*

65. Gautam Surhid, Onursal Bekir, "*Motor vehicles; Air; Air Quality Management; Urban Pollution; Motors; Exhaust Gas; Environmental Aspects; Case Studies; Pollution; Latin America*", Book (ISBN 0821340166 [pbk]), 1982;Vol pp373: 282

66. Gautam, M. and Martin, D. W., "Combustion characteristics of higher Alcohol/Gasoline blends ", *Proc. I. Mech. E.* (2000)*,* vol.214, part A, pp 497-511

67. Ghose K and Banerjee M, "Assessment of the Impacts of Vehicular Emissions on Urban Air Quality And Its Management in Indian Context: The Case of Kolkata (Calcutta)" *Environmental Science & Policy* August 2004; Volume 7 Issue 4: pp 345-351.

68. Ghose, M. K., "Controlling of Motor Vehicle Emissions for A Sustainable City", *TERI Information Digest on Energy and Environment* 2000; Volume 1, Number 2: pp 273-282

69. Giuseppe, M. C. and Francesco, F., "Effect of *Environment on Atopic Status and Respiratory Disorders In Children", Journal of Allergy, Clinical Immunology* 1993; 92: pp 616–645.

70. Glassman, I., "Soot Formation in Combustion Processes. *In Proceedings of the 22nd International Symposium on Combustion* 1988; pp 295–311.

71. Glesen,C. and Peshkin, A., Becoming Qualitative Researchers: An Introduction, *Longman Publication Group*,1992,New York.

72. Gogate P. R., Tayal. R. K and Pandit. A. B, "Cavitation: A Technology on the Horizon", Current Science 2006; 91:pp 35-46.

73. Gogate. P. R, and Pandit. A. B., "A Review and Assessment of Hydrodynamic Cavitation as a technology for the future", Ultrasonics Sonochemistry 2005; 12:pp 21–27.

74. Gouahalli S. R. and Khan, N " Performance and Emission Characteristics of a Diesel Engine Burning Unstabilized Emulsions of Diesel Fuel with Water, Methanol, and Ethanol", *SAE International,1981 Paper* no. 811210.

75. Goyal, P. and Ramakrishna, T. V. B. P. S., "Various Methods of Emission Estimation of Vehicular Traffic In Delhi", *Transportation Research Part D: Transport And Environment* September 1998; Volume 3, Issue 5:pp 309-317.

76. Goyal, S. K. et al. (12 Nov. 2006). "Understanding Urban Vehicular Pollution Problem Vis-a-Vis Ambient Air Quality - Case Study of a Megacity, Delhi, India", *Environmental Monitoring and Assessment* 2005; 119:pp 557-569.

77. Gupta, C. P., "Use of Alcohols in Diesel Engines- A Review," *Journal of the Institution of Engineers (Mechanical Engineering) India* 2003;pp *56-60*

78. Gurjar, B. R., et al.., "Emission Estimates and Trends (1990-2000) for Megacity Delhi and Implications." *Atmospheric Environment* 2004; 38: pp 5663-5681

79. Hakan, Bayraktar. "Experimental and theoretical investigation of using gasoline–ethanol blends in spark-ignition engines", *Renewable Energy*, 2005; *Volume 30, Issue 11:pp1733-1747.*

80. Hanh, H. D.; Dong, N. T.; Okitsu, K.; Nishimura, R.; Maeda, Y. Effect of Molar ratio, Catalyst Concentration and Temperature on transesterification of Triolin with Ethanol

under Ultrasonic Irradiation. Journal of the Japan Petroleum Institute 2007, 50 (4), pp195-199.

81. Hansen Alan C., Qin hang and Peter W. L. Lyne, "Ethanol–Diesel Fuel Blends — A Review", *Bioresource Technology,* February 2005; Volume 96, Issue 3: pp 277-285

82. Hasan, M. Al. "Effect of Ethanol–Unleaded Gasoline Blends on Engine Performance and Exhaust Emission"*, Energy Conversion and Management*, June 2003; Volume 44, Issue 9:pp 1547-1561.

83. Haynes, Bsahggw Dale R. Tree, and Kenth I. Svensson 1981; "Soot formation in C. I. Engines", *Progress in Energy and Combustion Science June2007; Volume 33, Issue 3:pp 272-309.*

84. He, et. al., "Continuous Production of Biodiesel Fuel from Vegetable Oil Using Supercritical Methanol Process", Fuel 2007**,** 86, pp 442-447.

85. Hebbal O. D. et al., "Performance Characteristics of A Diesel Engine with Deccan Hemp Oil", *Fuel* 18 April 2006; 85: pp 2187–2194.

86. Heisey, J. B. and S. S. Lestz, "Aqueous Alcohol Fumigation of A Single-Cylinder DICI Engine", *SAE International 1981, Paper no.* 811208

87. Hengwen Han, Weilang Cao, Jingchang Zhang, "Preparation of Biodiesel from Soyabean Oil Using Supercritical Methanol and CO_2 as Co-Solvent", *Process Biochemistry* 2005; 40:pp 3148-3151.

88. Heywood John B. "Internal Combustion Engine Fundamentals", *International edition, McGraw -Hill* New York: 1989, USA; pp: 34, 82,145-146, and 235

89. Heywood, J. B., and Komiyama, K. "Predicting NO_x Emissions and Effect of Exhaust Gas Recirculation in Spark-Ignition Engines", *1973, International paper no*. 730475.

90. Hoang Duc Hanh, guyen The Dong, Carmen Starvarache, Kenji Okitsu, Yasuaki Maeda and Rokuro Nishimura, " Methanolysis of Triolein by Low Frequency Ultrasonic Irradiation", *Energy Conversion and Management* 2008; 419: pp 276-280.

91. Irshad, Ahmed, "Oxygenated Diesel: Emissions and Performance Characteristics of Ethanol-Diesel Blends in CI Engines", *SAE International* 2001, paper no. 2001-01-2475.

92. Ismail et al., "Diesel Engine Convert to Port Injection CNG Engine Using Gaseous Injector Nozzle Multi Holes Geometries Improvement: A Review" *American J. of Engineering and Applied Sciences* 2009; 2 (2):pp 268-278,

93. J. Fulton, F. Lynch, "Leverage use of Hydrogen in Internal Combustion Engines", Energy Progress XI, pp. 123-132, 1996 *(Proceedings of the 11th World Hydrogen Energy Conference*, Stuttgart, 23 - 28 June 1996)

94. J. Huang, Y. Wang, S. Li, A.P. Roskilly, H. Yu, H. Li, " Experimental Investigation on the Performance and Emissions of a Diesel Engine Fuelled with Ethanol-diesel Blends", *Applied Thermal Engineering* (2008), 10.1016/ j.applthermaleng 2008.

95. Jianbing Ji, Jianli Wang, Yongchao Li, Yunliang Yu, Zhichao Xu, " Preparation of biodiesel with the help of ultrasonic and hydrodynamic cavitation", *Ultrasonics* 2006; 44: e411-e414.

96. Jincheng Huang, Yaodong Wang, Shuangding Li, Anthony P. Roskilly, Hongdong Yu and Huifen Li., "Experimental Investigation on the Performance and Emissions of a Diesel Engine Fuelled with Ethanol-diesel Blend", *Applied Thermal Engineering* 2008; Volume 29 Issues 11-12: pp 2484-2490.

97. John Rogers et al., "Consultation Draft Energy Efficiency and Climate Change Considerations for Energy Efficiency", prepared under TA - 6261 (REG), Initiative Consultation Workshop on Transport, Energy Efficiency and Climate Change in Asia, *Asian Development Bank,* June 16, 2006; Version 9a.

98. Jolson, M. A. & Rossow, G. "The Delphi Process in Organization Marketing Decision Making", *Journal of Marketing Research* 1971; 8: pp 443–448.

99. Kaleemuddin Syed, Rao AmbaPrasad (2009), "Development of Dual Fuel Single Cylinder Natural Gas Engine an Analysis and Experimental Investigation for Performance and Emission" *American Journal of Applied Sciences,* pp: 929-936, 2009

100. Kandlikar, M. and Ramachandran, G., "The Causes and Consequences of Particulate Air Pollution in Urban India: A Synthesis of the Science", *Annual Review of Energy and the Environment* 2000; 25: pp 629-684.

101. Kandlikar, M., Ramachandran, G., Maynard, A.D., Murdock, B., Toscano, W.A., "Health Risk Assessment for Nanoparticles: A Case for Using Expert Judgment*", Journal of Nanoparticle Research* 2007; 9:137-156, DOI 10.1007/s11051-006-9154-x

102. Kappanna, Hemanth, K. (2006). "Reduction of Toxic Air Contaminants (TACs) and Particulate Matter Emissions from Heavy-Duty Natural Gas Engines" a Master of Science in Mechanical Engineering thesis, *College of Engineering and Mineral Resources at West Virginia University.*

103. Karen, E. and Michak, F.W., "Smoking Cessation and Acute Airway Response to Ozone", *Arch. Environ. Health* 1991; 46: pp 288–295.

104. Karimi, M. N. and Nath, B. K., 'Implementation of Compressed Natural Gas Technology in Delhi Transport System', Proceeding of GLOGIFT, March13-15, 2004*, Jamia Millia Islamia,* New Delhi, pp 374-387.

105. Kathuria, Vinish (2004). "Impact of CNG on Vehicular Pollution in Delhi: a Note", J. Elsevier, *Transportation Research Part* D 9(2004);pp 409-417.

106. Kathuria, Vinish, "Vehicular Pollution Control in Delhi." *Transport and Environment* 7 (2002): 373-387. 11 Nov. 2006.

107. Kelly, K. J. et al. "Federal Test Procedure Emissions Test Results from Ethanol Variable-Fuel Vehicle Chevrolet Luminas", *SAE International1996, Paper no*. 961092.

108. Keoleian, G. A., and G. McD. Lewis, "Application of Life Cycle Energy Analysis to Photovoltaic Module Design", *Progress in Photovoltaics* 1997; 5(4):pp 287-300.

109. Kerlingr, F.N., "Foundations of Behavioral Research", (1983) ; *Surjeet Publications*, Delhi.

110. Kumarappa S. and Prabhukumar G. P., "Improving the Performance of Two Stroke Spark Ignition Engine by Direct Electronic CNG Injection", *Jordan Journal of Mechanical and Industrial Engineering*, 2008, ISSN 1995-6665, pp 169 - 174

111. Labeckas Gvidonas and Slavinskas Stasys, "The Effect of Rapeseed Oil Methyl Ester on Direct Injection Diesel Engine Performance and Exhaust Emissions", *Energy Conversion and Management* 2006; 47 : pp1954–1967.

112. Lapuerta Magin et al.," Effect of Biodiesel Fuels on Diesel Engine Emissions". *Progress in Energy and Combustion Science* 2008; *34*: pp198–223.

113. Layford E.J. (2003), "An Emission and Performance Comparison of the Natural Gas Engine in Heavy-Duty Trucks" a report submitted to *National Renewable Energy Laboratory*, Colorado 2003.

114. Lee, K. O. et al., "Detailed Characterization of Morphology and Dimensions of Diesel Particulates Via Thermophoretic Sampling", SAE *International 2001, Paper no*. 2001-01-3572.

115. Likos, B.; T. J. Callahan; and C. A. Moses, "Performance and Emissions of Ethanol and Ethanol-Diesel Blends in Direct-Injected and Pre-Chamber Diesel Engines", *SAE International1982, Paper no*. 821039.

116. Lisa Garrity, "Hydrogen Fuel Cell Buses: The Future for Sustainable Transportation in Western Australia and Around the World", Prepared in January, 2002, by a Ph. D. student at *Murdoch University* focusing on 'Hydrogen as a Transport Fuel', With the assistance of Graeme Harman, Consultant/Project Director, Department of Planning and Infrastructure.

117. Liu Zhen Tao and FEI Shao Mei (2003), "Study of CNG/diesel dual Fuel Engines Emissions by Means of RBF Neural Network" *Journal of Zhejiang University of Science*, 2003, pp: 960-965.

118. Magbuhat, S. and Long, J.R., "Using Instrumented Vehicles to Improve Activity Estimates for the California Emissions Inventory Model", 1995, VIP-45, *The Emission Inventory: Applications and Improvement, Air and Waste Management Association.*

119. Maji S. "A Study of Alternative Fuels in S. I. Engines for Fuel Efficiency and Exhaust Emission Control", Ph. D. Thesis, 2002, *Faculty of Technology*, University of Delhi. India

120. Maji S., Pal Amit and Arora B. B. "Use of CNG and Diesel in C.I. Engine in Dual Fuel Mode ", SAE International 2008, paper 2008-28-0072.

121. Marchetti, J. M., Miguel, V. U. and Errazu, A. F., "Possible Methods for Biodiesel Production", *Renewable and Sustainable Energy Reviews* 2007; 11: pp 1300–1311.

122. Marinov, N. M., "A Detailed Chemical Kinetic Model for High Temperature Ethanol Oxidation", *International Journal of Chemical Kinetics* 1999; Vol. 31, No. 3: pp 183-220.

123. Martino, J., "Technological Forecasting for Decision Making", 2nd ed., *American Elsevier*, 1983. New York.

124. Mashelkar, R. A., Report of the expert committee on "Auto Fuel Policy" *Ministry of Petroleum and Natural Gas*, (2003) Government of India.

125. Meher. L. C, Sagar D. V, Naik. S. N, "Technical Aspects of Biodiesel Production by Transesterification- a review", *Renewable and Sustainable Energy Reviews* 2006; 10: pp 248-268.

126. Merritt, M. et al., "Developmental Fuels Emissions Evaluation", *SAE International 2005, paper no*. 2005-01-3704; pp 1235-1242.

127. Metghalchi, M. and Keck, J. C., "Burning Velocities of Mixtures of Air with Methanol, Isooctane, and Indolene at High Pressure and Temperature", *Combustion and Flame* 1982; 48: pp 191-210.

128. Milind, Kandlikar, "Air Pollution at a Hotspot Location in Delhi: Detecting Trends, Seasonal Cycles and Oscillations", Atmospheric *Environment* 2007; 41: pp 5934–5947.

129. Miner, F. C., "A Comparative Analysis of Three Diverse Group Decision Making Approaches", *Academy of Management Journal* 1979; 22(1): pp 81–93.

130. Ministry of Environment and Forestry, "White Paper on Pollution in Delhi with an Action Plan", 1997; *http://envfor.nic.in/divisions/cpoll/delpolln.html*.

131. Mittal, M. L. and Sharma C., "Anthropogenic Emissions from Energy Activities in India: Generation and Source Characterization", *Part II: emissions from vehicular transport in India* (2003a). *www.osc.edu/research/archive/pcrm/emissions/thermalemissions.html*

132. Mohan D, et al., “Planning for Public Transport: Integrating Safety, Environment and Economic Issues” *Workshop on Transportation, Land Use, and the Environment*, I. I. T. Delhi, December 3-4, 2001

133. Mukhopadhyay, P. K., Committee report, “Transport *Fuel Quality for Year 2005*”, (Dec. 2000) *CPCB*, Delhi, India.

134. Nagendra, S. M. S. and Khare M., “Vehicular Exhaust Emission Trends in the Delhi City”, *I E(I) Journal-EN,* March, 2006; 86:pp 45-50.

135. Narain, Urvashi and Alan, Krupnick, “The Impact of Delhi’s CNG Program on Air Quality”, *Resources for the Future* RFF DP 07-06, February 2007.

136. Narain, Urvashi and Bell Ruth, Greenspan, “Discussion paper: Who Changed Delhi’s Air? The Roles of the court and the Executive in Environmental Policymaking", *Resources for the future* (RFF) DP 05-48. (2005)

137. Naveen, kumar and Dhuwe Abhay, (2004). “Fuelling an Agricultural Diesel Engine with Derivatives of Palm Oil, *SAE International2004, Paper no.* 2004-28-0039.

138. Pal, Amit; Maji, S. and Babu, M. K. G., “Incorporating Fuel Flexibility In C I Engines: an Innovative Approach To Improve The Economy And Environment”, *Technology Transfer & Flexibility at Asian Institute of technology,* Bangkok, Thailand, December 20-22, 2006

139. Pal, Hansraj, “Educational Research”, 2004; *Madhya Pradesh Hindi Granth Academy,* India.

140. Papagiannakis, R. G., and. Hountalas, D. T, “Experimental Investigation Concerning the Effect of Natural Gas Percentage on Performance and Emissions of a DI Dual Fuel Diesel Engine,” *Applied Thermal Engineering* 2003; 3:pp 353-365,

141. Patrick Coroller & Gabriel Plassat, “Comparative Study on Exhaust Emissions from Diesel and Cng-Powered Urban Buses” *French Agency of Environment and Energy Management, Air & Transport Division*, 2003.

142. Peterson, J., “Global Population Projection through the 21st Century”, *Ambio*(1984); *Vol*ume. 13, No. 3: 141.

143. Pundir. B. P., et al., “Vehicular emissions and Control Perspective in India”, 1994, *Indian Institute of Petroleum*, Dehradun, India

144. Purushothaman K. and Nagarajan G. “Performance, Emission and Combustion Characteristics of a Compression Ignition Engine Operating on Neat Orange Oil”. *Renewable Energy* 2009; 34 pp 242–245.

145. Radwan, M. S., “Performance and Knock Limits of Ethanol-Gasoline Blends in Spark-Ignited Engines”, *SAE International 1985, Paper* no. 850213.

146. Ramanathan, R. "Link between Population and Number of Vehicles: Evidence from Indian Cities", *Cities* Nov. 2006); pp 263-269.

147. Ramesh D. and Sampathrajan A, "Investigations on Performance and Emission Characteristics of Diesel Engine with Jatropha Biodiesel and Its Blends". *Agricultural Engineering International: the CIGR Ejournal*. Manuscript EE 07 013. Vol. X. March, 2008.

148. Rao GVNSR Ratnakara, Raju V. Ramachandra and Rao, M. Muralidhara, "Optimizing The Compression Ratio Of Diesel Fuelled C.I Engine", *ARPN Journal of Engineering and Applied Sciences*, VOL. 3, NO. 2, APRIL 2008.

149. Raon, V. P. and Bata, R. M. "Effects of ethanol and or Methanol in Alcohol Gasoline blends on S.I. engine exhaust emissions", *ASME Journal of Engineering for Gas Turbines and Power,* 1989.

150. Raynolds, M. A. et al., "A Case Study for Life Cycle Assessment (LCA) as an Energy Decision Making Tool: The Production of Fuel Ethanol from Various Feedstock's", *SAE International 1998, Paper no*. 982205.

151. Riggs, W. E., "The Delphi Method: An Experimental Evaluation", *Technological Forecasting and Social Change* (1983); 23: pp 89–94.

152. Rogers John and Traflagar group," Assessment of the Pollution Under control Programme in India" *World Bank Report of the South Asia Urban Air Quality Management Programme,* 2002.

153. Rohrbaugh, J., "Improving the Quality of Group Judgment Social Judgment Analysis and the Delphi Technique", *Organizational Behavior and Human Performance* (1979); 24: pp 73–92.

154. Rowe, G. and Wright, G., "The Delphi Technique as a Forecasting Tool: Issues and Analysis", *International Journal of Forecasting* 1999 15, pp 353 –375.

155. Ruter, John C. et al., "Public Transport and Car Use in Developing Country: Energy and Management Issues" *Indian Journal of Transport Management* (1997); Vol. 21, No. 1: pp 89-96.

156. Sacchidananda , Vinish Kathuria, "Is Economic Growth Sustainable? Environmental quality of Indian States after 1991", *International Journal of Sustainable Development*, 01/2006; 9(1).

157. Samual S. et al. "The Most Significant Vehicle Operating Parameter for Real-World Emission Levels", *SAE International 2004, Paper no*. 2004-01-0636

158. Sanjib Kumar Karmee, A. Chadha, "Preparation of Biodiesel from crude oil of Pongamia Oinnata", Bioresource *Technology* 2005; 96: pp 1425-1429.

159. Saraf, R., Thipse R. and Saxena, P. K. , "Diesel-CNG Dual Fuel Technology -A Viable Alternative Energy Resource", 15th *ISME International Conference on Horizons of Mechanical Engineering,* March 18-20,2008.

160. Saxena M., Jain A.K., Singhal S., 2002. Science and Culture 68, pp 9-12.

161. Schwaderlapp, M., Habermann, K., and Yapici, K. "Variable Compression Ratio – A Design solution for Fuel Economy Concepts". *SAE International2002, paper* 2002-01-1103, 2002.

162. Semin et al., "Combustion Temperature Effect of Diesel Engine Convert to Combustion Temperature Effect of Diesel Engine Convert to" *American Journal of Engineering and Applied Sciences* 2 (1): 212-216, 2009

163. Sengupta, B. 'Air Quality Improvement in National Capital Region Delhi, India'—"A Case Study". Paper presented at the *International Seminar on Better Air Quality*, December, 2003, Manila, Philippines.

164. Senthil Kumar, Kerihuel, A. Bellettre, J. M. Tazerout, "Ethanol Animal Fat Emulsions as a Diesel Engine fuel – Part 2 Engine Test Analysis", *Department Systems Energy and Environment*, 23 June 2006.

165. Shaik Amjad; Vinayaga Moorthi N Shenbaga and Rudramoorthy R. "Variable Compression Ratio Engine: A Future Power plant for Automobiles – An Overview", *Proc. IMechE Vol. 221 Part D: J. Automobile Engineering;* JAUTO573 © IMechE 2007

166. Shamsudin, A. H., Yusaf, T.F., Ali, Y. & Ahamd, F. I., "Design Modification of High Speed Diesel Engine to Accommodate Compressed Natural Gas", *RERIC International Energy Journal*, vol. 18, no.1, 1996, pp. 19-26.

167. Sharma O.P., "Management of Flexible Manufacturing Technology: a Study in Indian Context", *Ph.D. Thesis* 2000, *Faculty of Technology*, *University of Delhi*, Delhi, India

168. Sibal V. K. and Savant Sujata, "Simulating the Behavior of Potential Passengers of the proposed Integrated MRTS-Feeder Bus System for Delhi", *Proceedings of the National Conference* held at IIT Delhi, 2002

169. Singh, Indrasen and Kapilastain K. (2002)., "Development of Urban Transport Infrastructure – Delhi, a Case Study", *"Transportation Systems Status and Directions*", I I T, Delhi.

170. Singoria V, "An Analysis of the Substitution of Carburetted Vehicles to MPFI", M.E. thesis, 2004; *Faculty of Technology, University of Delhi*, India.

171. Sinor, J. E. and Bailey, B. K., "Current and Potential Future Performance of Ethanol Fuels", *SAE International* 1993, Paper no. 930376.

172. Snethil, M. K., Ramesh, A. and Nagalinagam, B, "An experimental comparison of methods to use methanol and Jatropha oil", *Biomass and Bioenergy* 2003; 25: pp 309-318.

173. Srinivasachary and Bose, R. K., "Policies to Reduce Energy Use and Environmental Emissions in the Transport Sector: a Case of Delhi City", *Energy Policy* 2006; 25: pp 1137-1150.

174. Stavarache C, Vinatoru. M, Nishimura. R and Maeda, Y, "Fatty Acids Methyl Esters from Vegetable Oil by means of Ultrasonic Energy", *Ultrasonic Sonochemistry* 2005; 12: pp 367–372.

175. Steinberg, J. J., Janet, L. and Gilson, D. G. , "The Path Biology of Ozone - Including Damage", *Arch. Environ. Health* (1991); pp 46: 80–87.

176. Stewart, T. R., "The Delphi Technique and Judgmental Forecasting", *Climatic Change* (1987); *11*: pp 97–113.

177. Suresh Kumar et al., "Performance and Exhaust Emission Characteristics of a C I Engine Fuelled with Pongamia Pinnata Methyl Ester (PPME) and its Blends with Diesel". *Renewable Energy* 6 March 2008; 33: pp 2294–2302.

178. Sushil, "Flexible Systems Management in Dynamic Business Environment", *Presented in a workshop on Meeting Challenges in Dynamic Business Environment Science: A SystemsApproach* on April 29th 1994, IIT, New Delhi.

179. Swiatek, G., Rudinicki, R., Getel, L. and Unger T., "Catalytic Emission Control of Small Internal Combustion Engines", *SAE International 1989, Paper no*. 891769. (1989).

180. Szwarc, A. and Branco, G. M., "Automotive use of Alcohol in Brazil and Air pollution related aspects", *SAE International1985,* paper no. 850390.

181. Taylor, C. F. "The Internal-Combustion Engine in Theory and Practice", 1960 *MIT Press, Cambridge, Massachusetts.*

182. Thomas, S. & Zalbowitz, M., "Fuel Cells – Green Power*", Los Alamos National Laboratory*, New Mexico.

183. Tiratsoo, E. N. 'Natural Gas - Fuel for the Future?' "A World Survey", 3rd edn, 1979, *Gulf Publishing Company Houston*, Texas.

184. Tree, D. R., Foster, D. E. (1994). "Optical Measurements of Soot Particle Size, Number Density, and Temperature in A Direct Injection Diesel Engine as A Function of Speed and Load", SAE International 1994, Paper no. 940270.

185. Tunestal, G., Johansson, P. B. and Hyvonen, J. "HCCI Combustion Phasing in a Multi Cylinder Engine Using Variable Compression Ratio". *SAE International 2002, paper* 2002-01-2858, 2002.

186. US Environmental Protection Agency, “A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions: Draft Technical Report”, October (2002); EPA 420-P-02-001.

187. Utell, M., Warren, J. and Sawyer, R. F., “Public Health from Auto Emissions”, *Annu. Rev. Public Health*, (1998); 15:pp 157–158.

188. Vaitheeswaran and Krishnakumar, (2005), “Common Rail Fuel Injection System”, Proceedings of the *14th ISME International Conference* on Mechanical Engineering in Knowledge Age, December12-14, 2005 at Delhi College of Engineering, Delhi – 110 042, India.

189. Van de Ven, A. H., & Delbecq, A. L., “The Effectiveness of Nominal, Delphi, and Interacting Group Decision Making Processes”, *Academy of Management Journal* (1974); 17(4): pp 605–621.

190. Wakdikar, Sandhya, “Compressed Natural Gas: A Problem or a Solution”, *Journal of Current Science* (10 January, 2002); 82(1).

191. Walsh, M. P., “Highway Vehicle Activity Trends and their Implications for Global Warming: The United States in an International Context”, (1993). In: Greene, D. L., Santini, D. J. (Eds.), Transportation and Global Climate Change, *American Council for Energy Efficient Economy,* Washington.

192. Wang, M., Saricks, C. and Santini, D., “Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions”, (1999). *U. S. DOE*, ANL-CTR.

