PERFORMANCE AND EMISSION ANALYSIS OFA MULTI CYLINDER C.I. ENGINE FUELED WITH DIESEL-CNG DUAL FUEL

A MAJOR DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

MASTER OF ENGINEERING
IN
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This is certified that the work contained in this dissertation entitled **“PERFORMANCE AND EMISSION ANALYSIS OF A MULTI CYLINDER C.I. ENGINE FUELED WITH DIESEL-CNG DUAL FUEL”** by RAJESH KUMAR is the requirement for the partial fulfillment for the award of degree of Master of Engineering in Thermal Engineering at Delhi College of Engineering. This work was completed under our direct supervision and guidance. He has completed his work with utmost sincerity and diligence.

The work embodied in this major project has not been submitted for the award of any other degree to the best of our knowledge.

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this project report entitled "**PERFORMANCE AND EMISSION ANALYSIS OF A MULTICYLINDER C.I. ENGINE FUELED WITH DIESEL-CNG DUAL FUEL**" submitted as major project towards the fulfillment of the requirements for the award of the degree of Master of Engineering with specialization in Thermal Engineering, D.C.E. Delhi, is an authentic record of my own work carried out under the supervision of **Mr. Amit Pal, Sr. Lecturer,** Mechanical Engineering Department, Delhi College of Engineering, Delhi.

The matter embodied in this dissertation report has not been submitted by me for the award of any other degree.

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ABSTRACT

The smoke is the main problem in the diesel engines. One of the main reasons of increased level of air pollution is transportation vehicles. Diesel engine produces harmful gases like carbon monoxides, nitrogen oxides, unburnt hydrocarbon, smoke, soot and particulate matter which are harmful to the environment and human kind. The environmental pollution can be controlled by utilization of alternative fuels such as Biodiesel and CNG (Compressed Natural Gas). In this project the performance testing of Biodiesel and diesel-CNG dual fuel is done on CI engine and the results were compared with performance of pure diesel. The project work was carried out on a 44.5 kW four-stroke, four-cylinder, Tata Indica diesel engine which was converted into dual fuel mode by substituting the CNG in the intake of suction pipe with the help of air mixer. Engine was operated in dual-fuel mode with substitution of diesel with CNG. The performance and emission characteristic of the engine were compared with pure diesel, different blends of Biodiesel (B10, B20 and B30) and diesel-CNG dual fuel. Knock levels were also analysed in both (pure diesel and diesel-CNG dual fuel) cases by recording the sound produced by the engine in both cases. These multimedia sounds are then converted to graphical form by using MATLAB software.

It was observed that the use of diesel-CNG dual fuel reduced the noise level at higher speed. The result shows higher torque in dual fuel mode. The specific fuel consumption is also reduced. In emissions the diesel-CNG dual fuel reduced the NOx emissions and smoke opacity but there was slight increase in carbon monoxide emissions and unburned hydrocarbons which can be controlled by using emission control techniques and after exhaust treatments.

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1.1 General

It is well known that fossil fuel reserves all over the world are diminishing at an alarming rate and a shortage of crude oil is expected in near future. The country's 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 like coal, petroleum based products and natural gas. Past and projected increased demand is shown in Table 1.1

Table 1.1: Primary Energy Consumption million tonnes of oil equivalent (Mtoe)

country	oil	Natural gas	coal	Nuclear energy	Hydro electric energy	Total
USA	914.3	566.8	573.9	181.9	60.9	2297.8
Canada	96.4	78.7	31	16.8	68.6	291.4
France	94.2	39.4	12.4	99.8	14.8	260.6
Russian Federation	124.7	365.2	111.3	34	35.6	670.8
United Kingdom	76.8	85.7	39.1	20.1	1.3	223.2
China	275.2	29.5	799.7	9.8	64	1178.3
India	113.3	27.1	185.3	4.1	15.6	345.3
Japan	248.7	68.9	112.2	52.2	22.8	504.8
Malaysia	23.9	25.6	3.2	-	1.7	54.4
Pakistan	17	19	2.7	0.4	5.6	44.8
Singapore	34.1	4.8				38.9
TOTAL WORLD	3636.6	2331.9	2578.4	598.8	595.4	9741.1

Source: Planning commission report 2003

Domestic production of crude oil can only fulfill 25-30 percent of national consumption rest we are importing from other countries. In these circumstances bio fuels are going to play an important role in meeting India's growing 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. Energy consumption in India is shown in the table1.2.