193. Wright, G., Lawrence, M. J., and Collopy, F., “The Role and Validity of Judgment in Forecasting”, *International Journal of Forecasting* (1996); *12*:pp 1–8.

194. Young, B., Robert, E. and Ross Michel A. “Towards Knowledge-Based Control of Flexible Manufacturing Systems”, *IIE Transactions* (1988). ; 20:pp 36-42.

195. Young,V. P., Scientific Social Survey and Research,4th Ed.,1988 *Prentice Hall of India*, New Delhi.

196. Yüksel and Ceviz, M. A., “Effects of Ethanol-Unleaded Gasoline Blends on Cyclic Variability and Emissions in an SI Engine: *F. Applied Thermal Engineering*, 2005, 25, (56), pp 917–925.

197. Yusuf, T. F., Ali Al-Atabi, M. T., Ali, Y. & Shamsudin, A. H., ‘A Dual Fuel System (CNG-diesel) for a Single-Cylinder, Stationary Engine used in Power Generation’, *Brunei Darussalam Journal of Technology and Commerce*, vol. 2, no.1, 2001, pp. 58-64

APPENDIX -1

Dept. of Mechanical Engineering

Delhi College of Engineering, Bawana Road, Delhi, 110042

<u>Delphi Questionnaire Round-I</u>

Subject: Project for "Optimization of Vehicular Emissions of Public Transportation System of a Metro: Some strategies."

Objective: This project aims consideration of public opinion about the present status and possible alternatives for making the Public Transportation System more effective and environment friendly.

Dear Sir/Madam,

Please find enclosed a questionnaire for collating information regarding the objective stated above. You are, requested to please lend some of your valuable time and give your views/answers to the queries. This information is required in public interest as well as that of individual users of Private/Public Transport, because the result of this study are aimed at improving the quality of life and environment , better use of available fuels and identifying / addressing appropriate issues for setting the right direction for the research and development of alternative fuels. The result of the study will be used for academic work only and may be useful in the planning of a better Public Transportation System and will never be used for any private/ commercial purpose.

I will like to know from you that whether you would also like to be apprised about the results of our first round of analysis and participate in the second/final round of study?

Yes / No

I shall be grateful if you please fill up the questionnaire enclosed and return by e-mail /post at our address and if you recommend any of your colleagues/friends etc. whom you think is appropriate for this survey, I will be very much obliged. Please send their details to us or forward a copy of this questionnaire to them.

Looking for an early reply.

Thanking You

Your sincerely

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To

Dept. of Mechanical Engineering

Delhi College of Engineering, Bawana Road, Delhi, 110042

QUESTIONNAIRE FOR EMPIRICAL STUDY

OPTIMISING THE VEHICULAR EMISSIONS IN DELHI

Section-A

Please answer the following by putting a tick (✓) in the appropriate box.

Sr. N o.	Please indicate the level of your agreement with the following ↓ **Question** **Level of agreement** →	**Lowest**	**Very**	**Low**	**Modera**	**High**	**Highest**
1.	Present Public Transportation System (PTS) of Delhi is very poorly organized.						
2.	There has been considerable improvement in the PTS after the introduction of Delhi Metro.						
3.	Govt. should take immediate steps to control the growth of private motor vehicles in Delhi.						
*4.a	Cycle rickshaws are a source of menace and should be totally banned						
4.b	or Cycle rickshaws should be operated on internal routes & should be reorganized						
**5.a	Whole PTS of Delhi should be operated by a single agency like DTC						
5.b	or Whole PTS of Delhi should be operated by 5 to 10 competitors						
5.c	or Whole PTS of Delhi should be operated by thousands of contractors as presently						
6.	GPS enabled High Capacity Buses should be introduced with a substantial higher fare						
*7.a	Present vehicle Pollution Under Control (PUC) certification system is effective in controlling the vehicle emissions.						
7.b	Or PUC system should be replaced with necessary Bi-annual inspection/maintenance system by manufacturer / authorized service providers.						
8.	All new Govt. Offices, Extensions etc. in Delhi should be preferably located outside Delhi						
9.	Frequency of present Metro trains should be increased during peak hours						
10.	Metro system should be further discounted for students/ salaried class and BPL card holders. (In addition to present 10% for smart card holders) If you agree with the above please, indicate what should be revised discount %						
		15%		20 %		25%	
11.	Public should be made aware of the Present Ring Rail system and its connectivity should be improved.						
12.	Present Ring Rail should be reorganized and its frequency should be increased.						

* Please give your opinion for either (a) or (b) only

** Please give your opinion for either (a) or (b) or (c) only

Section-B

Please give your rating on a 10 points scale (0 to 10), More than one options may be given same rating.
(0 = Absolute minimum/nil; 10= Absolute maximum/full) to the following:-

Sr. No.	Which of the following step you think is best to control the vehicle emissions		Your Rating
1.	i	Phasing out of old Vehicles	
	ii	Improving the PTS	
	iii	Augmenting the Delhi Metro	
	iv	Constructing more Roads/ Elevated corridors and Flyovers	
	v	Using advanced Engine technologies like CRDI, TDSI etc	
	vi	Development of Bicycle Tracks	
	vii	Removing encroachments from the roads	
	viii	Improving parking facilities	
	ix	More subways or foot over bridges (conventional) or	
		More subways or foot over bridges (with escalators)	
	x	Creating awareness for efficient and safe driving	
	xi	Controlling adulteration of the fuel and improving fuel quality	
	xii	Any other (please specify)	
2	**Please indicate your level of awareness about the following**		
	i	Fuel Cell	
	ii	Mono Rail System	
	iii	Ring Rail System	
	iv	GPS	
	v	Hybrid vehicles	
	vi	Electric vehicles	
	vii	Euro Norms	
	viii	CRDI	
	ix	MPFI	
	x	Elevated corridor	
3.	**Please give your rating to the following steps to control the growth of private**		
	i	High taxation on vehicles	
	ii	Subsidized fares for PTS	
	iii	User friendly Routes of PTS	
	iv	Enhancing Punctuality of PTS Services	
	v	Creating Networked System for hiring conveyances (taxi)	
	vi	Creating Networked System for hiring conveyances (auto rickshaw)	
	vii	Reorganization Ring Rail System	
	viii	Creating and strengthening of Mono Rail System	
	ix	GPS enabled High Capacity Buses	
	x	Any other (please specify)	
4.	**If you agree that increase / decrease in the road tax is one of the tools to control the growth of Private Vehicles, then please give your rating to the following :-**		
	i	Increase the tax in proportion to the size of the Vehicle	
	ii	Increase the tax in proportion to the cost of the Vehicle	
	iii	Increase the tax in proportion to the age of the Vehicle	
	iv	Increase the tax, if the vehicle uses diesel as a fuel (using petrol as a reference)	
	v	Decrease the tax, if the vehicle uses CNG/LPG/Hydrogen as a fuel	
	vi	Decrease the tax, if the vehicle is operated on battery	
	vii	Increase/Decrease the tax in proportion to the fraction of Emissions per passenger	
	vii	Decrease the tax, if old vehicle are fitted with Catalytic converter/oxid catalyst	
	vii	Any other, (please specify)	

5	**Please give your rating to the following as a tool to control the vehicle emissions**		
	i	Using Bio-Diesel	
	ii	Using Ethanol/Methanol	
	ii i	Using Hydrogen	
	iv	Using CNG	
	v	Using LPG	
	vi	Using CNG/LPG as Dual-Fuel	
	v	Using Hybrid Vehicles	
	vi ii	Using Electric Vehicles	
	ix	Using Fuel Cell	
	x	Using Solar Vehicle	
	xi	Any other (please specify)	

The Respondents Profile

1. Name and Designation --
2. Complete Office address --

   City--District---

   State--Pincode--
3. Experience in years ---------------
4. Since when you have been living in Delhi ---------------
5. address for communication (If different from that given at no. 2 above)-------------------

   --City------------------------------

   District---------------------------------State---------------------------Pincode------------------
6. contact details Phone--

   E-mail

Signature (Optional)

Thank you very much for sparing your valuable time.

Amit Pal

APPENDIX - III

EMISSION NORMS

HISTORY OF EMISSION NORMS IN INDIA

- 1991 - Idle CO Limits for Gasoline Vehicles and Free Acceleration Smoke for Diesel Vehicles, Mass Emission Norms for Gasoline Vehicles.
- 1992 - Mass Emission Norms for Diesel Vehicles.
- 1996 - Revision of Mass Emission Norms for Gasoline and Diesel Vehicles, mandatory fitment of Catalytic Converter for Cars in Metros on Unleaded Gasoline.
- 1998 - Cold Start Norms Introduced.
- 2000 - India 2000 (Eq. to Euro I) Norms, Modified IDC (Indian Driving Cycle), Bharat Stage II Norms for Delhi.
- 2001 - Bharat Stage II (Eq. to Euro II) Norms for All Metros, Emission Norms for CNG & LPG Vehicles.
- 2003 - Bharat Stage II (Eq. to Euro II) Norms for 11 major cities.
- 2005 - From 1 April Bharat Stage III (Eq. to Euro III) Norms for 11 major cities.
- 2010 - Bharat Stage III Emission Norms for 4-wheelers for entire country whereas Bharat Stage - IV (Eq. to Euro IV) for 11 major cities. Bharat Stage IV also has norms on OBD (simalar to Euro III but diluted).

Indian Emissions Standards (4 Wheelers)

Standard	Reference	Applicable Date	Region
India 2000	Euro 1	2000	Nationwide
Bharat Stage II	Euro 2	2001	NCR*, Mumbai, Kolkata, Chennai
		2003.04	NCR*, 10 Cities†
		2005.04	Nationwide
Bharat Stage III	Euro 3	2005.04	NCR*, 10 Cities†
		2010.04	Nationwide
Bharat Stage IV	Euro 4	2010.04	NCR*, 10 Cities†
* National Capital Region (Delhi) † Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur and Agra			

Emission Standards for Two and Three-Wheeled Vehicles

Emission Standards for 2-Wheel Gasoline Vehicles, g/km			
Year	**CO**	**HC**	**HC+NOx**
1991	12-30	8-12	-
1996	4.50	-	3.60
2000	2.00	-	2.00
Emission Standards for 3-Wheel Gasoline Vehicles, g/km			
Year	**CO**	**HC**	**HC+NOx**
1991	12-30	8-12	-
1996	6.75	-	5.40
2000	4.00	-	2.00

For 2-and 3-wheelers, Bharat Stage II (Euro 2) is applicable from April 1, 2005 and Stage III (Euro 3) standards would come in force from April 1, 2010.

Emission Standards for Lorries and Buses

Whereas for passenger cars, the standards are defined in g/km, for lorries (trucks) they are defined by engine power, g/kWh, and are therefore in no way comparable. The following table contains a summary of the emission standards and their implementation dates. Dates in the tables refer to new type approvals; the dates for all type approvals are in most cases one year later (EU type approvals are valid longer than one year). The official category name is heavy-duty diesel engines, which generally includes lorries and buses.

European Emission Standards for Passenger Cars (Category M_1*), G/Km

Tier	Date	CO	HC	NO_x	$HC+NO_x$	PM
Diesel						
Euro 1†	July 1992	2.72	-	-	0.97 (1.13)	0.14 (0.18)
Euro 2	January 1996	1.0	-	-	0.7	0.08
Euro 3	January 2000	0.64	-	0.5	0.56	0.05
Euro 4	January 2005	0.5	-	0.25	0.3	0.025
Euro 5 (future)	September 2009	0.5	-	0.18	0.23	0.005
Euro 6 (future)	September 2014	0.5	-	0.08	0.17	0.005
Petrol (Gasoline)						
Euro 1†	July 1992	2.72	-	-	0.97 (1.13)	-
Euro 2	January 1996	2.2	-	-	0.5	-
Euro 3	January 2000	2.3	0.2	0.15	-	-
Euro 4	January 2005	1.0	0.1	0.08	-	-
Euro 5 (future)	September 2009	1.0	0.1	0.06	-	0.005**
Euro 6 (future)	September 2014	1.0	0.1	0.06	-	0.005**
* Before Euro 5, passenger vehicles > 2500 kg were type approved as light commercial vehicle N1–I,** Applies only to vehicles with direct injection engines,† Values in brackets are COP limits						

Light commercial vehicles ≤1305 kg (Category N1 - I), g/km

Tier	Date	CO	HC	NO_x	$HC+NO_x$	PM
Diesel						
Euro 1	October 1994	2.72	-	-	0.97	0.14
Euro 2	January 1998	1.0	-	-	0.7	0.08
Euro 3	January 2000	0.64	-	0.5	0.56	0.05
Euro 4	January 2005	0.5	-	0.25	0.3	0.025
Euro 5 (future)	September 2009	0.5	-	0.18	0.23	0.005
Euro 6 (future)	September 2014	0.5	-	0.08	0.17	0.005
Petrol (Gasoline)						
Euro 1	October 1994	2.72	-	-	0.97	-
Euro 2	January 1998	2.2	-	-	0.5	-
Euro 3	January 2000	2.3	0.2	0.15	-	-
Euro 4	January 2005	1.0	0.1	0.08	-	-
Euro 5 (future)	September 2009	1.0	0.1	0.06	-	0.005*
Euro 6 (future)	September 2014	1.0	0.1	0.06	-	0.005*
* Applies only to vehicles with direct injection engines						

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Light commercial vehicles 1305 kg – 1760 kg (Category N1 - II), g/km

Tier	Date	CO	HC	NO_x	$HC+NO_x$	PM
Diesel						
Euro 1	October 1994	5.17	-	-	1.4	0.19
Euro 2	January 1998	1.25	-	-	1.0	0.12
Euro 3	January 2001	0.8	-	0.65	0.72	0.07
Euro 4	January 2006	0.63	-	0.33	0.39	0.04
Euro 5 (future)	September 2010	0.63	-	0.235	0.295	0.005
Euro 6 (future)	September 2015	0.63	-	0.105	0.195	0.005
Petrol (Gasoline)						
Euro 1	October 1994	5.17	-	-	1.4	-
Euro 2	January 1998	4.0	-	-	0.65	-
Euro 3	January 2001	4.17	0.25	0.180	-	-
Euro 4	January 2006	1.81	0.13	0.1	-	-
Euro 5 (future)	September 2010	1.81	0.13	0.075	-	0.005*
Euro 6 (future)	September 2015	1.81	0.13	0.075	-	0.005*
* Applies only to vehicles with direct injection engines						

Emission Standards for Light commercial vehicles >1760 kg max 3500 kg. (Category N1 - III), g/km

Tier	Date	CO	HC	NO_x	$HC+NO_x$	PM
Diesel						
Euro 1	October 1994	6.9	-	-	4.9	0.25
Euro 2	January 1998	1.5	-	-	0.96	0.17
Euro 3	January 2001	0.95	-	0.780	0.86	0.1
Euro 4	January 2006	0.95	-	0.39	0.46	0.06
Euro 5 (future)	September 2010	0.74	-	0.28	0.35	0.005
Euro 6 (future)	September 2015	0.74	-	0.125	0.215	0.005
Petrol (Gasoline)						
Euro 1	October 1994	6.9	-	-	1.7	-
Euro 2	January 1998	5.0	-	-	0.8	-
Euro 3	January 2001	5.22	0.29	0.210	-	-
Euro 4	January 2006	2.27	0.16	0.110	-	-
Euro 5 (future)	September 2010	2.27	0.16	0.082	-	0.005*
Euro 6 (future)	September 2015	2.27	0.16	0.082	-	0.005*

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Emission Standards for (older) ECE R49 cycle HD Diesel Engines, g/kWh (smoke in m^{-1})

Tier	Date	Test cycle	CO	HC	NO_x	PM	Smoke
Euro I	1992, < 85 kW	ECE R-49	4.5	1.1	8.0	0.612	
	1992, > 85 kW		4.5	1.1	8.0	0.36	
Euro II	October 1996		4.0	1.1	7.0	0.25	
	October 1998		4.0	1.1	7.0	0.15	
Euro III	October 1999	ESC &	1.0	0.25	2.0	0.02	0.15
	October 2000	ESC & ELR	2.1	0.66	5.0	0.10	0.8
Euro IV	October 2005		1.5	0.46	3.5	0.02	0.5
Euro V	October 2008		1.5	0.46	2.0	0.02	0.5

* For engines of less than 0.75 dm³ swept volume per cylinder and a rated power speed of more than 3,000 per minute. EEV is "Enhanced environmentally friendly vehicle".

Emission standards for, category N2 EDC (2000 and up) Large Goods Vehicles

Standard	Date	CO (g/kWh)	NO_x (g/kWh)	HC (g/kWh)	PM (g/kWh)
Euro 0	1988-1992	12.3	15.8	2.6	none
Euro I	1992-1995	4.9	9.0	1.23	0.40
Euro II	1995-1999	4.0	7.0	1.1	0.15
Euro III	1999-2005	2.1	5.0	0.66	0.1
Euro IV	2005-2008	1.5	3.5	0.46	0.02
Euro V	2008-2012	1.5	2.0	0.46	0.02

www.siamindia.com/scripts/emission-standards.aspx

The above standards apply to all new 4-wheel vehicles sold and registered in the respective regions. In addition, the National Auto Fuel Policy introduces certain emission requirements for interstate buses with routes originating or terminating in Delhi or the other 10 cities.

APPENDIX-IV

BIODIESEL

The idea of using vegetable oil as a substitute for diesel fuel was demonstrated by the inventor of diesel engine. When Rudolph Diesel in a 1912 speech said, *"the use of vegetable oils for engine fuels may seem insignificant today, but such oils may become, in the course of time, as important as petroleum and the coal-tar products of the present time"*. The oil use as diesel fuel was limited due to its high viscosity. In order to adopt the fuel to the existing engines the properties of vegetable oil had to be modified.Various products derived from vegetable oils have been proposed as an alternative fuel for diesel engines (Ramesh and Sampathrajan, 2008).

ASTM International defines biodiesel as "***the Mono alkyl esters of long chain fatty acids derived from renewable lipid feed stocks, such as vegetable oils and animal fats, for use in compression ignition engines*.**"

The main commodity sources of biodiesel in India are non edible oils obtained from plant species such as Jatropha, Pongamia pinnata etc. (Demirbas 2003,2009). Biodiesel can be blended at any level with petroleum diesel to create a biodiesel blend or can be used in its pure form. Just like petroleum diesel, biodiesel operates in compression ignition engine; which essentially require very little or no engine modifications because biodiesel has properties similar to petroleum diesel fuels. It can be stored just like petroleum diesel fuel and hence does not require separate infrastructure. Nowadays various techniques have been developed for producing biodiesel; some of them are mechanical stirring, ultrasonic cavitation, hydrodynamic cavitation and supercritical methanol.

Advantages of the Bio-diesel over Petroleum based Diesel Fuel are as following:

1. Biodiesel is a good lubricant, about 66% better than petro diesel.
2. Biodiesel produces less smoke and particulate matter as it is free of and aromatics.
3. Biodiesel have higher cetane number having well anti knock property.
4. Produces lower carbon monoxide and hydrocarbon emissions.
5. Bio-diesel is renewable, biodegradable and non-toxic.

In comparison with petroleum-based diesel fuel, biodiesel is characterised by:

• Lower heating value (by about 10-12%)

• Higher cetane value (typically 45-60)

• About 11% oxygen content (petroleum-based diesel contains no oxygen)

• No aromatics contents (and no PAHs)

• No sulphur or extremely low sulphur content

• Better lubricity

• Higher viscosity

• Higher freezing temperature (higher cloud point and pour point)

• Higher flash point

• No toxicity or low toxicity

• Biodegradability

• Different corrosive properties

Some of the above properties, such as the high cetane value or good lubricity, are obvious advantages of biodiesel while others, including the lower heating value, high freezing point (and inferior flow properties at low temperature), or corrosion properties are its drawbacks. Biodiesel changes the character and can increase the intensity of the odour of diesel exhaust (Choudhury and Bose, 2008).

Biodiesel Production

Biodiesel can be produced by various conventional methods, such as: alkali catalysis, acid catalysis, lipase catalysis etc. Considering various limitations of these methods, there is a strong quest to develop an efficient, time-saving, economically functional and environmental friendly biodiesel production processes at industrial scale having superiority over the classical procedure. Keeping this aspect into consideration, some of the recently developed biodiesel production technologies are **power ultrasound**, **hydrodynamic cavitation** and **supercritical methanol processes**. Power ultrasound is a useful tool for strengthen mass transfer of liquid –liquid heterogeneous system. In this process cavities are created by the irradiation of power ultrasonic with sufficient energy in the immiscible liquids. As a result micro fine bubbles are formed and the asymmetric collapse of the cavitation of these bubbles disrupts the phase boundary and impinging of the liquids creates micro jets, leading to intensive emulsification of system. Among recently developed techniques, another cavitation technique, which is popularly known as hydrodynamic cavitation is a potential method for biodiesel production at industrial scale due to its easy scale-up property. This is a rapid technique for preparing alkyl esters from triglycerides at pilot plant scale operation. Supercritical methanol is a simple and fast process and produces high yield because of simultaneous transesterification of triglycerides and methyl esterification of fatty acids at critical state. Supercritical methanol with a co-solvent process require relatively lower reaction temperature and pressures and hence energy, as compared to conventional supercritical methanol method. All these methods have future potential for biodiesel production at industrial scale..

Vegetable oils have their own advantages because of their easy availability, being renewable and eco-friendly to the environment, and they are free of sulphur content in them. Bio-diesel have many advantages over petroleum diesel fuel; produce less smoke and particulates, have high cetane number, produce lower carbon monoxide and hydrocarbon emissions, renewable, biodegradable and non-toxic. In India, with abundance of forest resources, there are a number of other non-edible tree borne oilseeds with an estimated annual production of more than 20 million tones, which have large potential for making biodiesel to supplement other conventional sources. Among these, Karanja (*Pongamia glabra*) and Jatropha (*Jatropha curcas*) have been successfully proved for their potential as biodiesel.

Cavitation technology

The generation, subsequent growth and collapse of cavities resulting in very high energy densities of the order of 1 to 10^{18} kW/m^3. Cavitation can occur at millions of locations in a reactor simultaneously and generate conditions of very high temperatures and pressures locally, with the overall environment being that of ambient conditions. The chemical reactions requiring stringent conditions can be effectively carried out using cavitation at ambient conditions. Moreover, free radicals are generated in the process due to the dissociation of vapours trapped in the cavitating bubbles, which results in either intensification of the chemical reactions or in the propagation of certain unexpected reactions. Cavitation also results in the generation of local turbulence and liquid micro-circulation (acoustic streaming) in the reactor, enhancing the rates of transport processes. The two principle types of cavitations and their application for transesterification process are described below.

Ultrasound Energy

Power ultrasonic is a useful tool for strengthening mass transfer of liquid- liquid heterogeneous system. In this process cavities are created by the irradiation of power ultrasonic with sufficient energy in the immiscible liquids. As a result micro fine bubbles are formed. The asymmetric collapse of the cavitation bubbles disrupt the phase boundary and impinging of the liquids create micro jets, leading to intensive emulsification of the system. The transesterification of vegetable oil with short-chain alcohols in the presence of base-catalyst, by means of low frequency ultrasound (28 and 40 kHz) in order to obtain biodiesel fuel was studied by Stavarache et al. (2005). By using ultrasounds the reaction time was observed much shorter (10-40 min) than as compared to mechanical stirring. The quantity of required catalyst was 2 or 3 times lower. A typical schematic representation of ultrasonic bath is shown in Fig. 1. Other significant studies for biodiesel production using ultrasound irradiation are discussed in Hanh et al. (2007).

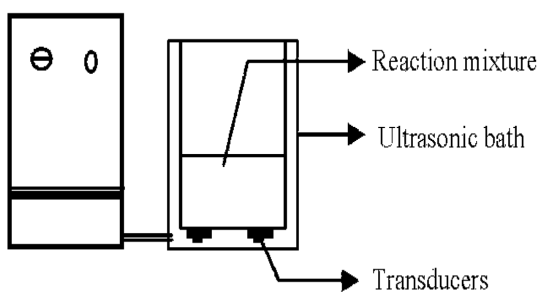

Figure IV- 1: Schematic Representation of Ultrasound Bath [Gogate. 2005]

An alkali-catalyzed biodiesel production method with power ultrasonic (19.7 kHz) has been developed by Ji et al. (2006) that allows a short reaction time and high yield because of emulsification and cavitation of the liquid-liquid immiscible system. Continuous ultrasound give a short reaction equilibrium time of 10-20 min and almost 100% yield under 6:1 substrate molar ratio. According to range of factors, substrate molar ratio was the prime factor, while temperature and pulse frequency of ultrasonic were secondary.

The order of the effect on FAMEs yield of the factors was substrate molar ratio>temperature>pulse frequency>ultrasonic power. In this study, the optimal reaction condition was at 6:1 substrate molar ratio, 45 ^{0}C, and continuous ultrasonic and 150 W ultrasonic power. The schematic diagram of ultrasonic horn setup is shown in Fig. 2.

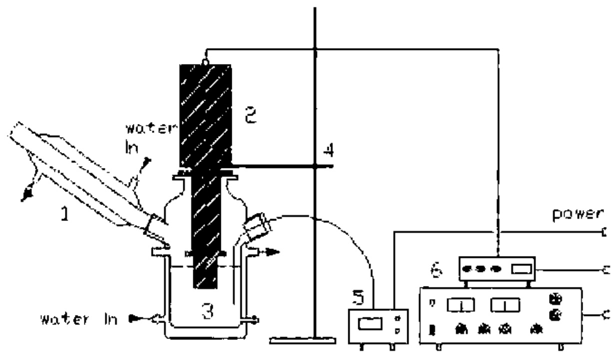

Figure IV-2: Schematic Diagram of Ultrasonic Horn Setup [Ji et al., 2006]

[1-condenser; 2-transducer; 3-ultrasonic reactor; 4-stand support; 5-thermometer] 6-generator

The ultrasound energy technique appears to be a rapid and effective technique compared to the conventional approach, for preparing alkyl esters from triglycerides at laboratory scale of operation. It can be seen that using ultrasonic method reaction time is almost half compare to conventional method which is beneficial for industrial purpose.

Hydrodynamic cavitation

Hydrodynamic cavitation is another technology developed recently and allows the generation of cavity collapse conditions similar to acoustic cavitation, thereby enabling different applications requiring different cavitational intensities, which have been successfully carried out using acoustic cavitation phenomenon but at much lower energy inputs. Hydrodynamic cavitation is a potential method for biodiesel production at industrial scale due to its easy scale-up property. *The schematic diagram of the test rig developed at DCE lab during this work is shown in Figure 3.* **The biodiesel used in the performance testing during this research work were made by both hydrodynamic cavitation and ultrasonic cavitation method in DCE I.C. Engines laboratory**

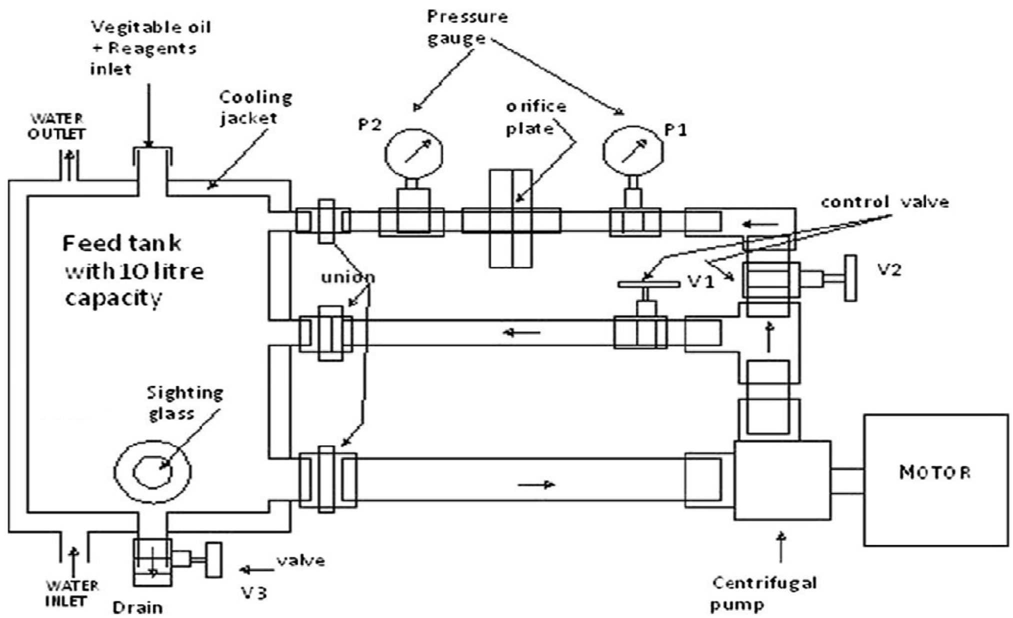

Figure IV- 3: Schematic Diagram of Hydrodynamic Cavitation System Setup Developed at DCE I. C. Engines Laboratory

The setup consists of a closed loop circuit comprising a feed tank, centrifugal pump (2.2 kW), control valve and a coupling to accommodate the orifice plate. The suction side of the pump is connected to the bottom of the feed tank. Discharge from the pump branches into two lines, which help in the control of inlet pressure and inlet flow rate into the main line housing and the orifice with the help of valves V_1 and V_2. The main line consists of a coupling to accommodate the orifice plate (single or multiple holes with different configurations). Four orifice plates with the numbers of holes 1, 3, 5 and 7 are used during experimentation. The diameter of each hole was 3 mm.

The cavitating conditions are generated just after the orifice plates in the main line and hence the intensity of the cavitating conditions strongly depends on the geometry of the orifice plate. When the liquid passes through the orifice plate (single or multiple holes), the velocities at the orifice increase due to the sudden reduction in the area offered for the flow, resulting in the decrease of the pressure. At the downstream of the orifice, however, due to an increase in the area of cross-section, the velocity decreases giving rise to increasing pressure and pressure fluctuations, which control the different states of cavitation, mainly formation, growth & collapse. The feed tank is provided with a cooling jacket to control the temperature of the circulating liquid. The biodiesel yield increases with increase in the number of holes and afterwards it provided with a cooling jacket to control the temperature of the circulating liquid.

Furthermore, scale-up of hydrodynamic cavitation to meet industrial-scale operations had better opportunities than the ultrasonic reactor due to its easier generating and less sensitivity to the geometric details of the reactor. The reaction time is shortened in the order of PU, HC and MS [where PU= Power Ultrasound, HC= Hydrodynamic Cavitation, MS= Mechanical Stirring]. Power ultrasonic gives the shortest reaction time and the highest yield. Mechanical stirring offered the slowest reaction rate. PU and the HC methods reduced the reaction equilibrium time to 10-30 min. The energy consumption (Wh/kg) for the transesterification of 1 kg of soybean oil by Ms, PU and HC are 500, 250 and 183 respectively. Thus PU and HC processes require approximately a half of the energy that is consumed by the MS method.

Supercritical Methanol Transesterification Process

Supercritical methanol is believed to solve the problems associated with the two-phase nature of normal methanol/oil mixtures by forming a single phase as a result of the lower value of the dielectric constant of methanol in the supercritical state. As a result the reaction is found to be complete in a very short time. SC methanol allows a simple process and high yield because of simultaneous transesterification of triglycerides and methyl esterification of fatty acids. A typical supercritical methanol transesterification system is shown in Fig 4.

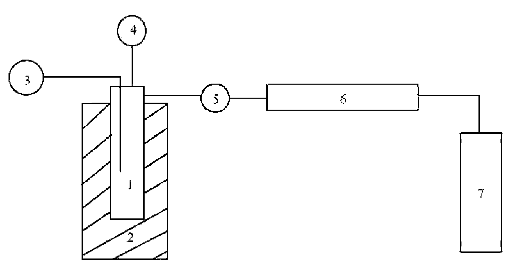

Figure AIV- 5: Supercritical methanol transesterification system, [Demirbas, 2003] [1-Autoclave, 2-Electric furnace, 3-Temperature control monitor, 4-Pressure control monitor, 5-Product exit valve, 6- Condenser, 7-Product collecting vessel]

In a typical run, the autoclave is charged with a given amount of vegetable oil and liquid methanol with a specific molar ratio. After each run, the gas is vented, and the autoclave is poured into a collecting vessel. All the contents are removed from the autoclave by washing with methanol. Compared with the catalytic processes, purification of products is much simpler and more environmental friendly. However, the reaction requires temperatures of 350-400 ^{0}C and pressures of 45-65 MPa, which are not viable in practice in industry. Furthermore, such high temperatures and pressures lead to high production costs and energy consumption. Transesterification of soybean oil in supercritical methanol has been carried out by Hanh et al. (2007) in the absence of catalyst. A co-solvent was added to the reaction mixture in order to decrease the operating temperature, pressure and molar ratio of alcohol to vegetable oil. With CO_2 as co-solvent in the reaction system, there was a significant decrease in the severity of the conditions required for supercritical reaction. It was demonstrated that, with an optimal reaction temperature of 280 ^{0}C, methanol to oil ratio of 24 and CO_2 to methanol ratio of 0.1, a 98% yield of methyl esters viable as an industrial process. In the absence of catalyst the purification of the products after transesterification is much simpler and more environmental friendly. The relatively mild reaction conditions and high yield of methyl esters using this environmentally friendly method make it practical use in Industry. A system for continuous transesterification of vegetable oil using supercritical methanol was developed using a tube reactor was investigated by He et al. (2007). Increasing the proportion of methanol, a reaction pressure and reaction temperature can enhance the production yield effectively. However, side reactions of unsaturated fatty acid methyl esters (FAME) occur when the reaction temperature is over 300 ^{0}C, which lead to much loss of material.

Low frequency ultrasound and hydrodynamic cavitation methods are energy efficient, time saving and economically functional, offering a lot of advantages over the conventional mechanical stirring method. Supercritical methanol with a co-solvent process require relatively lower reaction temperature and pressures and hence energy, as compared to conventional supercritical methanol method. In addition because of the absence of catalyst, the purification of products after transesterification is much simpler and more environmentally friendly. The relatively mild reaction conditions and high yield of methyl esters using this environmentally friendly method makes it viable for industry. All these methods have future potential for biodiesel production at industrial scale due to their easy scale up property.

Indian Scenario in Biodiesel

Indian energy demand is expected to grow at an annual rate of 6.8 per cent over the next couple of decades. Most of the energy requirements are currently satisfied by fossil fuels – coal, petroleum based products and natural gas. Past and projected future Indian demand for diesel and biodiesel is shown in table IV-A. Domestic production of crude oil can only fulfil 25-30 per cent of national consumption rest we are importing from other countries. In these circumstances bio fuels are going to play an important role in meeting growing Indian energy needs. Bio fuels offer an attractive alternative to fossil fuels, but a consistent scientific framework is needed to ensure policies that maximize the positive and minimize the negative aspects of bio fuels. The government of India has formulated an ambitious National Biodiesel Mission to meet 20 per cent of the country's diesel requirements by 2016-2017.

A commercialization period during 2007-2012 will continue Jatropha cultivation and install more transesterification plants which will position India to meet 20 per cent of its diesel needs through biodiesel. Many developed countries have active biodiesel programs. Currently biodiesel is produced mainly from field crop oil like rapeseed, sunflower etc. in Europe and soybean in US. Malaysia utilises palm oil for biodiesel production while in Nicaragua it is Jatropha oil. The productions of vegetable oil globally are given in Table IV-B. There are many countries which have large amount of bio-diesel potential. And if this potential is used for the production of biodiesel than the crisis of petroleum based diesel and fossil fuel can be solved.

Table IV-A: Indian Demand for Diesel and Biodiesel Requirement

Year	Diesel demand Mt	Biodiesel Blending Requirement Mt (in metric ton)		
		@5%	@10%	@20%
2006-07	52.32	2.62	5.23	10.46
2011-12	66.91	3.35	6.69	13.38
2016-17	83.58	4.18	8.36	16.72

Planning commission of India report, 2003

Table IV- B Global Productions of the Major Vegetable Oils

S. No.	Oil	Production (million tons)	S. No.	Oil	Production (million tons)
1	Soybean	27.8	11	Palm kernel	2.9
2	Rapeseed	13.7	12	Olive	2.7
3	Cottonseed	4.0	13	Corn	2.0
4	Sunflower	8.2	14	Castor	0.5
5	Peanut	5.1	15	Groundnut	1.40
6	Coconut	3.5	16	Mustard	1.55
7	Linseeds	0.6	17	Sunflower	0.3
8	Palm	23.4	18	Niger	0.03
9	Sesame	0.26	19	Rice Bran	0.55
10	Castor	0.25	20	Linseeds	0.1
	Total	**86.81**		**Total**	**12.03**

Planning commission of India report, 2003

Additives for Oxidative Stability of Biodiesel

Oxidative stability is a major industry issue for diesel and biodiesel fuels. Some biodiesels are more stable than others and some unstable biodiesel contain stability additives that perform very well. The tendency of a fuel to be unstable can be predicted by the Iodine number (ASTM D 1510) but the test method may not pick up the presence of stability additives. Iodine number actually measures the presence of C=C bonds that are prone to oxidation.

The general rule of thumb is that instability increases by a factor of 1 for every C=C bond on the fatty acid chain; thus, 18:3 are three times more reactive than C18:0. Stability can be predicted from knowledge of the feedstock only if you know the proportion of C18:2 and C18:3 fatty acids present in the fuel and know whether or not the fuel has been treated for stability. High fractions of those two types of fatty acids can adversely affect fuel stability if additives are not used.

Poor stability can lead to increasingly high acid numbers, high viscosity, and formation of gums and sediments that can clog filters. Comparing the acid number and viscosity of fuel over time can provide some idea about whether or not the fuel is oxidising, but one need to take a sample at the beginning when the fuel is fresh and then sample on a regular basis after that. Long-term storage in the presence of diesel fuel, diesel additives, water, sediments, heat, and air has not been adequately documented in the field. Biodiesel and blends of biodiesel and diesel fuel should not be stored for longer than 6 months in either storage tanks or vehicles until better field data is available. If it becomes necessary to store biodiesel for longer than 6 months, or the storage conditions are poor, use antioxidants. The common antioxidants that work with biodiesel are TBHQ (t-butyl hydroquinone), Tenox 21, and tocopherol (Vitamin E). Powdered antioxidants are difficult to mix into biodiesel. When a small amount of biodiesel is heated (1 gallon or so) up to 37.7 ^{0}C or until all the powdered antioxidant is dissolved. Then this can be mixed with the remaining bulk biodiesel (Stavarache Carmen et al., 2006).

Material Compatibility

Brass, bronze, copper, lead, tin, and zinc will oxidize diesel and biodiesel fuels and create sediments. Lead solders and zinc linings should be avoided, as should copper pipes, brass regulators, and copper fittings. The fuel or the fittings will tend to change colour and sediments may form, resulting in plugged fuel filters. Affected equipment should be replaced with stainless steel or aluminium. Acceptable storage tank materials include aluminium, steel, fluorinated polyethylene, fluorinated polypropylene, and Teflon. The effect of B20 on vulnerable materials is diluted compared to higher blends. Some slow oxidation can occur, although it may take longer to materialize. Biodiesel can also affect some seals, gaskets, and adhesives, particularly those made before 1993 made from natural or nitrile rubber. It is primarily for these reasons that vehicle and storage equipment are modified. Most engines made after 1994 have been constructed with gaskets and seals that are generally biodiesel resistant.

Earlier engine models or rebuilds may use older gasket and seal materials and present a risk of swelling, leaking, or failure. Fuel pumps may contain rubber valves that may fail. The typical approach is to create a maintenance schedule that checks for potential failures. Users can also contact engine manufacturers for more information (Stavarache Carmen et al., 2006).

Chemistry of Biodiesel

Biodiesel is made using the process of transesterification. In the transesterification of different type of oils, triglycerides react with an alcohol, generally methanol or ethanol, to produce esters and glycerin. To make it possible, a catalyst is added to the reaction.

CH_2-OOC-R_1				R_1-COO-R'	CH_2-OH
|			Catalyst	|	|
CH-OOC-R_2	+	3R'OH	$\longleftrightarrow$	R_2-COO-R' +	CH-OH
|				|	|
CH_2-OOC-R_3				R_3-COO-R'	CH_2-OH
Glycerides		Alcohol		Esters	Glycerin

Where, term R represents to different alkyl groups.

The overall process is normally a sequence of three consecutive steps, which are reversible reactions. In the first step from triglycerides, diglyceride is obtained. From diglyceride, monoglyceride is produced and in the last step from monoglycerides, glycerin is obtained. In all these reactions esters are produced. The stoiecheometric relation between alcohol and the oil is 3:1. However, an excess of alcohol is usually more appropriate to improve the reaction towards the desired product**.**

Triglycerides (TG) + R'OH $\longleftrightarrow$ Diglycerides (DG) + R'COOR$_1$

Diglycerides (DG) + R'OH $\longleftrightarrow$ Monoglycerides (MG) + R'COOR$_2$

Monoglycerides (MG) + R'OH $\longleftrightarrow$ Glycerin (GL) + R'COOR$_3$

The catalyst used for the reaction is mainly of three types which are given below:-

Alkali Catalyst

This catalyst can be used with methanol or ethanol as well as any kind of oils, refine, crude or frying. The main alkali catalysts are sodium hydroxide (NaOH) and potassium hydroxide (KOH).

Acidic Catalyst

Acid transesterification is a great way to make biodiesel if the sample has relatively high free fatty acid content. The main acidic catalysts are Sulphuric acid (H_2SO_4) and Sulfonic acid.

Enzymes-catalyzed

Enzymes-catalyzed procedures, using lipase as catalyst, but the lipases are very expensive for industrial scale production and there are three-step processes required to achieve a 95% conversion. Due to this three step process the reaction time is too large.

Properties of Biodiesel

A general understanding of the various properties of biodiesel is essential to study their implications in engine use, storage; handling and safety are well documented by Barnwal and Sharma (2005).

Viscosity

In addition to lubrication of fuel injection system components, fuel viscosity controls the characteristics of the injection from the diesel injector (droplet size, spray characteristics etc.). The viscosity of methyl esters can go to very high levels and hence, it is important to control it within an acceptable level to avoid negative impact on fuel injection system performance. Therefore, the viscosity specifications proposed are same as that of the diesel fuel.

Density/ Specific Gravity

Biodiesel is slightly heavier than conventional diesel fuel (specific gravity 0.88 compared to 0.84 for diesel fuel). This allows use of splash blending by adding biodiesel on top of diesel fuel for making biodiesel blends.

Flash Point

Flash point of a fuel is defined as the temperature at which it will ignite when exposed to a flame or spark. The flash point of biodiesel is higher than the petroleum based diesel fuel. Flash point of biodiesel blends is dependent on the flash point of the base diesel fuel used, and increase with percentage of biodiesel in the blend. Thus in storage, biodiesel and its blends are safer than conventional diesel. The flash point of biodiesel is around 160 ^{0}C.

Aromatics

Biodiesel does not contain any aromatics so aromatic limit not specified.

Cold Filter Plugging Point (CFPP)

At low operating temperature fuel may thicken and not flow properly affecting the performance of fuel lines, fuel pump and injectors. Cold filter plugging point of biodiesel reflects its cold weather performance. It defines the fuels limit of filterability. Biodiesel thicken at low temperatures so need cold flow improver additives to have acceptable CFPP.

Cloud Point

Cloud point is the temperature at which a cloud or haze of crystals appear in the fuel under test conditions and thus becomes important for low temperature operations. Biodiesel generally has higher cloud point than diesel fuels.

Iodine Number

Iodine number refers to the amount of iodine required to convert unsaturated oil into saturated oil. It refers to the amount of unsaturated fatty acid in the fuel. One value of iodine number can be obtained by using several grades of unsaturated acids. Therefore an additional parameter, linolenic acid (C18: 3) content is specified and limited to 15% in Austrian Standard ON C 1191.

Acid number/ Neutralization number

Acid number reflects the presence of free fatty acids or acid used in manufacture of biodiesel. It also reflects the degradation of biodiesel due to thermal effect. The resultant high acid number can cause damage to injector and also result in deposit in fuel system and affect life of pumps and filters.

Cetane Number

Biodiesels has higher cetane number than conventional diesel fuel. This results in higher combustion efficiency and smoother combustion.

Stability

Biodiesel age more quickly than fossil diesel fuel due to the chemical structure of fatty acids and methyl esters present in biodiesel. Typically there are up to 14 types of fatty acid methyl esters in the biodiesel. The individual proportion of presence of these esters in the fuel affects the final properties of biodiesel. Saturated fatty acid methyl esters (C14:0, C16:0, C16:0) increase cloud point, cetane number and improve stability whereas more polyunsaturates (C18:2, C18:3) reduce cloud point, cetane number and stability.

Some of other important properties and Indian specifications of biodiesel proposed by BIS (Bureau of Indian standards) are given in Table 2.3 (Chapter2)

APPENDIX-IV

BIODIESEL

The idea of using vegetable oil as a substitute for diesel fuel was demonstrated by the inventor of diesel engine. When Rudolph Diesel in a 1912 speech said, *"the use of vegetable oils for engine fuels may seem insignificant today, but such oils may become, in the course of time, as important as petroleum and the coal-tar products of the present time"*. The oil use as diesel fuel was limited due to its high viscosity. In order to adopt the fuel to the existing engines the properties of vegetable oil had to be modified.Various products derived from vegetable oils have been proposed as an alternative fuel for diesel engines (Ramesh and Sampathrajan, 2008).

ASTM International defines biodiesel as "***the Mono alkyl esters of long chain fatty acids derived from renewable lipid feed stocks, such as vegetable oils and animal fats, for use in compression ignition engines*.**"

The main commodity sources of biodiesel in India are non edible oils obtained from plant species such as Jatropha, Pongamia pinnata etc. (Demirbas 2003,2009). Biodiesel can be blended at any level with petroleum diesel to create a biodiesel blend or can be used in its pure form. Just like petroleum diesel, biodiesel operates in compression ignition engine; which essentially require very little or no engine modifications because biodiesel has properties similar to petroleum diesel fuels. It can be stored just like petroleum diesel fuel and hence does not require separate infrastructure. Nowadays various techniques have been developed for producing biodiesel; some of them are mechanical stirring, ultrasonic cavitation, hydrodynamic cavitation and supercritical methanol.

Advantages of the Bio-diesel over Petroleum based Diesel Fuel are as following:

1. Biodiesel is a good lubricant, about 66% better than petro diesel.
2. Biodiesel produces less smoke and particulate matter as it is free of and aromatics.
3. Biodiesel have higher cetane number having well anti knock property.
4. Produces lower carbon monoxide and hydrocarbon emissions.
5. Bio-diesel is renewable, biodegradable and non-toxic.

In comparison with petroleum-based diesel fuel, biodiesel is characterised by:

- Lower heating value (by about 10-12%)
- Higher cetane value (typically 45-60)
- About 11% oxygen content (petroleum-based diesel contains no oxygen)
- No aromatics contents (and no PAHs)
- No sulphur or extremely low sulphur content
- Better lubricity
- Higher viscosity
- Higher freezing temperature (higher cloud point and pour point)
- Higher flash point
- No toxicity or low toxicity
- Biodegradability
- Different corrosive properties

Some of the above properties, such as the high cetane value or good lubricity, are obvious advantages of biodiesel while others, including the lower heating value, high freezing point (and inferior flow properties at low temperature), or corrosion properties are its drawbacks. Biodiesel changes the character and can increase the intensity of the odour of diesel exhaust (Choudhury and Bose, 2008).

Biodiesel Production

Biodiesel can be produced by various conventional methods, such as: alkali catalysis, acid catalysis, lipase catalysis etc. Considering various limitations of these methods, there is a strong quest to develop an efficient, time-saving, economically functional and environmental friendly biodiesel production processes at industrial scale having superiority over the classical procedure. Keeping this aspect into consideration, some of the recently developed biodiesel production technologies are **power ultrasound**, **hydrodynamic cavitation** and **supercritical methanol processes**. Power ultrasound is a useful tool for strengthen mass transfer of liquid –liquid heterogeneous system. In this process cavities are created by the irradiation of power ultrasonic with sufficient energy in the immiscible liquids. As a result micro fine bubbles are formed and the asymmetric collapse of the cavitation of these bubbles disrupts the phase boundary and impinging of the liquids creates micro jets, leading to intensive emulsification of system. Among recently developed techniques, another cavitation technique, which is popularly known as hydrodynamic cavitation is a potential method for biodiesel production at industrial scale due to its easy scale-up property. This is a rapid technique for preparing alkyl esters from triglycerides at pilot plant scale operation. Supercritical methanol is a simple and fast process and produces high yield because of simultaneous transesterification of triglycerides and methyl esterification of fatty acids at critical state. Supercritical methanol with a co-solvent process require relatively lower reaction temperature and pressures and hence energy, as compared to conventional supercritical methanol method. All these methods have future potential for biodiesel production at industrial scale..

Vegetable oils have their own advantages because of their easy availability, being renewable and eco-friendly to the environment, and they are free of sulphur content in them. Bio-diesel have many advantages over petroleum diesel fuel; produce less smoke and particulates, have high cetane number, produce lower carbon monoxide and hydrocarbon emissions, renewable, biodegradable and non-toxic. In India, with abundance of forest resources, there are a number of other non-edible tree borne oilseeds with an estimated annual production of more than 20 million tones, which have large potential for making biodiesel to supplement other conventional sources. Among these, Karanja (*Pongamia glabra*) and Jatropha (*Jatropha curcas*) have been successfully proved for their potential as biodiesel.

Cavitation technology

The generation, subsequent growth and collapse of cavities resulting in very high energy densities of the order of 1 to 10^{18} kW/m^3. Cavitation can occur at millions of locations in a reactor simultaneously and generate conditions of very high temperatures and pressures locally, with the overall environment being that of ambient conditions. The chemical reactions requiring stringent conditions can be effectively carried out using cavitation at ambient conditions. Moreover, free radicals are generated in the process due to the dissociation of vapours trapped in the cavitating bubbles, which results in either intensification of the chemical reactions or in the propagation of certain unexpected reactions. Cavitation also results in the generation of local turbulence and liquid micro-circulation (acoustic streaming) in the reactor, enhancing the rates of transport processes. The two principle types of cavitations and their application for transesterification process are described below.

Ultrasound Energy

Power ultrasonic is a useful tool for strengthening mass transfer of liquid- liquid heterogeneous system. In this process cavities are created by the irradiation of power ultrasonic with sufficient energy in the immiscible liquids. As a result micro fine bubbles are formed. The asymmetric collapse of the cavitation bubbles disrupt the phase boundary and impinging of the liquids create micro jets, leading to intensive emulsification of the system. The transesterification of vegetable oil with short-chain alcohols in the presence of base-catalyst, by means of low frequency ultrasound (28 and 40 kHz) in order to obtain biodiesel fuel was studied by Stavarache et al. (2005). By using ultrasounds the reaction time was observed much shorter (10-40 min) than as compared to mechanical stirring. The quantity of required catalyst was 2 or 3 times lower. A typical schematic representation of ultrasonic bath is shown in Fig. 1. Other significant studies for biodiesel production using ultrasound irradiation are discussed in Hanh et al. (2007).

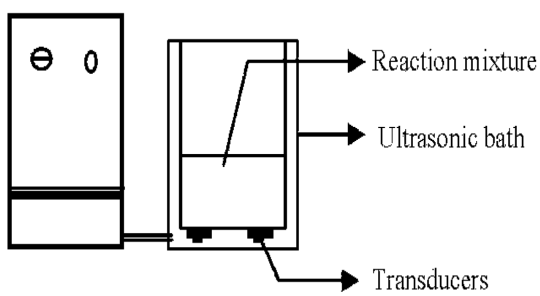

Figure IV- 1: Schematic Representation of Ultrasound Bath [Gogate. 2005]

An alkali-catalyzed biodiesel production method with power ultrasonic (19.7 kHz) has been developed by Ji et al. (2006) that allows a short reaction time and high yield because of emulsification and cavitation of the liquid-liquid immiscible system. Continuous ultrasound give a short reaction equilibrium time of 10-20 min and almost 100% yield under 6:1 substrate molar ratio. According to range of factors, substrate molar ratio was the prime factor, while temperature and pulse frequency of ultrasonic were secondary.

The order of the effect on FAMEs yield of the factors was substrate molar ratio>temperature>pulse frequency>ultrasonic power. In this study, the optimal reaction condition was at 6:1 substrate molar ratio, 45 ^{0}C, and continuous ultrasonic and 150 W ultrasonic power. The schematic diagram of ultrasonic horn setup is shown in Fig. 2.

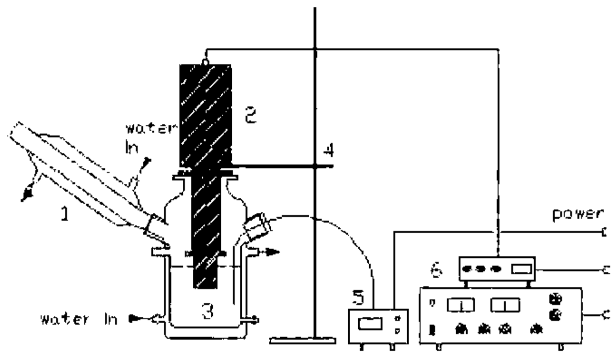

Figure IV-2: Schematic Diagram of Ultrasonic Horn Setup [Ji et al., 2006]

[1-condenser; 2-transducer; 3-ultrasonic reactor; 4-stand support; 5-thermometer] 6-generator

The ultrasound energy technique appears to be a rapid and effective technique compared to the conventional approach, for preparing alkyl esters from triglycerides at laboratory scale of operation. It can be seen that using ultrasonic method reaction time is almost half compare to conventional method which is beneficial for industrial purpose.