Table 1.2: Demand of energy for the consumption in India

Source	Units	1994-95	2001-02	2006-07	2011-12
Electricity	Billion units	289.36	480.08	712.67	1067.88
Coal	Million tonnes	76.67	109.01	134.99	173.47
Natural gas	Million cubic meters	9880	15730	18291	20853
Oil products	Million tonnes	63.55	99.89	139.95	196.47

Source: Planning commission report 2003

Gasoline and diesel will become scarce and most costly. Alternative fuel; technology, availability and use will become more common in the coming decades. Researchers are engaged in finding the substitute of fossil fuel replaced with alternative fuels.

The great problems of the world in the internal combustion engines usage until today are focuses on environment protection and most optimum consumption of available fuels. Presently in IC engines mainly gasoline and diesel engines are used to generate the power for industries and transportations [1]. The alternative fuels can be used in place of gasoline and diesel to make friendly environment, high power and efficient in fuel consumption, but presently this needs a lot of research work for the usage, storage and supply systems of alternative fuels.

Natural gas is one of the proven alternative fuel which is found in various locations in oil and gas bearing sand strata located at various depths below the earth surface. The natural gas is usually under considerable pressure and flows out naturally from the oil well. Natural gas is the most favorite for fossil fuel substitution. It has been recognized as one of the promising alternative fuel due to its substantial benefits compared to gasoline and diesel. The advantages include lower fuel cost, higher octane number and cleaner exhaust gas emissions. Therefore, the numbers of vehicle powered by compressed natural gas engine are growing rapidly.

1.2 Air Quality Trend in Delhi

In India pollution has become a great topic of debate at all levels and especially the air pollution because of the enhanced anthropogenic activities such as burning fossil fuels. The harmful emissions leaved in the atmosphere are Carbon Dioxide (CO_2), Carbon Monoxide (CO), Nitrogen Oxides (NO_X), Sulphur Dioxide (SO_2) and unburned hydrocarbons.

Delhi is one of the 10 most polluted cities of the world and the third most populated city in India with 13.8 million inhabitants spread over 1483 km [2]. The population density has increased in last 10 years from 6352 per km^2 in 1991 to nearly 9500 per km^2 in 2000. Its length of 51.9 km and width of 48.5 km gives it a circular structure. The transportation network in Delhi is predominantly road based with 1284 km of road per 100 km^2. Its urban area has quadrupled from 182 km in 1970 to more than 750 km^2 in 1999 with the number of industries from 26,000 in 1971 to 137,000 in 1997 [3]. The steep increase in vehicular population has resulted in corresponding increase in pollutants emitted by these vehicles. Presently, more than 1300 tonnes of pollutants are emitted by the vehicles plying in Delhi.

1.2.1 Growth Trend of Motor Vehicles

The vehicle population in India is growing at an exponential rate and is fast approaching the 50 million mark. Delhi faces the same transportation, economic and environmental challenges of other megacities. Population, motor vehicles, pollution, and traffic congestion are all increasing. In the past 30 years, its population more than tripled and vehicles increased almost fifteen fold. By 2000, Delhi had about 2.6 million motor vehicles - 200 for every 1,000 inhabitants, a rate far higher than most cities with similar incomes. Most of these vehicles are small, inexpensive motorcycles and scooters, rather than automobiles. This proliferation of vehicles in a relatively poor city is indicative of the strong desire for personal transport – a phenomenon observed virtually everywhere. Delhi is an emerging example of how this desire can now be met with relatively low incomes. Delhi is expected to continue growing at a rapid rate into the foreseeable future. Its population is expected to surpass 22 million by 2020, and motor vehicles, including cars, trucks, and motorized two- and three-wheelers, are expected to grow at an even faster rate. The domestic auto industry is predicting car sale increase of ten percent per year. With an extensive network of roads and increasing income, there is every reason to expect vehicle sales and use to continue on a sharp upward trajectory. That is why emission standards & fuel quality specifications are being tightened progressively and significant improvements in vehicle emissions have been achieved. The auto-fuel policy in India has prepared the road map for emission norms in the coming years.