Hydrodynamic cavitation

Hydrodynamic cavitation is another technology developed recently and allows the generation of cavity collapse conditions similar to acoustic cavitation, thereby enabling different applications requiring different cavitational intensities, which have been successfully carried out using acoustic cavitation phenomenon but at much lower energy inputs. Hydrodynamic cavitation is a potential method for biodiesel production at industrial scale due to its easy scale-up property. *The schematic diagram of the test rig developed at DCE lab during this work is shown in Figure 3.* **The biodiesel used in the performance testing during this research work were made by both hydrodynamic cavitation and ultrasonic cavitation method in DCE I.C. Engines laboratory**

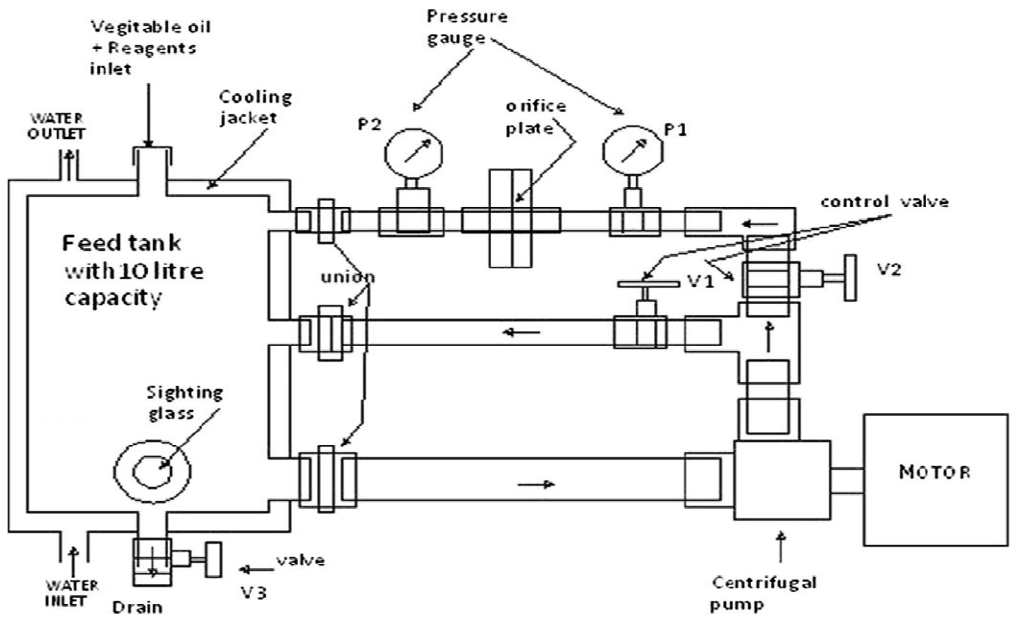

Figure IV- 3: Schematic Diagram of Hydrodynamic Cavitation System Setup Developed at DCE I. C. Engines Laboratory

The setup consists of a closed loop circuit comprising a feed tank, centrifugal pump (2.2 kW), control valve and a coupling to accommodate the orifice plate. The suction side of the pump is connected to the bottom of the feed tank. Discharge from the pump branches into two lines, which help in the control of inlet pressure and inlet flow rate into the main line housing and the orifice with the help of valves V_1 and V_2. The main line consists of a coupling to accommodate the orifice plate (single or multiple holes with different configurations). Four orifice plates with the numbers of holes 1, 3, 5 and 7 are used during experimentation. The diameter of each hole was 3 mm.

The cavitating conditions are generated just after the orifice plates in the main line and hence the intensity of the cavitating conditions strongly depends on the geometry of the orifice plate. When the liquid passes through the orifice plate (single or multiple holes), the velocities at the orifice increase due to the sudden reduction in the area offered for the flow, resulting in the decrease of the pressure. At the downstream of the orifice, however, due to an increase in the area of cross-section, the velocity decreases giving rise to increasing pressure and pressure fluctuations, which control the different states of cavitation, mainly formation, growth & collapse. The feed tank is provided with a cooling jacket to control the temperature of the circulating liquid. The biodiesel yield increases with increase in the number of holes and afterwards it provided with a cooling jacket to control the temperature of the circulating liquid.

Furthermore, scale-up of hydrodynamic cavitation to meet industrial-scale operations had better opportunities than the ultrasonic reactor due to its easier generating and less sensitivity to the geometric details of the reactor. The reaction time is shortened in the order of PU, HC and MS [where PU= Power Ultrasound, HC= Hydrodynamic Cavitation, MS= Mechanical Stirring]. Power ultrasonic gives the shortest reaction time and the highest yield. Mechanical stirring offered the slowest reaction rate. PU and the HC methods reduced the reaction equilibrium time to 10-30 min. The energy consumption (Wh/kg) for the transesterification of 1 kg of soybean oil by Ms, PU and HC are 500, 250 and 183 respectively. Thus PU and HC processes require approximately a half of the energy that is consumed by the MS method.

Supercritical Methanol Transesterification Process

Supercritical methanol is believed to solve the problems associated with the two-phase nature of normal methanol/oil mixtures by forming a single phase as a result of the lower value of the dielectric constant of methanol in the supercritical state. As a result the reaction is found to be complete in a very short time. SC methanol allows a simple process and high yield because of simultaneous transesterification of triglycerides and methyl esterification of fatty acids. A typical supercritical methanol transesterification system is shown in Fig 4.

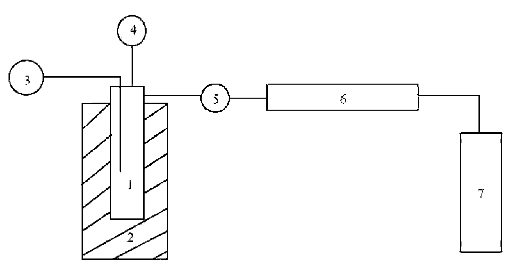

Figure AIV- 5: Supercritical methanol transesterification system, [Demirbas, 2003] [1-Autoclave, 2-Electric furnace, 3-Temperature control monitor, 4-Pressure control monitor, 5-Product exit valve, 6- Condenser, 7-Product collecting vessel]

In a typical run, the autoclave is charged with a given amount of vegetable oil and liquid methanol with a specific molar ratio. After each run, the gas is vented, and the autoclave is poured into a collecting vessel. All the contents are removed from the autoclave by washing with methanol. Compared with the catalytic processes, purification of products is much simpler and more environmental friendly. However, the reaction requires temperatures of 350-400 ^{0}C and pressures of 45-65 MPa, which are not viable in practice in industry. Furthermore, such high temperatures and pressures lead to high production costs and energy consumption. Transesterification of soybean oil in supercritical methanol has been carried out by Hanh et al. (2007) in the absence of catalyst. A co-solvent was added to the reaction mixture in order to decrease the operating temperature, pressure and molar ratio of alcohol to vegetable oil. With CO_2 as co-solvent in the reaction system, there was a significant decrease in the severity of the conditions required for supercritical reaction. It was demonstrated that, with an optimal reaction temperature of 280 ^{0}C, methanol to oil ratio of 24 and CO_2 to methanol ratio of 0.1, a 98% yield of methyl esters viable as an industrial process. In the absence of catalyst the purification of the products after transesterification is much simpler and more environmental friendly. The relatively mild reaction conditions and high yield of methyl esters using this environmentally friendly method make it practical use in Industry. A system for continuous transesterification of vegetable oil using supercritical methanol was developed using a tube reactor was investigated by He et al. (2007). Increasing the proportion of methanol, a reaction pressure and reaction temperature can enhance the production yield effectively. However, side reactions of unsaturated fatty acid methyl esters (FAME) occur when the reaction temperature is over 300 ^{0}C, which lead to much loss of material.

Low frequency ultrasound and hydrodynamic cavitation methods are energy efficient, time saving and economically functional, offering a lot of advantages over the conventional mechanical stirring method. Supercritical methanol with a co-solvent process require relatively lower reaction temperature and pressures and hence energy, as compared to conventional supercritical methanol method. In addition because of the absence of catalyst, the purification of products after transesterification is much simpler and more environmentally friendly. The relatively mild reaction conditions and high yield of methyl esters using this environmentally friendly method makes it viable for industry. All these methods have future potential for biodiesel production at industrial scale due to their easy scale up property.

Indian Scenario in Biodiesel

Indian energy demand is expected to grow at an annual rate of 6.8 per cent over the next couple of decades. Most of the energy requirements are currently satisfied by fossil fuels – coal, petroleum based products and natural gas. Past and projected future Indian demand for diesel and biodiesel is shown in table IV-A. Domestic production of crude oil can only fulfil 25-30 per cent of national consumption rest we are importing from other countries. In these circumstances bio fuels are going to play an important role in meeting growing Indian energy needs. Bio fuels offer an attractive alternative to fossil fuels, but a consistent scientific framework is needed to ensure policies that maximize the positive and minimize the negative aspects of bio fuels. The government of India has formulated an ambitious National Biodiesel Mission to meet 20 per cent of the country's diesel requirements by 2016-2017.

A commercialization period during 2007-2012 will continue Jatropha cultivation and install more transesterification plants which will position India to meet 20 per cent of its diesel needs through biodiesel. Many developed countries have active biodiesel programs. Currently biodiesel is produced mainly from field crop oil like rapeseed, sunflower etc. in Europe and soybean in US. Malaysia utilises palm oil for biodiesel production while in Nicaragua it is Jatropha oil. The productions of vegetable oil globally are given in Table IV-B. There are many countries which have large amount of bio-diesel potential. And if this potential is used for the production of biodiesel than the crisis of petroleum based diesel and fossil fuel can be solved.

Table IV-A: Indian Demand for Diesel and Biodiesel Requirement

Year	Diesel demand Mt	Biodiesel Blending Requirement Mt (in metric ton)		
		@5%	@10%	@20%
2006-07	52.32	2.62	5.23	10.46
2011-12	66.91	3.35	6.69	13.38
2016-17	83.58	4.18	8.36	16.72

Planning commission of India report, 2003

Table IV- B Global Productions of the Major Vegetable Oils

S. No.	Oil	Production (million tons)	S. No.	Oil	Production (million tons)
1	Soybean	27.8	11	Palm kernel	2.9
2	Rapeseed	13.7	12	Olive	2.7
3	Cottonseed	4.0	13	Corn	2.0
4	Sunflower	8.2	14	Castor	0.5
5	Peanut	5.1	15	Groundnut	1.40
6	Coconut	3.5	16	Mustard	1.55
7	Linseeds	0.6	17	Sunflower	0.3
8	Palm	23.4	18	Niger	0.03
9	Sesame	0.26	19	Rice Bran	0.55
10	Castor	0.25	20	Linseeds	0.1
	Total	**86.81**		**Total**	**12.03**

Planning commission of India report, 2003

Additives for Oxidative Stability of Biodiesel

Oxidative stability is a major industry issue for diesel and biodiesel fuels. Some biodiesels are more stable than others and some unstable biodiesel contain stability additives that perform very well. The tendency of a fuel to be unstable can be predicted by the Iodine number (ASTM D 1510) but the test method may not pick up the presence of stability additives. Iodine number actually measures the presence of C=C bonds that are prone to oxidation.

The general rule of thumb is that instability increases by a factor of 1 for every C=C bond on the fatty acid chain; thus, 18:3 are three times more reactive than C18:0. Stability can be predicted from knowledge of the feedstock only if you know the proportion of C18:2 and C18:3 fatty acids present in the fuel and know whether or not the fuel has been treated for stability. High fractions of those two types of fatty acids can adversely affect fuel stability if additives are not used.

Poor stability can lead to increasingly high acid numbers, high viscosity, and formation of gums and sediments that can clog filters. Comparing the acid number and viscosity of fuel over time can provide some idea about whether or not the fuel is oxidising, but one need to take a sample at the beginning when the fuel is fresh and then sample on a regular basis after that. Long-term storage in the presence of diesel fuel, diesel additives, water, sediments, heat, and air has not been adequately documented in the field. Biodiesel and blends of biodiesel and diesel fuel should not be stored for longer than 6 months in either storage tanks or vehicles until better field data is available. If it becomes necessary to store biodiesel for longer than 6 months, or the storage conditions are poor, use antioxidants. The common antioxidants that work with biodiesel are TBHQ (t-butyl hydroquinone), Tenox 21, and tocopherol (Vitamin E). Powdered antioxidants are difficult to mix into biodiesel. When a small amount of biodiesel is heated (1 gallon or so) up to 37.7 ^{0}C or until all the powdered antioxidant is dissolved. Then this can be mixed with the remaining bulk biodiesel (Stavarache Carmen et al., 2006).

Material Compatibility

Brass, bronze, copper, lead, tin, and zinc will oxidize diesel and biodiesel fuels and create sediments. Lead solders and zinc linings should be avoided, as should copper pipes, brass regulators, and copper fittings. The fuel or the fittings will tend to change colour and sediments may form, resulting in plugged fuel filters. Affected equipment should be replaced with stainless steel or aluminium. Acceptable storage tank materials include aluminium, steel, fluorinated polyethylene, fluorinated polypropylene, and Teflon. The effect of B20 on vulnerable materials is diluted compared to higher blends. Some slow oxidation can occur, although it may take longer to materialize. Biodiesel can also affect some seals, gaskets, and adhesives, particularly those made before 1993 made from natural or nitrile rubber. It is primarily for these reasons that vehicle and storage equipment are modified. Most engines made after 1994 have been constructed with gaskets and seals that are generally biodiesel resistant.

Earlier engine models or rebuilds may use older gasket and seal materials and present a risk of swelling, leaking, or failure. Fuel pumps may contain rubber valves that may fail. The typical approach is to create a maintenance schedule that checks for potential failures. Users can also contact engine manufacturers for more information (Stavarache Carmen et al., 2006).

Chemistry of Biodiesel

Biodiesel is made using the process of transesterification. In the transesterification of different type of oils, triglycerides react with an alcohol, generally methanol or ethanol, to produce esters and glycerin. To make it possible, a catalyst is added to the reaction.

CH_2-OOC-R_1			R_1-COO-R'	CH_2-OH
|		Catalyst	|	|
CH-OOC-R_2	+ 3R'OH	$\longleftrightarrow$	R_2-COO-R' +	CH-OH
|			|	|
CH_2-OOC-R_3			R_3-COO-R'	CH_2-OH
Glycerides	Alcohol		Esters	Glycerin

Where, term R represents to different alkyl groups.

The overall process is normally a sequence of three consecutive steps, which are reversible reactions. In the first step from triglycerides, diglyceride is obtained. From diglyceride, monoglyceride is produced and in the last step from monoglycerides, glycerin is obtained. In all these reactions esters are produced. The stoiecheometric relation between alcohol and the oil is 3:1. However, an excess of alcohol is usually more appropriate to improve the reaction towards the desired product.

Triglycerides (TG) + R'OH $\longleftrightarrow$ Diglycerides (DG) + R'COOR$_1$

Diglycerides (DG) + R'OH $\longleftrightarrow$ Monoglycerides (MG) + R'COOR$_2$

Monoglycerides (MG) + R'OH $\longleftrightarrow$ Glycerin (GL) + R'COOR$_3$

The catalyst used for the reaction is mainly of three types which are given below:-

Alkali Catalyst

This catalyst can be used with methanol or ethanol as well as any kind of oils, refine, crude or frying. The main alkali catalysts are sodium hydroxide (NaOH) and potassium hydroxide (KOH).

Acidic Catalyst

Acid transesterification is a great way to make biodiesel if the sample has relatively high free fatty acid content. The main acidic catalysts are Sulphuric acid (H_2SO_4) and Sulfonic acid.

Enzymes-catalyzed

Enzymes-catalyzed procedures, using lipase as catalyst, but the lipases are very expensive for industrial scale production and there are three-step processes required to achieve a 95% conversion. Due to this three step process the reaction time is too large.

Properties of Biodiesel

A general understanding of the various properties of biodiesel is essential to study their implications in engine use, storage; handling and safety are well documented by Barnwal and Sharma (2005).

Viscosity

In addition to lubrication of fuel injection system components, fuel viscosity controls the characteristics of the injection from the diesel injector (droplet size, spray characteristics etc.). The viscosity of methyl esters can go to very high levels and hence, it is important to control it within an acceptable level to avoid negative impact on fuel injection system performance. Therefore, the viscosity specifications proposed are same as that of the diesel fuel.

Density/ Specific Gravity

Biodiesel is slightly heavier than conventional diesel fuel (specific gravity 0.88 compared to 0.84 for diesel fuel). This allows use of splash blending by adding biodiesel on top of diesel fuel for making biodiesel blends.

Flash Point

Flash point of a fuel is defined as the temperature at which it will ignite when exposed to a flame or spark. The flash point of biodiesel is higher than the petroleum based diesel fuel. Flash point of biodiesel blends is dependent on the flash point of the base diesel fuel used, and increase with percentage of biodiesel in the blend. Thus in storage, biodiesel and its blends are safer than conventional diesel. The flash point of biodiesel is around 160 ^{0}C.

Aromatics

Biodiesel does not contain any aromatics so aromatic limit not specified.

Cold Filter Plugging Point (CFPP)

At low operating temperature fuel may thicken and not flow properly affecting the performance of fuel lines, fuel pump and injectors. Cold filter plugging point of biodiesel reflects its cold weather performance. It defines the fuels limit of filterability. Biodiesel thicken at low temperatures so need cold flow improver additives to have acceptable CFPP.

Cloud Point

Cloud point is the temperature at which a cloud or haze of crystals appear in the fuel under test conditions and thus becomes important for low temperature operations. Biodiesel generally has higher cloud point than diesel fuels.

Iodine Number

Iodine number refers to the amount of iodine required to convert unsaturated oil into saturated oil. It refers to the amount of unsaturated fatty acid in the fuel. One value of iodine number can be obtained by using several grades of unsaturated acids. Therefore an additional parameter, linolenic acid (C18: 3) content is specified and limited to 15% in Austrian Standard ON C 1191.

Acid number/ Neutralization number

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Cetane Number

Biodiesels has higher cetane number than conventional diesel fuel. This results in higher combustion efficiency and smoother combustion.

Stability

Biodiesel age more quickly than fossil diesel fuel due to the chemical structure of fatty acids and methyl esters present in biodiesel. Typically there are up to 14 types of fatty acid methyl esters in the biodiesel. The individual proportion of presence of these esters in the fuel affects the final properties of biodiesel. Saturated fatty acid methyl esters (C14:0, C16:0, C16:0) increase cloud point, cetane number and improve stability whereas more polyunsaturates (C18:2, C18:3) reduce cloud point, cetane number and stability.

Some of other important properties and Indian specifications of biodiesel proposed by BIS (Bureau of Indian standards) are given in Table 2.3 (Chapter2)

APPENDIX-V

ETHANOL BLENDS

The ever rising cost of fossil fuel internationally has forced major world economies, which are also major importers of fossil fuel, to examine renewable and cheaper alternatives to fossil fuel to meet their energy demands. Biodiesel and bio ethanol have emerged as the most suitable renewable alternatives to fossil fuel as their quality constituents match diesel and petrol respectively. In addition they are less polluting than their fossil fuel counterparts. Environmental concerns and the desire to be less dependent on imported fossil fuel have intensified worldwide efforts for production of biodiesel from vegetable oils and ethanol from starch and sugar producing crops.

Ethanol is a clear, colourless liquid. In dilute aqueous solution, it has a somewhat sweet flavour , but in more concentrated solutions it has a burning taste. Ethanol (CH_3CH_2OH) is made up of a group of chemical compounds whose molecules contain a hydroxyl group, -OH, bonded to a carbon atom. Ethanol made from cellulosic biomass materials instead of traditional feed stocks (starch crops) is called bio ethanol. Over the past several years, numerous tests have been conducted on diesel fuel containing various oxygen bearing components, including ethanol. The interest in such fuels is primarily for their ability to reduce exhaust emissions, especially particulate matter. A number of tests have shown that adding ethanol to diesel fuel can reduce certain components of exhaust emissions. Table V-A shows the comparision of various fuel properties with diesel

Table V-A: Properties of Diesel, Ethanol and n-Butanol

Fuel/properties	Diesel	Ethanol	n-butanol
Formula	$C_{12}H_{23}(C_{10}H_{20}C_{15}H_{28})$	C_2H_5OH	$C_4H_{10}O$
Mole weight	190 -220	46.07	74.12
Density at 20%^{o}c	0.840	0.789	0.810
Oxygen Content (Wt %)	0	34.8	21.58
Carbon content (Wt %)	86	52.2	64.82
Hydrogen content (Wt %)	14	13	13.60
Viscosity at 20% ^{o} c Ns/m^2	3.35	1.2	3.0
Cetane number	40-50	8 -9	17
Lower Heat value (MJ/kg)	42.5	26.4	33.2

Source: (Ajav and Akingbehin, 2002)

Properties of Ethanol-Diesel Blends

There are a number of fuel properties that are essential to the proper operation of a diesel engine. The addition of ethanol to diesel fuel affects certain key properties with particular reference to blend stability, viscosity and lubricity, energy content and cetane number. Materials compatibility and corrosiveness are also important factors that need to be considered. Properties that affect safety should be foremost in any fuel evaluation. These include flash point and flammability. Finally fuel biodegradability has become a significant factor with respect to ground water contamination.

Specific Gravity

Specific gravity will provide more information about how the fuel will perform in a diesel engine than any other single test. Specific gravity will measure the density of the fuel. The density of the fuel is related to its viscosity. A higher specific gravity may indicate an incomplete reaction and the fuel should not be used in an engine. Specific gravity of the fuel at different temperature is shown in the Table V-B.

Table V-B: Specific Gravity of Fuel Blends

S. no	Fuels %		Specific Gravity/Temperature						
	Ethanol	diesel	**15^{o}c**	**20^{o}c**	**26^{o}c**	**32^{o}c**	**38^{o}c**	**44^{o}c**	**50^{o}c**
1	0	100	.8583	.8485	.845	.844	.8409	.8390	.837
2	5	95	.8414	.8385	.836	.835	.8308	.8288	.825
3	10	90	.8394	.8351	.834	.833	.8288	.8268	.823
4	15	85	.8382	.8345	.831	.829	.8268	.8266	.822
5	20	80	.8365	.8342	.831	.828	.8258	.8241	8218

Source: (Ajav and Akingbehin, 2002)

Calorific Value of Fuels

One of the important characteristics of good fuel is high calorific value of the fuel as the amount of heat liberated and the temperature attained, thereby depending upon the calorific value of the fuel. Calorific value of the fuel is the amount of heat liberated, when a unit mass of fuel is burnt completely. Calorific value of the fuel is measured by Bomb Calorimeter. Table V-C shows the calorific value for various ethanol-diesel blends.

TableV-C: Calorific Value of Fuel

S. No.	Ethanol	Diesel	Cal. Value (kJ/kg)	% difference to diesel
1	0	100	44514.6	-
2	5	95	43631.8	1.983
3	10	90	43192.5	2.970
4	15	85	42744.8	3.976
5	20	80	41874.5	5.931
6	25	75	41004.2	7.886
7	30	70	40577.4	8.845

Source: (Ajav and Akingbehin, 2002)

Viscosity and Lubricity

Fuel viscosity and lubricity play significant roles in the lubrication of fuel injection systems, particularly those incorporating rotary distributor injection pumps that rely fully on the fuel for lubrication within the high pressure pumping mechanism. In the common rail accumulator fuel-injection system, the high-pressure pump that delivers fuel to the rail also relies on the fuel for lubrication. In in-line pumps and unit injectors, there is less reliance on the fuel for lubrication; however, there are still some metal interfaces that require lubrication by the fuel such as between plunger and barrel. Injector lubrication also is affected, particularly at the needle guide-nozzle body interface. Lower fuel viscosities lead to greater pump and injector leakage reducing maximum fuel delivery and ultimately power output. Hot restart problems also may be encountered as insufficient fuel may be injected at cranking speed when fuel leakage in the high-pressure pump is amplified because of the reduced viscosity of the hot fuel.

Fuel viscosity also affects the atomization and spray characteristics in the combustion chamber. Lower viscosities typically result in smaller mean droplet diameters, thereby increasing the surface area of droplets and significantly influencing the evaporation characteristic time .The lack of reports of specific measurements to substantiate these trends with e–diesel blends indicates a need to investigate their atomization and spray characteristics, as these parameters have a significant effect on the combustion process. Table V-D shows the viscosity value for various ethanol-diesel blends.

Table V-D: Viscosity of Fuels

S.No	Sample %		Viscosity (cp)/ Temperature						
	Ethanol	Diesel	**15^{0}C**	**20^{0}C**	**26^{0}C**	**32^{0}C**	**38^{0}C**	**44^{0}C**	**50^{0}C**
1	0	100	6.2451	5.611	4.687	3.800	3.423	2.900	2.814
2	5	95	6.1597	5.534	4.493	3.652	3.278	2.799	2.636
3	10	90	5.9410	5.456	4.246	3.559	3.295	2.739	2.561
4	15	85	5.7471	5.163	4.004	3.451	3.139	2.602	2.469
5	20	80	5.6677	5.058	3.867	3.370	2.739	2.392	2.176
6	25	75	5.4957	5.034	3.439	2.890	2.602	2.256	1.919
7	30	70	6.7125	4.917	3.065	2.804	2.456	2.078	1.829

Source: (Ajav and Akingbehin, 2002)

Flash Point

Flash point of the fuel is the minimum temperature at which it gives enough vapours to from a flammable mixture that ignites for a moment, when a tiny flame is brought near to it. The flash point of oil is generally measured by using Pensky-Marten’s meter. It is desirable that the fuel should have higher flash point. Flash point is important primarily from a fuel-handling standpoint. Too low a flash point will cause fuel to be fire hazard, subject to flashing, and possible continued ignition and explosion.

Blend Stability

Ethanol solubility in diesel is affected mainly by two factors, temperature and water content of the blend. At warm ambient temperatures dry ethanol blends readily mixes with diesel fuel. However, below about 10 ^{0}C the two fuels separate. Prevention of this separation can be accomplished in two ways: by adding an emulsifier which acts to suspend small droplets of ethanol within the diesel fuel, or by adding a co-solvent that acts as a bridging agent through molecular compatibility and bonding to produce a homogeneous blend

Emulsification usually requires heating and blending steps to generate the ethanol blend, whereas co-solvents allow fuels to be ‘‘splash-blended’’, thus simplifying the blending process. The polar nature of ethanol induces a dipole in the aromatic molecule allowing them to interact reasonably strongly, while the aromatics remain compatible with other hydrocarbons in diesel fuel. Hence aromatics act to some degree as bridging agents and co-solvents. Reducing the aromatic content of diesel fuels will influence the miscibility of ethanol in diesel fuel and will affect the amount of additive require achieving a stable blend. Table V-E shows the details flash point, cloud point and pour point of fuel.