The entire vehicle fleet, motorized and non-motorized is growing rapidly. From 1975 to 1998, the car population increased from about 68,000 to almost 800,000, and the motorized two wheelers from about 100,000 to almost 2 million. With continued income growth, the motor vehicle population is expected to continue expanding at a high rate (see Table 1.3). The number of bicycles and cycle rickshaws is also very large and increasing, though the number is unknown since many owners do not comply with the requirement for annual registration. It is estimated by the authors that as many as 300,000 cycle rickshaws currently travel on Delhi roads.

Table 1.3: Motor vehicles in use in Delhi, 1990-2020 (thousands)

Year	Scooters and motorcycles	Cars/ jeeps	Auto rickshaws	Taxis	Buses	Freight	All motor Vehicles
1971	93	57	10	4	3	14	180

1980	334	117	20	6	8	36	521
1990	1077	327	45	5	11	82	1547
2000	1568	852	45	8	18	94	2584
2010	2958	1472	103	14	39	223	4809
2020	6849	2760	209	28	73	420	10336

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

Buses form the backbone of the transport system in Delhi. As a generalization, buses are the most economically and environmentally efficient means of providing transport services to most people. In Delhi, buses constitute less than one percent of the vehicle fleet, but serve about half of all travel demand. Since 1992, Delhi has turned increasingly to the private sector to help expand and improve bus service. 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. Bus service was expanded in 1996 by adding more buses, with buses per route increasing from 0.8 to 1.7. The regular fixed-route bus system now comprises about 4,000 privately operated buses and 3,760 publicly operated buses. It is complemented by 5,000 private charter buses that provide point-to-point service during peak hours to subscribers who pay a monthly fee for a guaranteed seat.

Despite these expanded transit services, at both the lower and upper end of the market, overall transit use continues to lose market share. Buses accounted for 57 percent of total passenger kilometers in 1990, dropping to about 49 percent in 2000 (see Table1.4). This drop is largely due to increased use of motorized personal vehicles in upper income households, mostly two-wheelers but also cars and the expanding population of very poor immigrants who cannot afford to ride the bus.

Table 1.4: Historical and forecasted travel demand in Delhi, 1990-2020, billion passenger kilometers (Motorized Travel Only)

Year	Two Wheelers	Cars & jeeps	Auto rickshaws	Taxis	Buses	Rail Transit	Total
1990	8.0 (17)	8.6 (18)	3.4 (7)	0.3 (<1)	27.2 (57)	0.0 (-)	47.5 (100)
2000	14.8 (16)	29.0 (31)	3.5 (4)	0.4 (<1)	46.8 (49)	0.0 (-)	94.4 (100)
2010	33.8 (15)	61.6 (28)	7.6 (3)	0.6 (<1)	105.0 (48)	10.4 (5)	219.1 (100)
2020	102.6 (20)	153.3 (30)	15.8 (3)	1.3 (<1)	220.0 (44)	10.4 (2)	503.4 (100)

Source: Bose and Nesamani, 2000 [4]

1.3 Emissions from Diesel Vehicles

Since diesel engines breathe only air, blow by gases from the crankcase (consisting primarily of air and HC) is rather low. Due to its low volatility, evaporative emissions from the fuel tank can also be ignored. However, the low concentration of CO and unburnt HC in the diesel exhaust are compensated for by high concentration of NOx. There are smoke particles and oxygenated HC, including aldehydes and odour-producing compounds which have high nuisance value.

Smoke from diesel engines comes in three different hues-white smoke emitted during cold start idling and at low loads; blue smoke from the burning of lubricating oil and additives; and black smoke, a result of incomplete combustion. Black smoke consists of irregular shaped agglomerated fine soot/particulates, the formation of which depends on injector nozzle parameter and type of combustion chamber (direct or indirect injection). It is a particular problem with engines that are not well tuned.