Table V-E: Flash point, Cloud Point and Pour Point of Fuel

S.No	Ethanol	Diesel	Flash Point ^{0}C	Cloud Point ^{0}C	Pour Point ^{0}C
1	0	100	74	5	5
2	5	95	24	5	-7
3	10	90	25	5	-10
4	15	85	27	5	-13
5	20	80	25	5	-36
6	25	75	25	5	-
7	30	70	26	4	-

Source: (Ajav and Akingbehin, 2002)

Materials Compatibility

The use of ethanol in gasoline engines in the early 1980s resulted in numerous materials compatibility studies, many of which are also applicable to the effect of e–diesel blends in diesel engines and particularly in the fuel injection system. The quality of the ethanol has a strong influence on its corrosive effects. In addressing the problems of ethanol corrosion associated with gasoline blends, divided ethanol corrosion into three categories: general corrosion, dry corrosion and wet corrosion. General corrosion was caused by ionic impurities, mainly chloride ions and acetic acid. Dry corrosion was attributed to the ethanol molecule and its polarity. Reviewed reports of dry corrosion of metals by ethanol and found that magnesium, lead and aluminum were susceptible to chemical attack by dry ethanol. Wet corrosion is caused by azeotropic water, which oxidizes most metals. Freshly formulated blends containing pH neutral dry ethanol would be expected to have relatively little corrosive effect. However, if a blend has been standing in a tank for sufficient time to allow the ethanol to absorb moisture from the atmosphere, it may tend to be more corrosive as it passes through the fuel injection system. In addition, the fuel may stand in the fuel injection pump for a number of months, for example in a combine harvester engine, thus allowing the fuel time to corrode parts of the pump internally. Corrosion inhibitors have been incorporated in some additive packages used with e–diesel blends Non-metallic components have also been affected by ethanol with particular reference to elastomeric components such as seals and O-rings in the fuel injection system. These seals tend to swell and stamen. Resin-bonded or resin-sealed components also are susceptible to swelling and seals may be compromised.

Energy Content

The energy content of a fuel has a direct influence on the power output of the engine. Stated that it would be desirable for ethanol– diesel blends to have gross energy contents at least 90– 95% of that for e-diesel to permit existing engines to deliver adequate power for the loads for which the vehicle is designed. The energy content of e–diesel blends decreases by approximately 2% for each 5% of ethanol added, by volume, assuming that any additive included in the blend has the same energy content as diesel fuel.

Cetane Number

The minimum cetane number specified by ASTM Standard D 975-02 diesel is 40. Typical diesel fuels have cetane numbers of 45–50. With the inverse relationship of octane number and cetane number, ethanol exhibits a low cetane rating. Hence, increasing concentrations of ethanol in diesel lower the cetane number proportionately. Using cetane numbers to describe the ignition characteristics of e–diesel blends was unreliable, because of discrepancies in the determination of cetane numbers below 30. However, it is estimated that the cetane number of ethanol was between 5 and 15. Lower cetane numbers mean longer ignition delays, allowing more time for fuel to vapourise before combustion starts. Initial burn rates are higher causing more heat release at constant volume, which is a more efficient conversion process of heat to work. Nevertheless, it is preferable to add an ignition improver to raise the cetane number of e–diesel blends so that they fall within an acceptable range equivalent to that expected of e-diesel fuel. We can use a number of ignition improvers for ethanol fuel with special emphasis on biomass-derived nitrates. They noted a significant dependence of the energy release per equivalent nitrate on the molecular weight of the ignition improving nitrate found tri-ethylene glycol di-nitrate (TEGDN) to be the most satisfactory ignition improver in tests performed in Brazil, especially since it could be manufactured from ethanol.

Vapour Lock and Cavitations

The vapour pressure of an ethanol-in-diesel fuel is considerably greater than that of neat diesel. In addition, the viscosity is lower—the lower viscosity results in a lower static pressure in the fuel delivery system. As a result of these combined traits, ethanol-in-diesel has a significantly greater tendency to evaporate and form erratic locations of vapour lock in the fuel delivery system. This vapour lock will happen at the locations of lowest static pressure, such as the fuel intake of the injector, resulting in too little fuel being delivered to the injector and subsequent cavitation inside the injector. Both the vapour lock and cavitation can be detrimental to fuel performance. To prevent the vapour lock and subsequent cavitation, the static pressure of the fuel delivery system must be increased either by:

(1) Reducing the size of the restrictive orifice on the diesel fuel return line or

(2) Introducing a backpressure regulator to the diesel fuel return line can achieve this. The good performances of ethanol-in-diesel fuels were achieved only after vapour lock problems were corrected.

Safety

Ethanol's high polarity and tendency toward hydrogen bonding cause ethanol to have a high activity in gasoline and diesel. This high activity leads to both limited miscibility's and high vapour pressures. The ethanol-in-diesel blends have flash point temperatures estimated to be slightly below typical ambient temperatures; this translates to fuel tanks having ignitable mixtures of fuel and air during most operating conditions. By comparison, vapour spaces of diesel storage tanks are typically too fuel lean for ignition while vapour spaces over gasoline and E-85 are typically too fuel rich for ignition. This is a safety issue that should be addressed for both ethanol-in-diesel solutions and ethanol-in-diesel emulsions. One method for solving potential vapour pressure problems of ethanol-in-diesel solutions is to add an additional volatile component to the system so as to increase the vapour pressure into a fuel-rich regime that is outside ignition limits-candidate blend stocks include hexane, pentane, naphtha, and diethyl ether. Table V-F shows the stratification time of Ethanol-Diesel Fuel Blends with and without Solvent

Table V-F: Stratification of Ethanol-Diesel Fuel Blends with and without Solvent

Fuel blend	E10D90	E15D85	E20D80	E25D75	E30D70
Stratification Time	72 (hours)	48(hours)	24 (hours)	2(hours)	5(min)
Fuel blend	Z5E10D95	Z5E10D95	Z5E20D90	Z5E25D85	Z5E30D80
Stratification Time	-	18(days)	14 (Days)	14 (Days))	11 (Days)

Source: (Ajav and Akingbehin, 2002)

Flash Point and Vapour Pressure

Flash point is the lowest temperature at which the vapour pressure of a liquid is sufficient to produce a flammable mixture in the air above the liquid surface in a vessel. Vapour pressure is a related property (not a part of the ASTM D975 diesel specification), which is defined as the pressure exerted by a vapour over a liquid in a container at a specified temperature. Vapour pressure and flash point are important from both a fire safety standpoint and from the standpoint of evapourative hydrocarbon emissions.

Table V-G: Flash Point and Vapour Pressure of Fuel

parameter	Diesel	Ethanol	Gasoline
Vapour pressure@ 38 psi	0.04	2.5	7-9
Flash point	55-65	13	-40
Boiling point, ^{O}C	170-340	78	33-213
Auto ignition temperature ^{O}C	230	366	300
Flammability limits, Vol %	0.6-5.6	3.3-19.0	1.4-7.6
Flammability limits, ^{O}C	64-150	13-42	(-40)-(-18)

Jincheng Source:Huang et al., (2008).

Solubility, Water Tolerance, and Stability

While ethanol is reasonably soluble in diesel fuel at room temperature, the presence of water can lead to phase separation. Conventional diesel fuel can carry very little water, on the order of 0.1%. Emulsifier manufacturers claim that their products make ethanol-diesel blends tolerant of reasonable water content without phase separation. For example, recent presentations and product literature indicate tolerances of up to 3% water under some conditions. It would be desirable for emulsifier manufacturers to publish more detailed data quantifying the water tolerance of their products in diesel fuel of varying properties. For both ethanol solubility and water tolerance, a minimum requirement for e-diesel needs to be specified. No data on the water tolerance of diesel/ bio-diesel /ethanol blends appear to be available.

A related issue is the stability of e-diesel blends. While e-diesel formulation is stable to -30°C (-22°F), stability in a range of diesel fuels over a range of normal temperatures and water content needs to be proven. Maintenance of a stable micro emulsion for a period of several months would seem to be required at a minimum. In addition to stability with respect to phase separation, oxidative and biological stability also need to be examined.

Cold Flow Properties

Cold flow properties are quantified in the United States by cloud point and pour point. Cloud point is the temperature at which initial crystallization or phase separation (i.e. freezing) of the fuel begins (because diesel fuel is a mixture of many components it does not have a well defined freezing point but solidifies over a wide temperature range). Pour point is the temperature below which the fuel will not pour, using a definition specific to the standard procedure. Because of the very low freezing point of ethanol relative to diesel fuel it would improve low temperature flow properties, as long as the ethanol remains soluble. All emulsifier manufacturers claim that their products make ethanol soluble to very low temperatures. Engineers in the e-diesel industry believe that upon cooling of e-diesel micro-emulsions the micelles grow to near micron size causing a clouding of the fuel. These ethanol micelles are liquid and will apparently flow through a fuel filter. This is in contrast to the cloud point of a conventional diesel, which indicates the onset of formation of solid wax crystals that can plug a fuel filter. Including the cold filter plugging point (CFPP) test may therefore be desirable in future e-diesel property measurements. Because of the relatively high cost and limited availability of diesel and kerosene in some markets, the ability to use e-diesel during the winter months may have an economic advantage should the claims regarding cold flow properties be substantiated.

It is unknown to what extent emissions can be effected by the emulsifier. A diesel oxidation catalyst or other advanced catalytic after treatment technology could easily reduce hydrocarbon emissions to very low levels. It seems likely that CO emissions are decreasing in concert with PM emissions on a cycle average basis. It is likely that adding ethanol will have no effect on cycle average NOx emissions as long as the cetane number of the e-diesel is matched to that of the blending diesel. If the emulsifier package is formulated to increase the cetane number relative to the base fuel by 5 or more cetane numbers, it may be possible to realise NOx benefits. Because of the cost of cetane improving additives there may be significant economic barriers to this approach, and the same NOx benefit could be obtained by adding cetane improver to a conventional diesel.

Ethanol as a CI Engine Fuel

Due to easy miscibility with petrol and a higher octane ethanol is preferably blended in with gasoline. But keeping in mind the supremacy of the ethanol, the use of ethanol blended with diesel was a subject of research in the 1980's and it was shown that ethanol-diesel blends were technically acceptable for existing diesel engines.

The relatively high cost of ethanol production at that time meant that the fuel could only be considered in cases of fuel shortages. Today the economics are much more favourable in the production of ethanol and it is able to compete fairly well with standard diesel. Hence there has been renewed interest in the ethanol-diesel blends with particular emphasis on emissions reductions. (Hansen et al., 2005).

Ethanol is used as an automotive fuel by itself and can be mixed with gasoline to form what has been called "gasohol" or can be mixed with diesel to form "diesehol or "E-diesel". Because the ethanol molecule contains oxygen, it allows the engine to more completely combust the fuel, resulting in fewer emissions. Since ethanol is produced from plants that harness the power of the sun, ethanol is also considered a renewable fuel. Lower calorific value of ethanol, higher surface tension, greater solvent power etc., restrict its use as a complete motor vehicle fuel. It can be best utilised as a blend constituent with up to around 30% ethanol -Diesel blends useable in the modern day automobiles without requiring any major engine modifications; and giving reduced levels of exhaust CO and HC emissions.

Merits of Ethanol:

- It is not a fossil fuel thus, manufacturing it and burning it does not increase the greenhouse effect.
- It reduces dependence on imported fuels.
- Refuelling is similar to that of gasoline or diesel.
- It can be used in both light and heavy duty vehicles.
- Ethanol is biodegradable without harmful effects on the environment.
- It significantly reduces harmful exhaust emissions, thereby reduces air pollution.
- More energy density compared to gasoline with optimized compression ratio.

- Ethanol's high oxygen content reduces carbon monoxide levels more than any other oxygenate by 25-30%.
- Ethanol reduces nitrogen oxide, sulphur dioxide, hydrocarbon and CO_2 emissions.
- It provides high octane no. at low cost as an alternative to harmful fuel additives.
- As an octane-enhancer, ethanol can cut emissions of cancer-causing benzene and butadiene by more than 50%.

Demerits of Ethanol:

- The relatively low boiling point and high vapour pressure of ethanol indicate that vapour lock could be a serious problem, particularly at high altitudes on warm summer days.
- The relatively high latent heat of ethanol causes problems in its mixing with air and transporting it through the intake manifold of the engine. Heating the intake manifold may be necessary in cold weather or before the engine reaches operating temperatures. Without external heat to more completely vapourise the fuel, the engine may be difficult to start and sluggish for a considerable time after starting.
- Although ethanol. When used near its stoichiometric air-fuel ratio, produces more power, a larger quantity of fuel is required to produce a specified power output. For example, in an automobile, more fuel is required for each mile driven.
- Ethanol has strong affinity for water. Less engine power is produced as the water content of an ethanol increases. Further, vapour lock, fuel mixing and starting problems increase with water.
- Ethanol is corrosive to certain materials used in engines and thus can dissolve them. It can also cause injury or physical harm if not used properly. People who use in motor they should observe warning labels and follow precautions to avoid problems.

APPENDIX VI

CALCULATION OF FUTURE EMISSIONS
Estimation of Projected Emissions for Taxies and Auto Rickshaws …1

	Emission	Mfvcc	Mf1	Mf2	Mf3	Mf4	Pollution (TPD)
BUSINESS AS USUAL	CO 2010	6.33	1.06	1	–	–	**6.71**
	CO2020	6.33	1.272	1	–	–	**8.05**
	CO2030	6.33	1.5264	1	–	–	**9.66**
	HC2010	4.07	1.06	1	–	–	**4.31**
	HC2020	4.07	1.272	1	–	–	**5.17**
	HC2030	4.07	1.5264	1	–	–	**6.21**
	NOx2010	2.07	1.06	1	–	–	**2.19**
	NOx2020	2.07	1.272	1	–	–	**2.63**
	NOx2030	2.07	1.5264	1	–	–	**3.16**
	PM2010	0.48	1.06	1	–	–	**0.51**
	PM2020	0.48	1.272	1	–	–	**0.61**
	PM2030	0.48	1.5264	1	–	–	**0.73**
CONTROL ACTION PLAN- 1	CO 2010	6.33	1.06	1.03	0.98	0.98	**6.63**
	CO2020	6.33	1.272	1.13	0.93	0.93	**7.86**
	CO2030	6.33	1.5264	1.243	0.88	0.88	**9.29**
	HC2010	4.07	1.06	1.03	0.98	0.98	**4.26**
	HC2020	4.07	1.272	1.13	0.93	0.93	**5.05**
	HC2030	4.07	1.5264	1.243	0.88	0.88	**5.97**
	NOx2010	2.07	1.06	1.03	0.98	0.98	**2.17**
	NOx2020	2.07	1.272	1.13	0.93	0.93	**2.57**
	NOx2030	2.07	1.5264	1.243	0.88	0.88	**3.04**
	PM2010	0.48	1.06	1.03	0.98	0.98	**0.50**
	PM2020	0.48	1.272	1.13	0.93	0.93	**0.60**
	PM2030	0.48	1.5264	1.243	0.88	0.88	**0.70**
CONTROL ACTION PLAN- 2	CO 2010	6.33	1.06	1.06	0.98	0.98	**6.83**
	CO2020	6.33	1.272	1.272	0.93	0.93	**8.85**
	CO2030	6.33	1.5264	1.526	0.88	0.88	**11.41**
	HC2010	4.07	1.06	1.06	0.98	0.98	**4.39**
	HC2020	4.07	1.272	1.272	0.93	0.93	**5.69**
	HC2030	4.07	1.5264	1.526	0.88	0.88	**7.33**
	NOx2010	2.07	1.06	1.06	0.98	0.98	**2.23**
	NOx2020	2.07	1.272	1.272	0.93	0.93	**2.89**
	NOx2030	2.07	1.5264	1.526	0.88	0.88	**3.73**
	PM2010	0.48	1.06	1.06	0.98	0.98	**0.52**
	PM2020	0.48	1.272	1.272	0.93	0.93	**0.67**
	PM2030	0.48	1.5264	1.526	0.88	0.88	**0.86**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for Taxies and Auto Rickshaws …2

	Emission	Mfvcc	Mf1	Mf2	Mf3	Mf4	Pollution TPD
CONTROL ACTION PLAN- 3	CO 2010	6.33	1.06	1.03	0.98	0.98	**6.63**
	CO2020	6.33	1.272	1.13	0.9	0.93	**7.61**
	CO2030	6.33	1.5264	1.37	0.82	0.88	**9.55**
	HC2010	4.07	1.06	1.03	0.98	0.98	**4.26**
	HC2020	4.07	1.272	1.13	0.9	0.93	**4.89**
	HC2030	4.07	1.5264	1.37	0.82	0.88	**6.13**
	NOx2010	2.07	1.06	1.03	0.98	0.98	**2.17**
	NOx2020	2.07	1.272	1.13	0.9	0.93	**2.49**
	NOx2030	2.07	1.5264	1.37	0.82	0.88	**3.12**
	PM2010	0.48	1.06	1.03	0.98	0.98	**0.50**
	PM2020	0.48	1.272	1.13	0.9	0.93	**0.58**
	PM2030	0.48	1.5264	1.37	0.82	0.88	**0.72**
CONTROL ACTION PLAN- 4	CO 2010	6.33	1.06	1.03	0.98	0.98	**6.63**
	CO2020	6.33	1.272	1.13	0.9	0.9	**7.36**
	CO2030	6.33	1.5264	1.37	0.82	0.82	**8.89**
	HC2010	4.07	1.06	1.03	0.98	0.98	**4.26**
	HC2020	4.07	1.272	1.13	0.9	0.9	**4.73**
	HC2030	4.07	1.5264	1.37	0.82	0.82	**5.72**
	NOx2010	2.07	1.06	1.03	0.98	0.98	**2.17**
	NOx2020	2.07	1.272	1.13	0.9	0.9	**2.41**
	NOx2030	2.07	1.5264	1.37	0.82	0.82	**2.91**
	PM2010	0.48	1.06	1.03	0.98	0.98	**0.50**
	PM2020	0.48	1.272	1.13	0.9	0.9	**0.56**
	PM2030	0.48	1.5264	1.37	0.82	0.82	**0.67**
CONTROL ACTION PLAN-5	CO 2010	6.33	1.06	1.03	0.98	0.98	**6.63**
	CO2020	6.33	1.272	1.13	0.93	0.9	**7.61**
	CO2030	6.33	1.5264	1.37	0.88	0.82	**9.55**
	HC2010	4.07	1.06	1.03	0.98	0.98	**4.26**
	HC2020	4.07	1.272	1.13	0.93	0.9	**4.89**
	HC2030	4.07	1.5264	1.37	0.88	0.82	**6.13**
	NOx2010	2.07	1.06	1.03	0.98	0.98	**2.17**
	NOx2020	2.07	1.272	1.13	0.93	0.9	**2.49**
	NOx2030	2.07	1.5264	1.37	0.88	0.82	**3.12**
	PM2010	0.48	1.06	1.03	0.98	0.98	**0.50**
	PM2020	0.48	1.272	1.13	0.93	0.9	**0.58**
	PM2030	0.48	1.5264	1.37	0.88	0.82	**0.72**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for Taxies and Auto Rickshaws …3

	Emission	Mfvcc	Mf1	Mf2	Mf3	Mf4	Pollution TPD
CONTROL ACTION PLAN- 6	CO 2010	6.33	1.06	1.06	0.98	0.98	**6.83**
	CO2020	6.33	1.272	1.272	0.93	0.9	**8.57**
	CO2030	6.33	1.5264	1.526	0.88	0.82	**10.63**
	HC2010	4.07	1.06	1.06	0.98	0.98	**4.39**
	HC2020	4.07	1.272	1.272	0.93	0.9	**5.51**
	HC2030	4.07	1.5264	1.526	0.88	0.82	**6.83**
	NOx2010	2.07	1.06	1.06	0.98	0.98	**2.23**
	NOx2020	2.07	1.272	1.272	0.93	0.9	**2.80**
	NOx2030	2.07	1.5264	1.526	0.88	0.82	**3.48**
	PM2010	0.48	1.06	1.06	0.98	0.98	**0.52**
	PM2020	0.48	1.272	1.272	0.93	0.9	**0.65**
	PM2030	0.48	1.5264	1.526	0.88	0.82	**0.81**
CONTROL ACTION PLAN- 7	CO 2010	6.33	1.06	1.03	0.98	0.98	**6.63**
	CO2020	6.33	1.272	1.13	0.93	0.9	**7.61**
	CO2030	6.33	1.5264	1.37	0.88	0.82	**9.55**
	HC2010	4.07	1.06	1.03	0.98	0.98	**4.26**
	HC2020	4.07	1.272	1.13	0.93	0.9	**4.89**
	HC2030	4.07	1.5264	1.37	0.88	0.82	**6.13**
	NOx2010	2.07	1.06	1.03	0.98	0.98	**2.17**
	NOx2020	2.07	1.272	1.13	0.93	0.9	**2.49**
	NOx2030	2.07	1.5264	1.37	0.88	0.82	**3.12**
	PM2010	0.48	1.06	1.03	0.98	0.98	**0.50**
	PM2020	0.48	1.272	1.13	0.93	0.9	**0.58**
	PM2030	0.48	1.5264	1.37	0.88	0.82	**0.72**
CONTROL ACTION PLAN- 8	CO 2010	6.33	1.06	1.03	0.98	0.98	**6.63**
	CO2020	6.33	1.272	1.13	0.93	0.9	**7.61**
	CO2030	6.33	1.5264	1.37	0.88	0.82	**9.55**
	HC2010	4.07	1.06	1.03	0.98	0.98	**4.26**
	HC2020	4.07	1.272	1.13	0.93	0.9	**4.89**
	HC2030	4.07	1.5264	1.37	0.88	0.82	**6.13**
	NOx2010	2.07	1.06	1.03	0.98	0.98	**2.17**
	NOx2020	2.07	1.272	1.13	0.93	0.9	**2.49**
	NOx2030	2.07	1.5264	1.37	0.88	0.82	**3.12**
	PM2010	0.48	1.06	1.03	0.98	0.98	**0.50**
	PM2020	0.48	1.272	1.13	0.93	0.9	**0.58**
	PM2030	0.48	1.5264	1.37	0.88	0.82	**0.72**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for 2Wheeler…1

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	Pollution (TPD)
BUSINESS AS USUAL	CO 2010	202.923	1.16	_	_	_	**235.39**
	CO2020	202.923	2.05	_	_	_	**416.72**
	CO2030	202.923	3.65	_	_	_	**740.87**
	HC2010	136.203	1.16	_	_	_	**158.00**
	HC2020	136.203	2.05	_	_	_	**279.71**
	HC2030	136.203	3.65	_	_	_	**497.28**
	NOx2010	8.72343	1.16	_	_	_	**10.12**
	NOx2020	8.72343	2.05	_	_	_	**17.91**
	NOx2030	8.72343	3.65	_	_	_	**31.85**
	PM2010	6.28814	1.16	_	_	_	**7.29**
	PM2020	6.28814	2.05	_	_	_	**12.91**
	PM2030	6.28814	3.65	_	_	_	**22.96**
CONTROL ACTION PLAN-I	CO 2010	202.923	1.16	0.9	0.95	0.98	**197.23**
	CO2020	202.923	2.05	0.8	0.85	0.91	**257.87**
	CO2030	202.923	3.65	0.7	0.75	0.85	**330.61**
	HC2010	136.203	1.16	0.9	0.95	0.98	**132.38**
	HC2020	136.203	2.05	0.8	0.85	0.91	**173.08**
	HC2030	136.203	3.65	0.7	0.75	0.85	**221.91**
	NOx2010	8.72343	1.16	0.9	0.95	0.98	**8.48**
	NOx2020	8.72343	2.05	0.8	0.85	0.91	**11.09**
	NOx2030	8.72343	3.65	0.7	0.75	0.85	**14.21**
	PM2010	6.28814	1.16	0.9	0.95	0.98	**6.11**
	PM2020	6.28814	2.05	0.8	0.85	0.91	**7.99**
	PM2030	6.28814	3.65	0.7	0.75	0.85	**10.25**
CONTROL ACTION PLAN-2	CO 2010	202.923	1.16	0.8	0.95	0.98	**175.32**
	CO2020	202.923	2.05	0.7	0.85	0.91	**225.63**
	CO2030	202.923	3.65	0.6	0.75	0.85	**283.38**
	HC2010	136.203	1.16	0.8	0.95	0.98	**117.68**
	HC2020	136.203	2.05	0.7	0.85	0.91	**151.45**
	HC2030	136.203	3.65	0.6	0.75	0.85	**190.21**
	NOx2010	8.72343	1.16	0.8	0.95	0.98	**7.54**
	NOx2020	8.72343	2.05	0.7	0.85	0.91	**9.70**
	NOx2030	8.72343	3.65	0.6	0.75	0.85	**12.18**
	PM2010	6.28814	1.16	0.8	0.95	0.98	**5.43**
	PM2020	6.28814	2.05	0.7	0.85	0.91	**6.99**
	PM2030	6.28814	3.65	0.6	0.75	0.85	**8.78**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for 2Wheeler…2

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	Pollution
CONTROL ACTION PLAN-3	CO2010	202.923	1.16	0.9	0.90	0.98	**186.85**
	CO2020	202.923	2.05	0.8	0.8	0.91	**242.70**
	CO2030	202.923	3.65	0.7	0.7	0.85	**308.57**
	HC2010	136.203	1.16	0.9	0.9	0.98	**125.42**
	HC2020	136.203	2.05	0.8	0.8	0.91	**162.90**
	HC2030	136.203	3.65	0.7	0.7	0.85	**207.12**
	NOx2010	8.72343	1.16	0.9	0.9	0.98	**8.03**
	NOx2020	8.72343	2.05	0.8	0.8	0.91	**10.43**
	NOx2030	8.72343	3.65	0.7	0.7	0.85	**13.27**
	PM2010	6.28814	1.16	0.9	0.9	0.98	**5.79**
	PM2020	6.28814	2.05	0.8	0.8	0.91	**7.52**
	PM2030	6.28814	3.65	0.7	0.7	0.85	**9.56**
CONTROL ACTION PLAN--4	CO 2010	202.923	1.16	0.9	0.9	0.95	**181.13**
	CO2020	202.923	2.05	0.8	0.8	0.85	**226.70**
	CO2030	202.923	3.65	0.7	0.7	0.75	**272.27**
	HC2010	136.203	1.16	0.9	0.9	0.95	**121.58**
	HC2020	136.203	2.05	0.8	0.8	0.85	**152.16**
	HC2030	136.203	3.65	0.7	0.7	0.75	**182.75**
	NOx2010	8.72343	1.16	0.9	0.9	0.95	**7.79**
	NOx2020	8.72343	2.05	0.8	0.8	0.85	**9.75**
	NOx2030	8.72343	3.65	0.7	0.7	0.75	**11.70**
	PM2010	6.28814	1.16	0.9	0.9	0.95	**5.61**
	PM2020	6.28814	2.05	0.8	0.8	0.85	**7.02**
CONTROL ACTION PLAN-5	PM2030	6.28814	3.65	0.7	0.7	0.75	**8.44**
	CO 2010	202.923	1.16	0.9	0.95	0.95	**191.20**
	CO2020	202.923	2.05	0.8	0.85	0.85	**240.87**
	CO2030	202.923	3.65	0.7	0.75	0.75	**291.72**
	HC2010	136.203	1.16	0.9	0.95	0.95	**128.33**
	HC2020	136.203	2.05	0.8	0.85	0.85	**161.67**
	HC2030	136.203	3.65	0.7	0.75	0.75	**195.80**
	NOx2010	8.72343	1.16	0.9	0.95	0.95	**8.22**
	NOx2020	8.72343	2.05	0.8	0.85	0.85	**10.35**
	NOx2030	8.72343	3.65	0.7	0.75	0.75	**12.54**
	PM2010	6.28814	1.16	0.9	0.95	0.95	**5.92**
	PM2020	6.28814	2.05	0.8	0.85	0.85	**7.46**
	PM2030	6.28814	3.65	0.7	0.75	0.75	**9.04**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for 2Wheeler…3

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	Pollution
CONTROL ACTION PLAN-6	CO2010	202.923	1.16	0.8	0.90	0.98	**169.95**
	CO2020	202.923	2.05	0.7	0.85	0.85	**210.76**
	CO2030	202.923	3.65	0.6	0.75	0.75	**250.04**
	HC2010	136.203	1.16	0.8	0.95	0.95	**114.07**
	HC2020	136.203	2.05	0.7	0.85	0.85	**141.46**
	HC2030	136.203	3.65	0.6	0.75	0.75	**167.83**
	NOx2010	8.72343	1.16	0.8	0.95	0.95	**7.31**
	NOx2020	8.72343	2.05	0.7	0.85	0.85	**9.06**
	NOx2030	8.72343	3.65	0.6	0.75	0.75	**10.75**
	PM2010	6.28814	1.16	0.8	0.95	0.95	**5.27**
	PM2020	6.28814	2.05	0.7	0.85	0.85	**6.53**
	PM2030	6.28814	3.65	0.6	0.75	0.75	**7.75**
CONTROL ACTION PLAN-7	CO 2010	202.923	1.16	0.8	0.9	0.98	**166.09**
	CO2020	202.923	2.05	0.7	0.8	0.91	**212.36**
	CO2030	202.923	3.65	0.6	0.7	0.85	**264.49**
	HC2010	136.203	1.16	0.8	0.9	0.98	**111.48**
	HC2020	136.203	2.05	0.7	0.8	0.91	**142.54**
	HC2030	136.203	3.65	0.6	0.7	0.85	**177.53**
	NOx2010	8.72343	1.16	0.8	0.9	0.98	**7.14**
	NOx2020	8.72343	2.05	0.7	0.8	0.91	**9.13**
	NOx2030	8.72343	3.65	0.6	0.7	0.85	**11.37**
	PM2010	6.28814	1.16	0.8	0.9	0.98	**5.15**
	PM2020	6.28814	2.05	0.7	0.8	0.91	**6.58**
	PM2030	6.28814	3.65	0.6	0.7	0.85	**8.20**
CONTROL ACTION PLAN-8	CO 2010	202.923	1.16	0.8	0.9	0.95	**161.01**
	CO2020	202.923	2.05	0.7	0.8	0.85	**198.36**
	CO2030	202.923	3.65	0.6	0.7	0.75	**233.38**
	HC2010	136.203	1.16	0.8	0.9	0.95	**108.07**
	HC2020	136.203	2.05	0.7	0.8	0.85	**133.14**
	HC2030	136.203	3.65	0.6	0.7	0.75	**156.64**
	NOx2010	8.72343	1.16	0.8	0.9	0.95	**6.92**
	NOx2020	8.72343	2.05	0.7	0.8	0.85	**8.53**
	NOx2030	8.72343	3.65	0.6	0.7	0.75	**10.03**
	PM2010	6.28814	1.16	0.8	0.9	0.95	**4.99**
	PM2020	6.28814	2.05	0.7	0.8	0.85	**6.15**
	PM2030	6.28814	3.65	0.6	0.7	0.75	**7.23**

CALCULATION OF FUTURE EMISSIONS

	Estimation of Projected Emissions for Buses…1						
	Emission	**Mfvcc**	**Mf_1**	**Mf2**	**Mf3**	**Mf4**	**Pollution (TPD)**
Business as usual	CO 2010	1.18	1.12	1			**1.32**
	CO2020	1.18	1.57	1			**1.85**
	CO2030	1.18	1.20	1			**1.41**
	HC2010	0.29	1.12	1			**0.33**
	HC2020	0.29	1.57	1			**0.46**
	HC2030	0.29	1.20	1			**0.35**
	NOx2010	4.11	1.12	1			**4.60**
	NOx2020	4.11	1.57	1			**6.44**
	NOx2030	4.11	1.20	1			**4.91**
	PM2010	0.16	1.12	1			**0.18**
	PM2020	0.16	1.57	1			**0.25**
	PM2030	0.16	1.20	1			**0.19**
Control Action Plan 1	CO 2010	1.18	1.12	1.03	0.98	0.98	**1.31**
	CO2020	1.18	1.57	1.13	0.93	0.93	**1.81**
	CO2030	1.18	1.20	1.243	0.88	0.88	**1.36**
	HC2010	0.29	1.12	1.03	0.98	0.98	**0.32**
	HC2020	0.29	1.57	1.13	0.93	0.93	**0.45**
	HC2030	0.29	1.20	1.243	0.88	0.88	**0.34**
	NOx2010	4.11	1.12	1.03	0.98	0.98	**4.55**
	NOx2020	4.11	1.57	1.13	0.93	0.93	**6.29**
	NOx2030	4.11	1.20	1.243	0.88	0.88	**4.72**
	PM2010	0.16	1.12	1.03	0.98	0.98	**0.18**
	PM2020	0.16	1.57	1.13	0.93	0.93	**0.25**
	PM2030	0.16	1.20	1.243	0.88	0.88	**0.18**
Control Action Plan 2	CO 2010	1.18	1.12	1.06	0.98	0.98	**1.34**
	CO2020	1.18	1.57	1.272	0.93	0.93	**2.03**
	CO2030	1.18	1.20	1.526	0.88	0.88	**1.66**
	HC2010	0.29	1.12	1.06	0.98	0.98	**0.33**
	HC2020	0.29	1.57	1.272	0.93	0.93	**0.51**
	HC2030	0.29	1.20	1.526	0.88	0.88	**0.41**
	NOx2010	4.11	1.12	1.06	0.98	0.98	**4.68**
	NOx2020	4.11	1.57	1.272	0.93	0.93	**7.08**
	NOx2030	4.11	1.20	1.526	0.88	0.88	**5.80**
	PM2010	0.16	1.12	1.06	0.98	0.98	**0.18**
	PM2020	0.16	1.57	1.272	0.93	0.93	**0.28**
	PM2030	0.16	1.20	1.526	0.88	0.88	**0.23**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for Buses…2

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	Pollution(TPD)
Control Action Plan 3	CO 2010	1.18	1.12	1.03	0.98	0.98	**1.31**
	CO2020	1.18	1.57	1.13	0.9	0.93	**1.75**
	CO2030	1.18	1.20	1.37	0.82	0.88	**1.39**
	HC2010	0.29	1.12	1.03	0.98	0.98	**0.32**
	HC2020	0.29	1.57	1.13	0.9	0.93	**0.43**
	HC2030	0.29	1.20	1.37	0.82	0.88	**0.35**
	NOx2010	4.11	1.12	1.03	0.98	0.98	**4.55**
	NOx2020	4.11	1.57	1.13	0.9	0.93	**6.09**
	NOx2030	4.11	1.20	1.37	0.82	0.88	**4.85**
	PM2010	0.16	1.12	1.03	0.98	0.98	**0.18**
	PM2020	0.16	1.57	1.13	0.9	0.93	**0.24**
	PM2030	0.16	1.20	1.37	0.82	0.88	**0.19**
Control Action Plan 4	CO 2010	1.18	1.12	1.03	0.98	0.98	**1.31**
	CO2020	1.18	1.57	1.13	0.9	0.9	**1.69**
	CO2030	1.18	1.20	1.37	0.82	0.82	**1.30**
	HC2010	0.29	1.12	1.03	0.98	0.98	**0.32**
	HC2020	0.29	1.57	1.13	0.9	0.9	**0.42**
	HC2030	0.29	1.20	1.37	0.82	0.82	**0.32**
	NOx2010	4.11	1.12	1.03	0.98	0.98	**4.55**
	NOx2020	4.11	1.57	1.13	0.9	0.9	**5.89**
	NOx2030	4.11	1.20	1.37	0.82	0.82	**4.52**
	PM2010	0.16	1.12	1.03	0.98	0.98	**0.18**
	PM2020	0.16	1.57	1.13	0.9	0.9	**0.23**
	PM2030	0.16	1.20	1.37	0.82	0.82	**0.18**
Control Action Plan 5	CO 2010	1.18	1.12	1.03	0.98	0.98	**1.31**
	CO2020	1.18	1.57	1.13	0.93	0.9	**1.75**
	CO2030	1.18	1.20	1.37	0.88	0.82	**1.39**
	HC2010	0.29	1.12	1.03	0.98	0.98	**0.32**
	HC2020	0.29	1.57	1.13	0.93	0.9	**0.43**
	HC2030	0.29	1.20	1.37	0.88	0.82	**0.35**
	NOx2010	4.11	1.12	1.03	0.98	0.98	**4.55**
	NOx2020	4.11	1.57	1.13	0.93	0.9	**6.09**
	NOx2030	4.11	1.20	1.37	0.88	0.82	**4.85**
	PM2010	0.16	1.12	1.03	0.98	0.98	**0.18**
	PM2020	0.16	1.57	1.13	0.93	0.9	**0.24**
	PM2030	0.16	1.20	1.37	0.88	0.82	**0.19**

CALCULATION OF FUTURE EMISSIONS
Estimation of Projected Emissions for Buses…3

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	Pollution(TPD)
Control Action Plan 6	CO 2010	1.18	1.12	1.06	0.98	0.98	**1.34**
	CO2020	1.18	1.57	1.272	0.93	0.9	**1.97**
	CO2030	1.18	1.20	1.526	0.88	0.82	**1.55**
	HC2010	0.29	1.12	1.06	0.98	0.98	**0.33**
	HC2020	0.29	1.57	1.272	0.93	0.9	**0.49**
	HC2030	0.29	1.20	1.526	0.88	0.82	**0.39**
	NOx2010	4.11	1.12	1.06	0.98	0.98	**4.68**
	NOx2020	4.11	1.57	1.272	0.93	0.9	**6.85**
	NOx2030	4.11	1.20	1.526	0.88	0.82	**5.40**
	PM2010	0.16	1.12	1.06	0.98	0.98	**0.18**
	PM2020	0.16	1.57	1.272	0.93	0.9	**0.27**
	PM2030	0.16	1.20	1.526	0.88	0.82	**0.21**
Control Action Plan 7	CO 2010	1.18	1.12	1.03	0.98	0.98	**1.31**
	CO2020	1.18	1.57	1.13	0.93	0.9	**1.75**
	CO2030	1.18	1.20	1.37	0.88	0.82	**1.39**
	HC2010	0.29	1.12	1.03	0.98	0.98	**0.32**
	HC2020	0.29	1.57	1.13	0.93	0.9	**0.43**
	HC2030	0.29	1.20	1.37	0.88	0.82	**0.35**
	NOx2010	4.11	1.12	1.03	0.98	0.98	**4.55**
	NOx2020	4.11	1.57	1.13	0.93	0.9	**6.09**
	NOx2030	4.11	1.20	1.37	0.88	0.82	**4.85**
	PM2010	0.16	1.12	1.03	0.98	0.98	**0.18**
	PM2020	0.16	1.57	1.13	0.93	0.9	**0.24**
	PM2030	0.16	1.20	1.37	0.88	0.82	**0.19**
Control Action Plan 8	CO 2010	1.18	1.12	1.03	0.98	0.98	**1.31**
	CO2020	1.18	1.57	1.13	0.93	0.9	**1.75**
	CO2030	1.18	1.20	1.37	0.88	0.82	**1.39**
	HC2010	0.29	1.12	1.03	0.98	0.98	**0.32**
	HC2020	0.29	1.57	1.13	0.93	0.9	**0.43**
	HC2030	0.29	1.20	1.37	0.88	0.82	**0.35**
	NOx2010	4.11	1.12	1.03	0.98	0.98	**4.55**
	NOx2020	4.11	1.57	1.13	0.93	0.9	**6.09**
	NOx2030	4.11	1.20	1.37	0.88	0.82	**4.85**
	PM2010	0.16	1.12	1.03	0.98	0.98	**0.18**
	PM2020	0.16	1.57	1.13	0.93	0.9	**0.24**
	PM2030	0.16	1.20	1.37	0.88	0.82	**0.19**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for Car and Jeeps…1

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	Pollution
Business as usual	CO 2010	287.24	1.2592				**361.69**
	CO2020	287.24	2.851				**818.91**
	CO2030	287.24	6.389				**1835.15**
	HC2010	80.60	1.2592				**101.49**
	HC2020	80.60	2.851				**229.79**
	HC2030	80.60	6.389				**514.95**
	NOx2010	200.35	1.2592				**252.28**
	NOx2020	200.35	2.851				**571.19**
	NOx2030	200.35	6.389				**1280.02**
	PM2010	3.68	1.2592				**4.63**
	PM2020	3.68	2.851				**10.48**
	PM2030	3.68	6.389				**23.49**
CONTROL ACTION PLAN-I	CO 2010	287.24	1.2592	0.95	0.95	0.98	**319.89**
	CO2020	287.24	2.851	0.85	0.85	0.91	**538.41**
	CO2030	287.24	6.389	0.75	0.75	0.85	**877.43**
	HC2010	80.60	1.2592	0.95	0.95	0.98	**89.76**
	HC2020	80.60	2.851	0.85	0.85	0.91	**151.08**
	HC2030	80.60	6.389	0.75	0.75	0.85	**246.21**
	NOx2010	200.35	1.2592	0.95	0.95	0.98	**223.13**
	NOx2020	200.35	2.851	0.85	0.85	0.91	**375.54**
	NOx2030	200.35	6.389	0.75	0.75	0.85	**612.01**
	PM2010	3.68	1.2592	0.95	0.95	0.98	**4.09**
	PM2020	3.68	2.851	0.85	0.85	0.91	**6.89**
	PM2030	3.68	6.389	0.75	0.75	0.85	**11.23**
CONTROL ACTION PLAN-2	CO 2010	287.24	1.2592	0.95	0.95	0.98	**319.89**
	CO2020	287.24	2.851	0.85	0.85	0.91	**538.41**
	CO2030	287.24	6.389	0.75	0.75	0.85	**877.43**
	HC2010	80.60	1.2592	0.95	0.95	0.98	**89.76**
	HC2020	80.60	2.851	0.85	0.85	0.91	**151.08**
	HC2030	80.60	6.389	0.75	0.75	0.85	**246.21**
	NOx2010	200.35	1.2592	0.95	0.95	0.98	**223.13**
	NOx2020	200.35	2.851	0.85	0.85	0.91	**375.54**
	NOx2030	200.35	6.389	0.75	0.75	0.85	**612.01**
	PM2010	3.68	1.2592	0.95	0.95	0.98	**4.09**
	PM2020	3.68	2.851	0.85	0.85	0.91	**6.89**
	PM2030	3.68	6.389	0.75	0.75	0.85	**11.23**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for Car and Jeeps…2

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	Pollution (TPD)
CONTROL ACTION PLAN-3	CO2010	287.24	1.2592	0.90	0.90	0.98	**278.32**
	CO2020	287.24	2.851	0.85	0.8	0.91	**506.74**
	CO2030	287.24	6.389	0.75	0.7	0.85	**818.93**
	HC2010	80.60	1.2592	0.95	0.9	0.98	**85.04**
	HC2020	80.60	2.851	0.85	0.8	0.91	**142.19**
	HC2030	80.60	6.389	0.75	0.7	0.85	**229.80**
	NOx2010	200.35	1.2592	0.95	0.9	0.98	**211.38**
	NOx2020	200.35	2.851	0.85	0.8	0.91	**353.45**
	NOx2030	200.35	6.389	0.75	0.7	0.85	**571.21**
	PM2010	3.68	1.2592	0.95	0.9	0.98	**3.88**
	PM2020	3.68	2.851	0.85	0.8	0.91	**6.49**
	PM2030	3.68	6.389	0.75	0.7	0.85	**10.48**
CONTROL ACTION PLAN-4	CO 2010	287.24	1.2592	0.95	0.9	0.95	**293.78**
	CO2020	287.24	2.851	0.85	0.8	0.85	**473.33**
	CO2030	287.24	6.389	0.75	0.7	0.75	**722.59**
	HC2010	80.60	1.2592	0.95	0.9	0.95	**82.44**
	HC2020	80.60	2.851	0.85	0.8	0.85	**132.82**
	HC2030	80.60	6.389	0.75	0.7	0.75	**202.76**
	NOx2010	200.35	1.2592	0.95	0.9	0.95	**204.91**
	NOx2020	200.35	2.851	0.85	0.8	0.85	**330.15**
	NOx2030	200.35	6.389	0.75	0.7	0.75	**504.01**
	PM2010	3.68	1.2592	0.95	0.9	0.95	**3.76**
	PM2020	3.68	2.851	0.85	0.8	0.85	**6.06**
CONTROL ACTION PLAN-5	PM2030	3.68	6.389	0.75	0.7	0.75	**9.25**
	CO 2010	287.24	1.2592	0.9	0.95	0.95	**293.78**
	CO2020	287.24	2.851	0.8	0.85	0.85	**473.33**
	CO2030	287.24	6.389	0.7	0.75	0.75	**722.59**
	HC2010	80.60	1.2592	0.9	0.95	0.95	**82.44**
	HC2020	80.60	2.851	0.8	0.85	0.85	**132.82**
	HC2030	80.60	6.389	0.7	0.75	0.75	**202.76**
	NOx2010	200.35	1.2592	0.9	0.95	0.95	**204.91**
	NOx2020	200.35	2.851	0.8	0.85	0.85	**330.15**
	NOx2030	200.35	6.389	0.7	0.75	0.75	**504.01**
	PM2010	3.68	1.2592	0.9	0.95	0.95	**3.76**
	PM2020	3.68	2.851	0.8	0.85	0.85	**6.06**
	PM2030	3.68	6.389	0.7	0.75	0.75	**9.25**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for Car and Jeeps…3

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	Pollution TPD
CONTROL ACTION PLAN-6	CO2020	287.24	2.851	0.8	0.85	0.85	**473.33**
	CO2030	287.24	6.389	0.7	0.75	0.75	**722.59**
	HC2010	80.60	1.2592	0.9	0.95	0.95	**82.44**
	HC2020	80.60	2.851	0.8	0.85	0.85	**132.82**
	HC2030	80.60	6.389	0.7	0.75	0.75	**202.76**
	NOx2010	200.35	1.2592	0.9	0.95	0.95	**204.91**
	NOx2020	200.35	2.851	0.8	0.85	0.85	**330.15**
	NOx2030	200.35	6.389	0.7	0.75	0.75	**504.01**
	PM2010	3.68	1.2592	0.9	0.95	0.95	**3.76**
	PM2020	3.68	2.851	0.8	0.85	0.85	**6.06**
	PM2030	3.68	6.389	0.7	0.75	0.75	**9.25**
CONTROL ACTION PLAN-7	CO 2010	287.24	1.2592	0.9	0.9	0.98	**287.11**
	CO2020	287.24	2.851	0.8	0.8	0.91	**476.93**
	CO2030	287.24	6.389	0.7	0.7	0.85	**764.34**
	HC2010	80.60	1.2592	0.9	0.9	0.98	**80.56**
	HC2020	80.60	2.851	0.8	0.8	0.91	**133.83**
	HC2030	80.60	6.389	0.7	0.7	0.85	**214.48**
	NOx2010	200.35	1.2592	0.9	0.9	0.98	**200.26**
	NOx2020	200.35	2.851	0.8	0.8	0.91	**332.66**
	NOx2030	200.35	6.389	0.7	0.7	0.85	**533.13**
	PM2010	3.68	1.2592	0.9	0.9	0.98	**3.67**
	PM2020	3.68	2.851	0.8	0.8	0.91	**6.10**
	PM2030	3.68	6.389	0.7	0.7	0.85	**9.78**
CONTROL ACTION PLAN-8	CO 2010	287.24	1.2592	0.9	0.9	0.95	**278.32**
	CO2020	287.24	2.851	0.8	0.8	0.85	**445.49**
	CO2030	287.24	6.389	0.7	0.7	0.75	**674.42**
	HC2010	80.60	1.2592	0.9	0.9	0.95	**78.10**
	HC2020	80.60	2.851	0.8	0.8	0.85	**125.01**
	HC2030	80.60	6.389	0.7	0.7	0.75	**189.24**
	NOx2010	200.35	1.2592	0.9	0.9	0.95	**194.13**
	NOx2020	200.35	2.851	0.8	0.8	0.85	**310.73**
	NOx2030	200.35	6.389	0.7	0.7	0.75	**470.41**
	PM2010	3.68	1.2592	0.9	0.9	0.95	**3.56**
	PM2020	3.68	2.851	0.8	0.8	0.85	**5.70**
	PM2030	3.68	6.389	0.7	0.7	0.75	**8.63**

CALCULATION OF FUTURE EMISSIONS
Estimation of Projected Emissions for Goods vehicles…1

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	Pollution (TPD)
Business as Usual	CO 2010	19.65848	1.06	1	_	_	**20.84**
	CO2020	19.65848	1.27	1	_	_	**25.01**
	CO2030	19.65848	1.53	1	_	_	**30.00**
	HC2010	4.857071	1.06	1	_	_	**5.15**
	HC2020	4.857071	1.27	1	_	_	**6.18**
	HC2030	4.857071	1.53	1	_	_	**7.41**
	NOx2010	11.80703	1.06	1	_	_	**12.52**
	NOx2020	11.80703	1.27	1	_	_	**15.02**
	NOx2030	11.80703	1.53	1	_	_	**18.02**
	PM2010	3.308582	1.06	1	_	_	**3.51**
	PM2020	3.308582	1.27	1	_	_	**4.21**
	PM2030	3.308582	1.53	1	_	_	**_**
CONTROL ACTION PLAN-I	CO 2010	19.65848	1.06	1	0.98	0.98	**20.01**
	CO2020	19.65848	1.27	1	0.93	0.93	**21.63**
	CO2030	19.65848	1.53	1	0.88	0.88	**23.23**
	HC2010	4.857071	1.06	1	0.98	0.98	**4.94**
	HC2020	4.857071	1.27	1	0.93	0.93	**5.34**
	HC2030	4.857071	1.53	1	0.88	0.88	**5.74**
	NOx2010	11.80703	1.06	1	0.98	0.98	**12.02**
	NOx2020	11.80703	1.27	1	0.93	0.93	**12.99**
	NOx2030	11.80703	1.53	1	0.88	0.88	**13.95**
	PM2010	3.308582	1.06	1	0.98	0.98	**3.37**
	PM2020	3.308582	1.27	1	0.93	0.93	**3.64**
	PM2030	3.308582	1.53	1	0.88	0.88	**3.91**
CONTROL ACTION PLAN-2	CO 2010	19.658	1.06	1	0.98	0.98	**20.01**
	CO2020	19.658	1.27	1	0.93	0.93	**21.63**
	CO2030	19.658	1.53	1	0.88	0.88	**23.23**
	HC2010	4.8571	1.06	1	0.98	0.98	**4.94**
	HC2020	4.8571	1.27	1	0.93	0.93	**5.34**
	HC2030	4.8571	1.53	1	0.88	0.88	**5.74**
	NOx2010	11.807	1.06	1	0.98	0.98	**12.02**
	NOx2020	11.807	1.27	1	0.93	0.93	**12.99**
	NOx2030	11.807	1.53	1	0.88	0.88	**13.95**
	PM2010	3.3086	1.06	1	0.98	0.98	**3.37**
	PM2020	3.3086	1.27	1	0.93	0.93	**3.64**
	PM2030	3.3086	1.53	1	0.88	0.88	**3.91**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for Goods vehicles…2

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	**Pollution**
CONTROL ACTION PLAN-3	CO 2010	19.658	1.06	1	0.98	0.98	**20.01**
	CO2020	19.658	1.27	1	0.9	0.93	**20.93**
	CO2030	19.658	1.53	1	0.82	0.88	**21.65**
	HC2020	4.8571	1.27	1	0.9	0.93	**5.17**
	HC2030	4.8571	1.53	1	0.82	0.88	**5.35**
	NOx2010	11.807	1.06	1	0.98	0.98	**12.02**
	NOx2020	11.807	1.27	1	0.9	0.93	**12.57**
	NOx2030	11.807	1.53	1	0.82	0.88	**13.00**
	PM2010	3.3086	1.06	1	0.98	0.98	**3.37**
	PM2020	3.3086	1.27	1	0.9	0.93	**3.52**
	PM2030	3.3086	1.53	1	0.82	0.88	**3.64**
CONTROL ACTION PLAN-4	CO 2010	19.658	1.06	1	0.98	0.98	**20.01**
	CO2020	19.658	1.27	1	0.9	0.9	**20.25**
	CO2030	19.658	1.53	1	0.82	0.82	**20.17**
	HC2010	4.8571	1.06	1	0.98	0.98	**4.94**
	HC2020	4.8571	1.27	1	0.9	0.9	**5.00**
	HC2030	4.8571	1.53	1	0.82	0.82	**4.98**
	NOx2010	11.807	1.06	1	0.98	0.98	**12.02**
	NOx2020	11.807	1.27	1	0.9	0.9	**12.17**
	NOx2030	11.807	1.53	1	0.82	0.82	**12.11**
	PM2010	3.3086	1.06	1	0.98	0.98	**3.37**
	PM2020	3.3086	1.27	1	0.9	0.9	**3.41**
	PM2030	3.3086	1.53	1	0.82	0.82	**3.39**
CONTROL ACTION PLAN-5	CO 2010	19.658	1.06	1	0.98	0.98	**20.01**
	CO2020	19.658	1.27	1	0.93	0.9	**20.93**
	CO2030	19.658	1.53	1	0.88	0.82	**21.65**
	HC2010	4.8571	1.06	1	0.98	0.98	**4.94**
	HC2020	4.8571	1.27	1	0.93	0.9	**5.17**
	HC2030	4.8571	1.53	1	0.88	0.82	**5.35**
	NOx2010	11.807	1.06	1	0.98	0.98	**12.02**
	NOx2020	11.807	1.27	1	0.93	0.9	**12.57**
	NOx2030	11.807	1.53	1	0.88	0.82	**13.00**
	PM2010	3.3086	1.06	1	0.98	0.98	**3.37**
	PM2020	3.3086	1.27	1	0.93	0.9	**3.52**
	PM2030	3.3086	1.53	1	0.88	0.82	**3.64**

CALCULATION OF FUTURE EMISSIONS

Estimation of Projected Emissions for Goods vehicles…3

	Emission	Mfvcc	Mf_1	Mf2	Mf3	Mf4	**Pollution**
CONTROL ACTION PLAN-6	CO 2010	19.658	1.06	1	0.98	0.98	**20.01**
	CO2020	19.658	1.27	1	0.93	0.9	**20.93**
	CO2030	19.658	1.53	1	0.88	0.82	**21.65**
	HC2010	4.8571	1.06	1	0.98	0.98	**4.94**
	HC2020	4.8571	1.27	1	0.93	0.9	**5.17**
	HC2030	4.8571	1.53	1	0.88	0.82	**5.35**
	NOx2010	11.807	1.06	1	0.98	0.98	**12.02**
	NOx2020	11.807	1.27	1	0.93	0.9	**12.57**
	NOx2030	11.807	1.53	1	0.88	0.82	**13.00**
	PM2010	3.3086	1.06	1	0.98	0.98	**3.37**
	PM2020	3.3086	1.27	1	0.93	0.9	**3.52**
	PM2030	3.3086	1.53	1	0.88	0.82	**3.64**
CONTROL ACTION PLAN-7	CO 2010	19.658	1.06	1	0.98	0.98	**20.01**
	CO2020	19.658	1.27	1	0.9	0.93	**20.93**
	CO2030	19.658	1.53	1	0.82	0.88	**21.65**
	HC2010	4.8571	1.06	1	0.98	0.98	**4.94**
	HC2020	4.8571	1.27	1	0.9	0.93	**5.17**
	HC2030	4.8571	1.53	1	0.82	0.88	**5.35**
	NOx2010	11.807	1.06	1	0.98	0.98	**12.02**
	NOx2020	11.807	1.27	1	0.9	0.93	**12.57**
	NOx2030	11.807	1.53	1	0.82	0.88	**13.00**
	PM2010	3.3086	1.06	1	0.98	0.98	**3.37**
	PM2020	3.3086	1.27	1	0.9	0.93	**3.52**
	PM2030	3.3086	1.53	1	0.82	0.88	**3.64**
CONTROL ACTION PLAN-8	CO 2010	19.658	1.06	1	0.98	0.98	**20.01**
	CO2020	19.658	1.27	1	0.9	0.9	**20.25**
	CO2030	19.658	1.53	1	0.82	0.82	**20.17**
	HC2010	4.8571	1.06	1	0.98	0.98	**4.94**
	HC2020	4.8571	1.27	1	0.9	0.9	**5.00**
	HC2030	4.8571	1.53	1	0.82	0.82	**4.98**
	NOx2010	11.807	1.06	1	0.98	0.98	**12.02**
	NOx2020	11.807	1.27	1	0.9	0.9	**12.17**
	NOx2030	11.807	1.53	1	0.82	0.82	**12.11**
	PM2010	3.3086	1.06	1	0.98	0.98	**3.37**
	PM2020	3.3086	1.27	1	0.9	0.9	**3.41**
	PM2030	3.3086	1.53	1	0.82	0.82	**3.39**

OPTIMIZATION OF THE VEHICULAR EMISSIONS OF PUBLIC TRANSPORTATION SYSTEM OF A METRO CITY: SOME STRATEGIES

Synopsis of the Proposed Ph. D. Thesis, Submitted in Fulfillment of the Requirements
For the Award of the Degree of

DOCTOR OF PHILOSOPHY

By

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OPTIMIZATION OF THE VEHICULAR EMISSIONS OF PUBLIC TRANSPORTATION SYSTEM OF A METRO CITY: SOME STRATEGIES

Vehicular emissions in developed as well as developing countries are increasing very rapidly all over the world. Even most of the middle and lower middle class people are meeting their need for mobility through personal vehicles. Delhi figures prominently in the world environment map for its vehicular pollution. It is one of the most polluted cities in the world, which is caused by phenomenal vehicular growth primarily during the past two-three decades. Incidentally, few decades earlier Delhi was acclaimed as one of the greenest capital. In order to restore the air quality and refurbish its image, a number of plans have been prepared and implemented in Delhi during the past few years. Many factors like traffic congestion, type of available fuel quality, extent of overloading or over speeding and vehicle maintenance, have a definite impact on the environmental degradation.

The present research highlights the severity of the issues related to vehicular exhaust emissions and suggests the techniques for efficient planning and management of the Public Transportation System (PTS) for the city of Delhi. In this study, we propose a frame work of an optimization model for solving the vehicular emissions problem of the capital city of India. This study therefore, is an attempt to:

- ✓ Suggest a model to manage the complexities of the transport sector of Delhi.
- ✓ To examine the compatibility and potential of the alternative fuels and improvement in the fuel quality with a view to reduce the vehicular exhaust emissions.
- ✓ To incorporate feedback and expectations of the people in planning a Public Transportation System for the city of Delhi.
- ✓ To map what is the likely future scenario over a span of next couple of decades with different control action plans suggestive of mitigating the problem of pollution.
- ✓ To develop models to alter these future scenarios ensuring a clean and efficient transport system for Delhi.

In this work a comprehensive experimental work has been performed on different single cylinder, twin cylinder and four cylinders, Spark Ignition (S.I.) and Compression Ignition (C.I.) engines to assess the impact of several alternative fuels like Ethanol, Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG) and Bio-Diesel on the vehicular exhaust emissions and to ascertain the viability of these alternative fuels for the internal combustion engines that are being used currently.

The results of the exhaust emission testing of these alternative fuels were found to be highly encouraging and these have been used in proposing the *emission modification factors* for several alternative fuels, advanced engine types and fuel technologies in this study.

An estimate of the present vehicular exhaust emissions of the metro city of Delhi has been constituted and the future vehicle emission levels are projected, cater to various possibilities of the proposed control actions. Other than Business As Usual (BAU) scenario, eight different control scenarios have also been constructed for the years 2010, 2020 and 2030.The vehicular emissions are observed to rise very rapidly, e.g. for BAU scenario the vehicular emissions in Delhi may rise by approximately 15%, 150%, and 400% respectively for the years 2010, 2020 and 2030.

However by incorporating the proposed strategies it is anticipated that 20% to 70% emissions of the BAU scenario projections can be reduced, depending upon which proposed integrated approach is implemented and what is the amount of success achieved in its implementation? Further it is worth mentioning here that letting the BAU continue may be very much disastrous to the overall health of our people, and its overall impact may prove an expensive affair, considering the expenses incurred on health services.

Next section outlines a summary of the chapters detailing salient features and modules of the work.

CHAPTER 1: INTRODUCTION

The population of the world is increasing at an alarming rate of nearly three percent per year. India is the world's seventh largest country and in terms of population, it stands second only to China (Peterson, 1984). Delhi is one of the most populous metropolitan cities in the world, its population was listed at 13.8 million in 2006 (Kathuria, 2006). By the end of 2050 it is expected to touch a level of 1.9 times of what it is today, thus almost doubling this figure (Srinivasachary, 1997). As populations grow, numbers of vehicles too grow but the rate of this growth in the metropolitan cities is more than that of population growth due to a number of factors like: fast growth of economy; heavy migration of people from villages or small towns to metro cities; and rapid advancements in technologies.

This increase in vehicles, as well as the presence of other motorized forms of transportation (taxis, auto rickshaws, trains and buses); will further contribute to the already high levels of vehicular emissions. The principal elements of the vehicular emission are Sulfur Dioxide (SO_2), Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Ozone (O_3), Benzene, Carbon Di-oxide (CO_2), Particulate Matter (PM), Suspended Particulate Matter (SPM), and Hydrocarbons (HC) (Goyal, 2006).

An overview of this paradigm shift taking place globally, with emphasis on the Indian capital city of Delhi, is presented in this work. Although the statistical data for the vehicular pollution of Delhi is available, a comprehensive planning and optimization strategy to overcome the above problem is yet to be formulated for which an attempt has been made in this work.

CHAPTER 2: THE LITERATURE REVIEW

A comprehensive literature review was carried out to explore the level of activity in this area of investigations and to identify the regions unknown or little known to the experts and commoners in order to identify the issues related to, vehicular pollution for the capital city of Delhi, and its causes and to suggest remedial measures. For a systematic study the literature survey was briefly divided in following sub issues:

2.1 Studies on Transportation Systems

2.2 Studies on Vehicular emissions and Emission Norms

2.3 Studies on Quality of Fuels used

2.4 Studies on Alternative Fuels

2.5 Gaps in the Literature Review and Motivation for this Work

2.1 Studies on Transportation Systems

Many researchers have attempted to estimate or predict the future travel requirements. The estimated passenger travel demands for Delhi were given by Bose and Nesamani (2000) for the year 2000 as 94.4 billion passenger kilometers, while Mohan (2001) stressed the need for specifically reserved lines on the road for the bus transport in his proposed Bus Rapid Transit (BRT) corridor proposal. Bose and Sperling (2001) suggested restructuring land development patterns to reduce the demand for transport and accelerating the introduction of efficient and advanced vehicle technology. Kathuria (2006) stressed on an integrated approach, with combined use of transport policies like improved public transport, road pricing, improved parking facilities, advanced vehicle technologies etc.

In a comparative study by Das and Parikh (2004), reported that despite similar population and higher per capita Gross Domestic Profit (GDP) due to a higher share of public bus transport and efficient suburban railway system, the Mumbai transport system results in 60% less energy and emissions compared to Delhi. Socio-Economic implications of Delhi Metro were discussed by Singh and Kapilastain in 2002. In a survey work Sibal and Savant (2002) simulated 148 % increase in the ridership of the Delhi Metro, if the feeder buses are provided at every 0.5 km of walking distance.

2.2 Studies on Vehicular Emissions and Emission Norms

Probably, the first emission standards for different kind of Indian vehicles were proposed by Pundir(1994). The authors analyzed international driving cycles and accordingly, Bharat Standard Driving Cycle (BSDS) and Emission Standards were proposed for Exhaust, Evaporative and Crank Case Emissions. The Auto Fuel Policy (Mashelkar Committee Report, 2002) is one of the best document for the number of vehicles and their exhaust emissions for the Indian metro cities; it suggests that automobiles are major contributor to the overall air pollution problem in these cities.

As it is commonly perceived, a properly compiled emission inventory is the fundamental building block of any air quality management system in a country and two essential building blocks required for compiling emission inventory are the *emission factor*s and the activity data. In a project, the Automobile Research Association of India (ARAI) in 2007 experimentally developed *Emission Factor*s for all the vehicles categories based on their age, vintage, engine size (2005) and fuel used (2007). This data has been used in present study for the estimation of the present and future vehicular exhaust emissions.

2.3 Studies on Quality of Fuel

Use of poor quality fuel is a major contributor to vehicular exhaust emissions. First future Fuel Quality Specifications and roadmap for the improvement of Gasoline, Diesel and other fuels in India were laid out by Dr. Mukhopadhyay committee (2000). An expert committee of the Ministry of Petroleum and Natural Gas, Government of India, in the chairmanship of Dr. Mashelkar, (2002), on Auto Fuel Policy submitted its recommendations in the form of Auto Fuel Policy for the transportation system of the entire country and road map for its implementation. Various Fuel Quality Specifications and their requirement for the BS II and BS III are detailed in this section.

2.4 Studies on Alternative Fuels

An expert Committee under the chairmanship of Shri Bhure Lal (2001) recommended that the CNG be made a mandatory fuel for Public Transport (Mainly for the Buses) in Delhi from April 2001. This switchover was completed by the end of 2004 due to frequent and strong interventions of the Supreme Court of India. In an experimental work on a Ricardo, four stroke VCR engine with CNG (Maji, 2004) reported 30-80% reduction in CO emissions, 15-20% reduction in HC emissions and about 15% reduction in NO_x emissions. Centre for Science and Environment, (CSE, 2004) reported reduction in most of the pollutants in the Delhi's air, as a result of the use of CNG, but alerted over increase in particulate matter pollution below 10 micron.In another study (Narain and Bell, 2005) reported the advantages gained through CNG transportation System and also the difficulties encountered in doing so.

Recent research studies performed at West Virginia University (Kappanna, 2006) have showed that natural gas engines emit PM emissions an order of magnitude lower, on a mass basis, when compared to diesel engines without any exhaust after treatment devices. However, on a number basis the emissions from natural gas fuelled buses were of an order of magnitude higher than that of their Diesel counterparts.

Among other alternative fuels, Ethanol and Bio-Diesel are most viable in near future. The Ethanol and Bio-Diesel fuels tests were conducted on a Diesel engine by Snethil, (2003) and Bhattacharya and Mishra(2003) at high loads, the blends reduce smoke significantly with a small penalty on CO. Besides, Ethanol is a most commonly used additive to increase Gasoline's Octane Number (ON). Results show that by increasing the Ethanol content, the heating value of the blended fuel is decreased, while the ON of the blended fuel increases. At the same time, the effect of the above Ethanol–containing fuels on the exhaust emissions from an S. I. engine was also studied by many researchers, e.g., Brusstar (2002) and Hasan (2003). The engine test indicated that CO and Total Hydrocarbon (THC) emissions decrease dramatically as a result of the leaning effect caused by the addition of Ethanol, (Hakan, 2005).

The use of Bio-Diesel in conventional diesel engines results in substantial reduction of HC, CO and PM along with a slight increase in NO_x. Bio-Diesel is considered clean fuel since it has almost no sulfur, no aromatics and has about 10% built-in oxygen, which helps it to burn fully and improves the combustion quality. In an experiment on a kirloscar single cylinder Diesel Engine with 10% and 20% Palm oil Bio-Diesel, Naveen and Dhuwe (2004), reported significant reduction in smoke levels. Viscosity of the Bio-Diesel is quite higher than that of Petroleum Diesel. Some researchers worked to find the effect of viscosity on emissions and performance of Diesel Engine (Aggarwal and Das; 2001, Gangwar, 2008; and Choudhary and Bose, 2008). They found Jatropha oil to be a promising alternative fuel for compression ignition engines. It can be directly used as a replacement of diesel fuel and does not require any major modifications in the engine.

The hydrogen fuel cell was first developed in the 1800's; however, it is only recently that further developments have made it a viable source of power for transportation. Since the 1960, fuel cells started to be used as a power source during space flights; today, environmental, economic, and resource issues are driving the hydrogen fuel cell rapidly into the mainstream transport market. Das (2004) has investigated of a CNG-Fuelled S.I. Engine by Hydrogen Addition and reported significant reduction in CNG fuel consumption.

2.5 Gaps in the Literature Review and Motivation for this Work

On the basis of literature review, it is observed that there is an urgent need for comprehensive study on the public transportation system requirements in Delhi owing to the reasons given below:

- Very few literatures listing the opinion of general public and or that of the experts in this area of research has been found.
- It appears on literature review that no comprehensive study on a holistic analysis of different modes of the public transportation system in Delhi has ever been carried out.
- Limited substantial/meaningful data to access and predict the effects of the current transportation policies in practice has been found.
- Very few studies/reports/data inter-relating the use of alternate fuels and advanced engine technologies has been noticed.
- Very limited study appears to have been carried out suggesting rationalized and simultaneous use of various modes in public transportation system of Delhi
- Very little study appears to have been carried out future impact on the quality of air and other pollution in Delhi over the next 10 to 20 years time span.
- Any comprehensive data is not available on the efficacy of the Bio-fuels as an alternative and economically viable source of energy.

Being declared as the fourth most polluted city in the world, Delhi is urgently in need for a research study, covering these gaps. This study is also aimed at developing a frame work for optimization leading to economical use of fuels, least air pollution, and adequate avenues of mobility for the general public.

In brief this study is an attempt to:

i) To investigate the status of Delhi’s transportation system

(ii) To suggest a model to resolve the complexities of Delhi's transport sector

(iii) To explore what is the likely future scenario over a span of next 10 to 20 years

And

(iv)To Know-how to alter this future to ensure a clean and efficient transport system

for Delhi?

CHAPTER 3.THE RESEARCH METHODOLOGY

The research methodology can be described as overall schematic map of research, listing various paths to be traversed right from writing the hypothesis and its operational formulations, to the ultimate analysis of data. Though perceived as overview or outline, it indeed acts as a reference frame for the execution of the entire research plan. In present work after the detailed literature review, it was planned to carry out this work in three main sub parts.

In first part of the study, collection of the complete data on the public transportation system e.g. vehicle numbers, type, technology, engine capacities, vehicle usage emission factors were carried out. Simultaneously the design, development and experimental testing on the use of alternative fuels on various Internal Combustion Engines were carried out in the laboratory to obtain the emission data precisely.

In second part a Delphi Survey was commissioned to acquire the general public and selected expert's opinion on present public transportation system and their desires and necessities. The questionnaire for the survey was designed scientifically to obtain the feedback of the experts on various issues, which were subdivided in to two main categories.

Category 'A' was mainly containing questions related to the opinion of the experts on the present public transportation system. While Category 'B' were subdivided in five different sections containing questions related to the judgment of the experts on the level of experts awareness about the transportation system and alternative fuels and various suggested measures in the questionnaire to optimize the vehicle emissions.

Finally all the responses of the experts were analyzed with the MATLAB and various statistical parameters were computed for proper interpretation of the expert's responses.

CHAPTER 4: THE TRANSPORTATION SYSTEM OF DELHI

Just few years back, in the capital City of Delhi, the commuters were primarily dependent on a single transport system, i.e., road. With 33283 km of road length, Delhi has one of the highest road densities in India. This has led to an enormous increase in the number of vehicles with the associated problems of traffic-congestion and increase in air pollution. As a result, among various sources of air pollution, vehicular traffic is presently a major contributor (about 72%) in Delhi. Railways, including rapid transit systems like the Delhi Metro, fulfill only 1% of the total demand. In this chapter detailed analysis of the present modes of transport, their main problems and the requirements of the PTS are discussed.

CHAPTER 5: CASE STUDY OF EFFICACY OF CNG AS A FUEL IN THE TRANSPORTATION SYSTEM OF DELHI

In this chapter, implementation of CNG as a transport fuel in Delhi is discussed. This chapter discusses the administrative and practical difficulties in doing so and also the benefits gained in last four-five years and adverse affects of CNG conversion of the public Transportation system of Delhi. The CNG adaption process in Delhi has been a success. Delhi today has one of the world's largest public transport fleet of buses running on CNG. Although CNG adaption has helped a lot to reduce pollutant concentrations in Delhi, but the gains have been negated by- poor technology, increase in number of diesel cars and an overall increase in the number of all types of vehicles. Therefore, while implementing any such necessary changeovers; proper plan must be prepared, for the minimization of the chaos on roads and availability of alternative means of transport to the commuters of Delhi.

CHAPTER 6: THE EXPERIMENTAL STUDY ON C.I. ENGINES

The experimental set ups were designed and fabricated to evaluate the emission of C.I. Engines with several alternative fuels like Ethanol, CNG, and Bio-Diesel etc. The engines used for the study were Tata Indica and Kirloskar Twin Cylinder and single cylinder Direct Ignition (DI) Engine. SAJ eddy current dynamometer and Kirloskar alternator along with bulb load were used for loading these engines. AVL437 smoke meter and AVL Multi-gas analyser was used for the measurement of the vehicular exhaust emissions. The emission reduction results obtained are detailed in the report, which show reduction in smoke opacity mainly in the range of 15-75% and variation of NO_x emissions as compared to that of Petroleum Diesel.

CHAPTER 7: THE EXPERIMENTAL STUDY ON S.I. ENGINES

The experimental set ups were designed and fabricated to evaluate the emission from S.I. Engines with various alternative fuels like Ethanol, CNG and LPG. The engine used was a Multi Cylinder Maruti Wagon (R) equipped with and SAJ eddy current dynamometer used for loading this engine. Observations were also made for the different compression ratios on a single cylinder C.I. Engine. An AVL Multi gas analyzer was used for the measurement of the vehicular exhaust emissions. Various alternative fuels were tested and emission reduction results obtained are detailed in the report, which show that various emissions are reduced mainly in the range of 15-45%.

CHAPTER 8: THE DELPHI INVESTIGATIONS

A Delphi survey was also commissioned to obtain feedback and the suggestions of the experts, who have a technical background such as industrial, scientific, transport administration, engineering academicians and engineering students. The designed questionnaire (Sharma, 2000 and Pal, 2004), included a wide spectrum of different modes of transportation, beginning with bicycles and cycle rickshaws, encompassing all the prevalent modes being used of automobiles and extending up to electric, and solar powered vehicles. This also included advanced forms of hybrid vehicles and fuel cell vehicles, for planning an appropriate strategy to reduce the vehicular emissions in the capital city of Delhi.

The experts have been asked to rate the proposed strategies for the reduction of the vehicle emissions from the transportation system, of the city of Delhi on a scale of 0-10 and they were also asked to give their narrative suggestions if any. About 300 experts were approached, 138of them responded, spending on an average of 30-45 minutes of their rationed time. Many of the experts have given their constructive suggestions and remarks also.

CHAPTER 9: ANALYSIS AND SYNTHESIS OF THE DELPHI INVESTIGATIONS

The responses generated through the Delphi questionnaire was analysed using various statistical tools. In the first round of the Delphi study the responses of 36 out of 138 responses received were found to be out of acceptable range; they were again contacted and requested to participate in the second round, with a view to arrive at a consensus worthy of framing a feasible solution/policy framework.

It is worth mentioning that all the respondents have rated our suggested strategies higher than 6. Observations show most of the experts have given a very high rating i.e. above 8 to the strategies, which are directly related and proven worldwide like improvement of fuel quality, augmentation of the Delhi metro, using CNG as fuel, augmentation of the PTS, stricter emission norms etc. While most of the indirect and innovative strategies like removing encroachments on the roads, Hydrogen as vehicular fuel, ring rail, mono rail and raising the vehicle taxes etc. were rated considerably less.

In this chapter vehicular emission load of the capital city of Delhi is estimated based on the present vehicle population, its composition and the emissions factors specified by ARAI, then future emission load is estimated incorporating the proposed changes and their possible effect as per the modifying factors for the Vehicle growth, Fuel Quality and the vehicle technology advancement. Also, for different possibilities of the proposed strategies the future scenario for the year 2010, 2020 and 2030 emission estimates are predicted. At the same time a Business as usual scenario is also estimated. And a comparison of all of these together is presented. Some of the results are compared with the available reported/published data of earlier researchers.

CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS

At the end of this research work the strategies that have been contemplated include the following:

i. Improvement of public transport system (PTS), by making it cheaper, comfortable, reliable, efficient and available within walkable distances.

ii. Optimization of traffic flow, improvement in traffic management (e.g., area traffic control system, no-traffic zones, green corridors, removal of encroachment on roads, strict regulation for construction activities and digging of roads etc.)

iii. Comprehensive inspection and certification system for Inspection and Maintenance (I&M) of on-road vehicles; emission warranty by manufacturers/ authorized service providers, which should not be just for the first few years but for the whole legally usable life of the vehicle.

iv. Phasing out of grossly polluting units or mandatory technological up-gradation.

v. Fuel quality improvements (e.g., benzene and aromatics reduction in Petrol, reformulated Gasoline with oxygenates/additives, reduction of sulfur in Diesel etc.).

vi. Accelerate the research on environment friendly alternative fuels such as Ethanol. Bio-diesel, Hydrogen etc. and laying their quality standards and ensuring their availability in the market with satisfactory quality at affordable price and to provide necessary subsidy wherever necessary.

vii. Tightening of emission norms regularly with the advancement of the technology for newer vehicles.

viii. Improvement in vehicle technology. (e.g., restriction on the two-stroke engines, on-board diagnostic system, commencement of the Gasoline Direct Injection systems, Hybrid vehicles, Electric, Fuel cell etc.)

ix. Checking adulteration of fuel and training the NGO's/general public to do so and devising the advanced technologies to check adulteration automatically.

x. Checking evaporative emissions from storage tanks and fuel distribution system.

Various future projections are estimated as per the different levels of progress on these strategies and on the basis of our estimates it is seen that there will be about 30% reduction in vehicular emissions by the year 2020 and it may be almost 50% less as compared to Business As Usual Scenario by the year 2030.

Key References

1. Aggarwal, Kumar Avinash and Das, L.M. (2001). "Biodiesel Development and Characterization for use as a Fuel in C.I. Engine*", Journal of Engineering for Gas Turbines and Power, (ASME transaction Journal) Volume 123, number 2, p 440-447.*
2. *ARAI, 2007, The Air Quality Monitoring And Emission Source Apportionment Studies, revision-4, dated August 8, 2007, Draft report* on "*Emission Factor* Development for Indian Vehicles-Indian Clean Air Program (ICAP), revision 4, August ,2007
3. Bhattacharya T K and Mishra T N, "Studies on Feasibility of using Lower Proof Ethanol-Diesel Blends as Fuel for Compression Ignition Engines", *Institution of Engineers (I) Journal*–AG, Vol 84, p56-60, December 2003
4. Bhure Lal Committee report, 2001, the recommendations of the, *Environment Pollution (Prevention & Control) Authority* for the National Capital Region India.
5. Bose R. K., Sperling and Daniel (8-10 October 2001). "Implications of Transport Policies on Local Environment & GHG Scenarios in Delhi", *Workshop on Good Practices in Policies and Measures*, Copenhagen, http://repositories.cdlib.org/itsdavis/UCD-ITS-REP-01-13, Institute of Transportation Studies, University of California, Davis, USA.
6. Brusstar, M et al., 2002, "High Efficiency and Low Emissions from a Port-Injected Engine with Neat Alcohol Fuels", *Journal of the Institution of Engineers (India),* vol 63, 1983. P-199.
7. Choudhary S. and Bose P. K. (2008), "Jatropha derived biodiesel – its suitability as CI engine fuel", *SAE* paper no. 2008-28-0040.

8. *CPCB (2005):* "For a Breath of Fresh Air: Ten Years of Progress and Challenges in Urban Air Quality Management in India" (1993–2002), World Bank report , New Delhi.

9. Das, A. and J. Parikh, 2004,"Transport scenarios in two metropolitan cities in India: Delhi and Mumbai", *Energy Conversion and Management* 45 (2004) 2603–2625

10. Das L. M. et al., has investigated "Performance improvement of a CNG-Fuelled S.I. Engine by Hydrogen Addition" SAE 2004 India Mobility International Conference paper no 2004-28-0033.

11. *Economic Survey of Delhi,* 2007-08, pp 138-139 &. Department of Transport, Govt. of National Capital Territory of Delhi (GNCTD)

12. Gangwar, Harish Kumar and Aggarwal, Avinash Kumar, (2008). "Emission and Combustion Characteristics of Vegetable oil blends in an Indirect Ignition Transportation Engine", *SAE* Paper no. 2008-28-0034.

13. Goyal, S. K., et al. . "Understanding Urban Vehicular Pollution Problem Vis-a-Vis Ambient Air Quality - Case Study of a Megacity, Delhi, India." *Environmental Monitoring and Assessment* 119 (2005): 557-569. 12 Nov. 2006.

14. Hakan, Bayraktar (September, 2005). "Experimental and theoretical investigation of using gasoline-ethanol blends in spark-ignition engines.", *Renewable Energy*, *Volume 30, Issue 11,*

15. *Hasan M. Al- June (2003), "*Effect of Ethanol–Unleaded Gasoline Blends on Engine Performance and Exhaust Emission*", Energy Conversion and Management, Volume 44,* Issue 9, p 1547-1561.

16. Kappanna, Hemanth, K. (2006). "Reduction of Toxic Air Contaminants (TACs) and Particulate Matter Emissions from Heavy-Duty Natural Gas Engines" *a Master of Science in Mechanical Engineering thesis*, College of Engineering and Mineral Resources at West Virginia University.

17. Kathuria, Vinish, "Vehicular Pollution Control in Delhi." *Transport and Environment* 7 (2006): 373-387. 11 Nov. 2006.

18. *Auto fuel Policy (Report of the expert committee* headed by, Dr. R.A. Mashelkar, Director General, Council of Scientific & Industrial Research, and India August, 2002.

19. Maji S., *Sharma P. B. and M.K.G. Babu, 2004, "A comparative Study of Performance and Emission Characteristics of CNG and Gasoline on a single Cylinder S.I. Engine",* SAE 2004 India Mobility International Conference paper no 2004-28-0038.

20. Mohan D, et al., "Planning for Public Transport: Integrating Safety, Environment and Economic Issues" *Workshop on Transportation, Land Use, and the Environment*, I.I.T. Delhi, December 3-4, 2001

21. Mukhopadhyay P. K. et al., *"Transport Fuel Quality for Year 2005*", CPCB, Delhi, India, Dec. 2000.

22. Narain Urvashi and Bell Ruth Greenspan, December 2005, Discussion paper "Who Changed Delhi's Air? The Roles of the court and the Executive in Environmental Policymaking", *Resources for the future*. RFF DP 05-48

23. Naveen Kumar and Dhuve Abhey, "Fuelling an Agriculture Diesel Engine with derivative of Palm oil" SAE 2004 India Mobility International Conference paper no. 2004-28-0039.

24. Pal, Hansraj, (2004), *Educational Research*, '*Hindi Granth Academy' - Madhya Pradesh*, India.

25. Peterson, J. (1984), "Global Population Projection through the 21st Century", *AmbioVol. 13, No. 3, p 141.*

26. Pundir. B.P., et al., 1994, *Vehicular emissions and Control Perspective in India, Indian Institute of Petroleum*, Dehradun, India

27. Sharma O.P., 2000, "Management of Flexible Manufacturing Technology: a Study in Indian Context", *Ph.D. Thesis", University of Delhi*,

28. Srinivasachary (1997). "Policies to Reduce Energy Use and Environmental Emissions in the Transport Sector: a Case of Delhi City." *Energy Policy* 25 (1997): 1137-1150. 9 Nov. 2006

29. Sibal V. K. and Savant Sujata,(2002) "Simulating the Behavior of Potential Passengers of the proposed Integrated MRTS-Feeder Bus System for Delhi", *Proceedings of the National Conference* held at IIT Delhi,2002

30. Singh Indrasen and Kapilastain K.K(2002). a report on *"Transportation Systems Status and Directions*", IIT, Delhi,

31. Snethil M. K., Ramesh A. and Nagalinagam B. (2003). "An Experimental Comparison of Methods to Use Methanol and Jatropha Oil", *Biomass and Bioenergy*, volume -25, p 309-318.

List of the Publications in Journals /Seminars/Conferences related to the present Ph.D. research work **by Mr. Amit Pal** (DU Enrollment No.Ph.D.86/03)

1. **"Vehicular Emissions: Estimation, Future Prediction and Control Strategies for the Capital City of India",** by Amit Pal, S. Maji, O. P. Sharma & M. K. G. Babu. Published in the **International Journal of Applied Engineering Research(IJAER)** Print ISSN0973-04562 Online ISSN 1087-1090Volume 4 Number 7 (2009) pp. 1391–1411

2. **"A Case Study of Using CNG as A Transportation Fuel in Delhi"**, by Amit pal, S. Maji, and O. P. Sharma. Published in the **International Journal of Applied Environmental Sciences(IJAES)** Print ISSN0973-6077 Online ISSN 0974-0260

3. "**Biodiesel: *Production through Hydrodynamic Cavitation and Performance Testing",*** by Amit Pal, Asish Verma, S.S. Kachhawaha and S. Maji. published in the **Journal of *Renewal Energy(Elsevier)*** Manuscript Number: RENE-D-09-00342R1 doi:10.1016/j.renene.2009.08.027, Vol.3, issue 39, pp619-624,March 2010

4. **"Thumba (citrullus colocyntis) seed oil: A sustainable source of renewable energy for Biodiesel Production",** by Amit Pal, , S. S. Kachhawaha, S. Maji, & M. K. G. Babu, communicated to the **Journal *of Scientific and IndustrialResearch India*** for publication, presently this is under review.

5. **"Innovative Techiiques for the production of Biodiesel from Vegetable Oils", by Amit Pal,** Snehlata gautam, S.S. Kachhwaha and O.P.Sharma., published and presented at 2nd National Conference on Energy at Faculty of Engineering and Technology, Mody Institute of Technology and Science, Lakshmangarh, Sikar Rajasthan on October 31-November1, 2009.

6. **“An Experimental Investigation of Ethanol-Gasoline blends in a SI Engine”,** by Amit Pal, Sulabh Dhingra, R.S. Mishra, S. Maji, & M. K. G. Babu, This paper has been accepted for publication in the first international conference on Biofuels at Delhi Technological University, Delhi, scheduled to be held on Jan 18-19, 2010.

7. **“Recent Developments in Biodiesel: Part I – Biodiesel Production Technology**”, by Amit Pal, S. S. Kachhwaha, S. Maji, P. B. Sharma. This paper has been accepted for publication in first international conference on Biofuels at Delhi Technological University, Delhi, scheduled to be held on Jan 18-19, 2010.

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9. Advanced Techniques for Biodiesel Production and Engine Performance Testing”, by Amit Pal, S. S. Kachhwaha, S. Maji., presented and published at National Conference on Energy Management at Engineering College **Bikaner, Bikaner, Rajasthan** on November, 20-21,2009. pp 28-37

10. **“Performance and Emissions Analysis of Ethanol-Diesel Blends on A Variable Compression Ratio Diesel Engine”** Amit Pal, Prem Kumar, S. Maji, O.P. Sharma. Submitted to the International Journal of Power and Energy Systems for publication, presently this is under review.

11. **“Optimizations of Vehicular Emissions in Delhi", by** Amit Pal, S. Maji and O. P. Sharma, published in the proceedings of *Glogift-08, an International Conference*,(**Publication ISBN No.978-81-906294-1-6**) held at Stevens Institute of Technology, Hoboken, NJ, USA, pp. 889-897, June 14-16,2008.

12. **“Advantages and Limitations of CNG as Transportation Fuel in Delhi”** by Amit Pal, J. D. Sharma, S. Maji, and O. P. Sharma, presented at ***SIAM “TECHNIX-08” GLOBAL Automotive Conference*** held at IHC Delhi, April 28-30, 2008.

13. **“Impact of CNG on Delhi’s vehicular Pollution”** presented by Amit Pal, S. Maji and O. P. Sharma, *National Seminar on ‘The Status of Vehicular Pollution in Delhi after the Court’s Directions– An Assessment’,* organized at Delhi College of Engineering, Delhi, Feb.25,2008.

14. **“Using CNG in Diesel Engines in Duel Fuel Mode”,** by Amit Pal, B. B. Arora and S. Maji, (**Publication ISBN No.0760-1441-7**) published and presented at ***SAE International Automotive Conference*** held at Delhi, India,. pp500-504, January 09-11, 2008

15. **“Incorporating Fuel Flexibility in C. I. Engines: an Innovative Approach To Improve The Economy And Environment”** by Amit Pal, S. Maji, O.P. Sharma and M. K. G. Babu published in the proceedings of the Glogift-06’, *An International Conference”* **(Publication ISBN No.81-903397-6-1)** *on Management of Innovation, Technology Transfer & Flexibility* at Asian Institute of technology , Bangkok, Thailand, December 20-22,2006.

16. **"Designing A Flexible Policy for the Reduction of Vehicular Emissions of the Capital City of Delhi",** by Amit Pal, S. Maji, O.P. Sharma and M. K. G. Babu Presented in the third ***Global Conference on Flexible Systems Management. Organized*** *by Global Institute of Flexible Systems Management* at Jamia Millia Isalamia, Delhi, India, March 13-15, 2004.

17. **"Vehicular Emission Control Strategies for the Capital City of Delhi",** by Amit Pal, S. Maji, O.P. Sharma and M. K. G. Babu, this paper has been presented and published in the third ***International Conference on Automotive and Fuel Technology.*** Organized by the Society of Automotive Engineers at India Habitat Centre, Delhi, India, pp341-35, January 16-19, 2004.

18. **"Multi Point Fuel Injection: An Effective Tool for Curbing Vehicular Pollution"**, by Amit Pal, Vinod Singoria and O.P. Sharma presented and published in the proceedings of ***National Conference on Recent Trends in Mechanical Engineering*** held at the Thapar Institute of Engineering and Technology, Patiala, pp206-213, October 30-31,2003.

19. **"Reduction in Vehicular Pollution after Implementation of the Euro II Norms" by** Amit Pal and O.P. Sharma, presented and published in the proceedings of ***National Conference on Innovative Approaches in the Management of Environment,*** held at Delhi College of Engineering, Delhi, October 17-18, 2003.

APPENDIX VII

CURRICULUM VITAE OF THE AUTHOR

Mr. Amit Pal was born at Indore (M.P.) in 1968. After his matriculation in 1985, he did his Diploma in Mechanical Engineering (First Division) from Government Polytechnic Kahndwa (M.P.) in the year 1988. After getting some industrial experience, he did his graduation in Mechanical Engineering (First Division- Honours) from Government Engineering College, Vikram University, Ujjain, M. P. and obtained his Post Graduate Degree (First Division) in Automobile Engineering from V.J.T.I., University of Mumbai in 1998. He completed his ME project on Design and Development of a Energy Absorbing Collapsible Steering Column at Mahindra and Mahindra Research and Development Centre, Nasik (Maharashtra). Subsequently he joined Directorate of Technical Education and Training, Delhi in the same year. Presently he is engaged in teaching and research work at Delhi Technological University (Formerly Delhi College of Engineering) from 2001. Other then teaching and research work he has been worked as Training and Placement Officer of the Institute and he is also the faculty advisor of the Society of Automotive Engineers Student Chapter of the institute and Guiding the Students Solaris-Solar Car- Project. He has published/presented more than 20 research papers in many National and International Journals/Conferences and Seminars. His research interest includes Biodiesel Production and Performance testing, CNG and Hydrogen, Public Transport Systems, Advances in I.C. Engines etc.

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1. **"Vehicular Emissions: Estimation, Future Prediction and Control Strategies for the Capital City of India",** by Amit Pal, S. Maji, O. P. Sharma & M. K. G. Babu. Published in the **International Journal of Applied Engineering Research(IJAER)** Print ISSN0973-04562 Online ISSN 1087-1090Volume 4 Number 7 (2009) pp. 1391–1411

2. **"A Case Study of Using CNG as A Transportation Fuel in Delhi"**, by Amit pal, S. Maji, and O. P. Sharma. Published in the **International Journal of Applied Environmental Sciences(IJAES)** Print ISSN0973-6077 Online ISSN 0974-0260

3. "**Biodiesel: Production through Hydrodynamic Cavitation and Performance Testing",** by Amit Pal, Asish Verma, S.S. Kachhawaha and S. Maji. published in the **Journal of** ***Renewal Energy(Elsevier)*** Manuscript Number: RENE-D-09-00342R1 doi:10.1016/j.renene.2009.08.027, Vol.3, issue 39, pp619-624,March 2010

4. **"Thumba (citrullus colocyntis) seed oil: A sustainable source of renewable energy for Biodiesel Production",** by Amit Pal, , S. S. Kachhawaha, S. Maji, & M. K. G. Babu, communicated to the **Journal *of Scientific and IndustrialResearch India*** for publication, presently this is under review.

5. **"Innovative Techiiques for the production of Biodiesel from Vegetable Oils", by Amit Pal,** Snehlata gautam, S.S. Kachhwaha and O.P.Sharma., published and presented at 2nd National Conference on Energy at Faculty of Engineering and Technology, Mody Institute of Technology and Science, Lakshmangarh, Sikar Rajasthan on October 31-November1, 2009.

6. **"An Experimental Investigation of Ethanol-Gasoline blends in a SI Engine",** by Amit Pal, Sulabh Dhingra, R.S. Mishra, S. Maji, & M. K. G. Babu, This paper has been accepted for publication in the first international conference on Biofuels at Delhi Technological University, Delhi, scheduled to be held on Jan 18-19, 2010.

7. **"Recent Developments in Biodiesel: Part I – Biodiesel Production Technology**", by Amit Pal, S. S. Kachhwaha, S. Maji, P. B. Sharma. This paper has been accepted for publication in first international conference on Biofuels at Delhi Technological University, Delhi, scheduled to be held on Jan 18-19, 2010.

8. **"Recent Developments in Biodiesel: Part II – Biodiesel Engine Performance and Emissions Studies"**, by Amit Pal, S. S. Kachhwaha, S. Maji, P. B. Sharma. This paper has been accepted for publication in first international conference on Biofuels at Delhi Technological University, Delhi, scheduled to be held on Jan 18-19, 2010.

9. **Advanced Techniques for Biodiesel Production and Engine Performance Testing",** by Amit Pal, S. S. Kachhwaha, S. Maji., presented and published at National Conference on Energy Management at Engineering College **Bikaner, Bikaner, Rajasthan** on November, 20-21,2009. pp 28-37

10. **"Performance and Emissions Analysis of Ethanol-Diesel Blends on A Variable Compression Ratio Diesel Engine"** Amit Pal, Prem Kumar, S. Maji, O.P. Sharma. Submitted to the International Journal of Power and Energy Systems for publication, presently this is under review.

11. **"Optimizations of Vehicular Emissions in Delhi", by** Amit Pal, S. Maji and O. P. Sharma, published in the proceedings of *Glogift-08, an International Conference*,(**Publication ISBN No.978-81-906294-1-6**) held at Stevens Institute of Technology, Hoboken, NJ, USA, pp. 889-897, June 14-16,2008.

12. **"Advantages and Limitations of CNG as Transportation Fuel in Delhi"** by Amit Pal, J. D. Sharma, S. Maji, and O. P. Sharma, presented at ***SIAM "TECHNIX-08" GLOBAL Automotive Conference*** held at IHC Delhi, April 28-30, 2008.

13. **"Impact of CNG on Delhi's vehicular Pollution"** presented by Amit Pal, S. Maji and O. P. Sharma, *National Seminar on 'The Status of Vehicular Pollution in Delhi after the Court's Directions– An Assessment',* organized at Delhi College of Engineering, Delhi, Feb.25,2008.

14. **"Using CNG in Diesel Engines in Duel Fuel Mode",** by Amit Pal, B. B. Arora and S. Maji, (**Publication ISBN No.0760-1441-7**) published and presented at ***SAE International Automotive Conference*** held at Delhi, India,. pp500-504, January 09-11, 2008

15. **"Incorporating Fuel Flexibility in C. I. Engines: an Innovative Approach To Improve The Economy And Environment"** by Amit Pal, S. Maji, O.P. Sharma and M. K. G. Babu published in the proceedings of the Glogift-06', *An International Conference"* **(Publication ISBN No.81-903397-6-1)** *on Management of Innovation, Technology Transfer & Flexibility* at Asian Institute of technology , Bangkok, Thailand, December 20-22,2006.

16. **"Designing A Flexible Policy for the Reduction of Vehicular Emissions of the Capital City of Delhi",** by Amit Pal, S. Maji, O.P. Sharma and M. K. G. Babu Presented in the third ***Global Conference on Flexible Systems Management. Organized*** *by Global Institute of Flexible Systems Management* at Jamia Millia Isalamia, Delhi, India, March 13-15, 2004.

17. **"Vehicular Emission Control Strategies for the Capital City of Delhi",** by Amit Pal, S. Maji, O.P. Sharma and M. K. G. Babu, this paper has been presented and published in the third ***International Conference on Automotive and Fuel Technology.*** Organized by the Society of Automotive Engineers at India Habitat Centre, Delhi, India, pp341-35, January 16-19, 2004.

18. **"Multi Point Fuel Injection: An Effective Tool for Curbing Vehicular Pollution"**, by Amit Pal, Vinod Singoria and O.P. Sharma presented and published in the proceedings of ***National Conference on Recent Trends in Mechanical Engineering*** held at the Thapar Institute of Engineering and Technology, Patiala, pp206-213, October 30-31,2003.

19. **"Reduction in Vehicular Pollution after Implementation of the Euro II Norms" by** Amit Pal and O.P. Sharma, presented and published in the proceedings of ***National Conference on Innovative Approaches in the Management of Environment,*** held at Delhi College of Engineering, Delhi, October 17-18, 2003.

OPTIMIZATION OF THE VEHICULAR EMISSIONS OF PUBLIC TRANSPORTATION SYSTEM OF A METRO CITY: SOME STRATEGIES

A Ph.D. Thesis

by

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CHAPTER 10.

CONCLUSIONS AND RECOMMENDATIONS

10.1 INTRODUCTION

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In this chapter the outcome of the present research is presented. All the aspects associated with the vehicle exhaust emissions from the transportation system of the metropolitan city of Delhi have been looked into. At the end of this research work the strategies that have been contemplated include the following:

i. Improvement of public transport system (PTS), by making it cheaper, comfortable, reliable, efficient and available within walkable distances.

ii. Optimization of traffic flow, improvement in traffic management (e.g., area traffic control system, no-traffic zones, green corridors, removal of encroachment on roads, strict regulation for construction activities and digging of roads etc.)

iii. Comprehensive inspection and certification system for Inspection and Maintenance (I&M) of on-road vehicles; emission warranty by manufacturers/ authorized service providers, which should not be just for the first few years but for the whole legally usable life of the vehicle.

iv. Phasing out of grossly polluting units or mandatory technological up-gradation.

v. Fuel quality improvements (e.g., benzene and aromatics reduction in Petrol, reformulated Gasoline with oxygenates/additives, reduction of sulfur in Diesel etc.).

vi. Accelerate the research on environment friendly alternative fuels such as Ethanol. Bio-diesel, Hydrogen etc. and laying their quality standards and ensuring their availability in the market with satisfactory quality at affordable price and to provide necessary subsidy wherever necessary.

vii. Tightening of emission norms regularly with the advancement of the technology for newer vehicles.

viii. Improvement in vehicle technology. (e.g., restriction on the two-stroke engines, on-board diagnostic system, commencement of the Gasoline Direct Injection systems, Hybrid vehicles, Electric, Fuel cell etc.)

ix. Checking adulteration of fuel and training the NGO's/general public to do so and devising the advanced technologies to check adulteration automatically.

x. Checking evaporative emissions from storage tanks and fuel distribution system.

Various future projections are estimated as per the different levels of progress on these strategies and on the basis of our estimates it is seen that there will be about 30% reduction in vehicular emissions by the year 2020 and it may be almost 50% less as compared to Business As Usual Scenario by the year 2030. The conclusion arrived out of the present research work is the need of an integrated action plan, which requires a significant contribution from all the stake holders of the city transportation system.

10.2 STAKE HOLDERS OF THE TRANSPORTATION SYSTEM

The transportation system of Delhi is dependent on the Central Government of India for any major infrastructure development. While Government of Delhi collects the revenue in the form of vehicle registration fee, fuel sale tax etc., and controls the matters of city transport system. Municipal Corporation of Delhi (MCD) looks after the construction and maintenance of a large number of roads. MCD is also responsible for providing the proper parking facilities and removing the encroachment from the roads. Responsibility for construction, planning and maintenance of the major roads and flyovers lies with CPWD and Delhi state PWD. Fuel Quality and vehicle exhaust emission legislation are framed by the central government of India in consultation with the CPCB, SIAM, ARAI, PETROFED etc.

General public has also taken its stand as and when government failed to react in safeguarding the health concern of the common people. People have approached to the supreme court of India, and it has been proven that the courts are not the mute spectators of the system but they may also intervene in the public matter at crucial times. But every time the judiciary cannot be expected to intervene in such matters.

So, there is no dearth of the stake holders for the Delhi city transport system, still, there is a need for the central co-coordinating agency, which may keep a strict vigil on regular basis on the responsibility and the action of all the stake holders. At the same time, there is a need for independent regulator headed by eminent and expert citizens like Shri M. C. Mehta who can take the responsibility and are actively vigilant to check the functioning of various government agencies.

10. 3 RECOMMENDATIONS FOR THE STAKE HOLDERS

The recommendations suggested for the various stake holders for mitigation of the vehicle exhaust emission from the transportation system of Delhi, are:

10.3.1 Recommendations for the Central Government and CPCB

* To promote research on environment friendly alternative fuels.
* To promote research and development of projects on mass transportation projects like City Metro, Sub Urban Local Trains and Monorail etc.
* To promote research on Fuel Cells, Hydrogen and Hythane as I C engine Fuel, and Development of Solar/Electric vehicles.
* To enact the legislation for stringent emission norms, engine technology and fuel quality standards.
* To help the state governments in preparing good quality roads, flyovers and other infrastructures.
* Active role to be played by Pollution Control Boards (PCBs) for addressing issues of in-use vehicle management.
* PCBs must lead the discussions on future emission norms in the country.

10.3.2 Recommendations for the Automobile Manufacturers

* To adopt/incorporate latest engine/vehicle technologies.
* To improve passenger comfort on public transport vehicles to make them more attractive than private vehicles, as per passenger emissions are quite small in public transport system.
* To offer regular inspection and maintenance facilities after sales for the entire usable life of the vehicles at rates competitive to other market service providers.
* To provide emission warranties for the entire usable life of the vehicles.

10.3.3 Recommendations for the Oil Companies

* To upgrade the available fuel quality as per international standards.
* To keep a regular check on adulteration of the fuel and fuel products.
* To promote research on environment friendly alternative fuels.
* To support development of fuel testing laboratories at academic institutes etc.
* To organize programmers to spread awareness on the quality of fuels.

10.3.4 Recommendations for the State Government

* To control the growth of the private vehicles by well thought taxation policy/ improving the public transport facilities etc. (Detailed action for these are given in chapter 8).
* Offer subsidies to bio-fuels manufacturers.
* Ensure sufficient number of buses plying under one control to strengthen the PTS.
* To formulate policies to minimize the official travel of the working employees by devising the policies to post them in the offices, near to their residences.

10.3.5 Recommendations for the MCD/DDA/PWD

* To remove the illegal encroachments from the roads on a regular basis.
* To develop enough parking facilities required for the vehicles.

∗ To maintain roads in good working condition.

∗ To ensure the proper working of the traffic signals and make plans to upgrade them.

10.3.6 Recommendations for the Transport Dept.

∗ To organize frequent I &M camps.

∗ To monitor pollution under control (PUC) checking process.

∗ To penalize overloading and highly polluting vehicles instantly.

∗ To regularize driver training/ licensing and promote the role of driver training institutes.

∗ To devise policies for the modernization of government/ public transport vehicle fleet.

∗ To improve overall traffic management.

∗ Prepare flexible time planning of the public transportation system and maintain availability as per the varying demand of the passengers.

10.4 LIMITATIONS OF THE PRESENT STUDY AND SCOPE FOR THE FUTURE WORK

Due to the limited resources and various constraints present study could not investigate many important factors affecting the vehicular pollution level of the city. Thus there exists a need for further extensive studies on the subject, such as:

1. Delhi Metro has been helpful in curtailing the vehicle emissions by indirectly reducing the usage of private vehicles and other motorized public transport vehicles which are contributing significantly lower emissions but definitely not reducing to zero level as in the case of Delhi Metro. A realistic study to find the actual reduction in number of usage of private vehicles and other motorized public transport vehicles on account of switch over to Delhi Metro service is required.

2. Bharat Stage Emission norms for the automobile exhaust pollutants partially express requirements for the purpose of the control of pollutants, particularly in Indian conditions. These norms are inadequate since no consideration has been

given to the engine characteristics, expressed either in terms of the engine swept volume or the power that it generates. These aspects need to be investigated to accommodate the wide varieties of the transport engines and varying transport densities.

3. PUC certification administration in India is highly inefficient, inadequate and unreliable, so an alternative system of original equipment manufacturers (OEM) certified inspection and maintenance has to be investigated by conducting live studies.

4. Present data used for the study is gathered from various government departments which may be different from the actual number of vehicles running on the roads. So, the live projects investigating the actual number of vehicle running on the roads at different times and their actual exhaust conditions, need to be studied.

5. Due to the limited resources and various other constraints, present study could not investigate the effect of alternative fuels on transport vehicles. Still there exists a need of case studies on the use of alternative fuels for longer periods and investigate the other effects on engine and the vehicle. These studies require substantially large infrastructure and hence can only be carried out by the organizations with a sizable man power and sufficient financial resources.

6. In this work only the registered vehicle in Delhi have been considered. But the actual number of vehicles running on Delhi roads may be different. Because a number of vehicles do not come every day on the roads, there is an inflow of traffic in city boundaries and outflow of traffic outside. Therefore, a realistic analysis of the actual number of vehicles plying on Delhi roads can be taken up.