Impact of fuel quality on emissions Pollution control depends heavily on the quality of the fuel. In diesel vehicles a higher density causes higher smoke, CO and NOx emissions, while a heightening of the cetane number lowers the smoke emission. The sulphur content of diesel has been observed to have a direct bearing on the PM and SO_2 emissions [4].

Vehicular Emissions typically constitute a number of gases in which CO is major constituent, accounting for almost more than 75% of exhaust gases. Other exhaust constituents are NO_x, VOCs, CO_2, and Particulates etc. For the ideal combustion of a hydrocarbon fuel there are only carbon dioxide and water vapor in the exhaust. However, in a real application the exhaust gas contains a number of other less desirable 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.

The fig. 1.1 shows the increase in number of vehicle per year which is one of the major causes of increase in emissions from these vehicles. Some of these emissions are discussed in more detail:

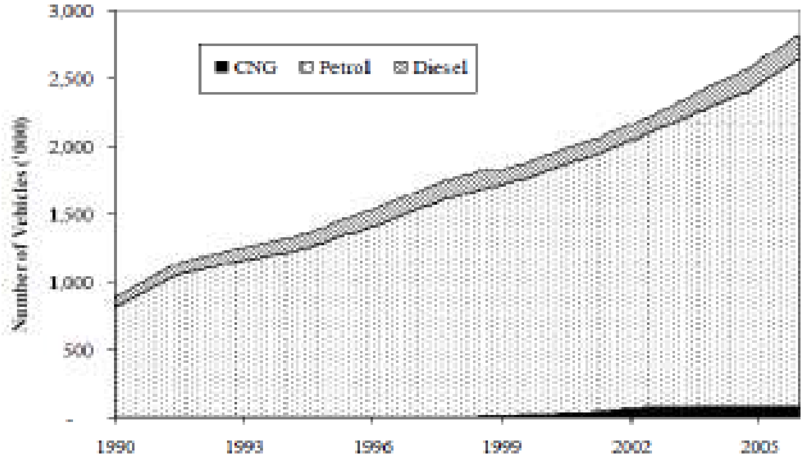


Figure 1.1: Number of Vehicles on the Road and the Number of Kilometers Traveled in Delhi (1990-2005)

1.3.1 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.

Formation of NOx

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 NO_X depends enormously on the temperature as the rate of dissociation of nitrogen is directly proportional to the temperature increase [5]. Therefore, the higher the combustion reaction temperature, the more NO_X will be produced. The chemical reactions of nitrogen and oxygen are as follows (Zeldovich Mechanism):

$$N + O_2 = NO+O$$

$$O+N_2 = NO+N$$

$$OH+N = NO+H$$

Concentration of NOx

The concentration of NO_X found in the emission of engines is dependent on the combustion temperature, the length of combustion time and the concentration of the nitrogen and oxygen in the engine. The measurement unit of NO_X is generally in parts per million (PPM) due to the dilution of NOx percentage with the excess air level in the flue gases. NO_X value tends to peak at an air-fuel ratio of approximately 1.1 times stoichiometric with the condition of excess oxygen present.

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 vapor 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 the 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 react chemically with other atmospheric gaseous compounds such as "volatile organic compounds" (VOCs) under the sunlight, it will form 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.

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.

Next, ozone depletion is also related to the excessive emission of NO_x. Nitrogen oxides formed will allow more penetration of harmful ultraviolet solar radiation to the earth and lead to skin irritation for humans.

The reaction mechanisms are listed below:-

$$NO + O_3 = NO_2 + O_2$$

$$NO_2+O= NO+O_2$$

Ozone (O_3) is destroyed in the first reaction to form nitrogen dioxide (NO_x), and then the nitric oxide (NO) is regenerated in the second reaction to repeat the ozone depletion step. These processes will continue and will stop only when the whole ozone layer is consumed. [6]

1.3.2 Unburned 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 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. [7]

Formation of HC Emissions

HC emissions rise rapidly as the mixture becomes substantially richer than stoichiometric. When combustion quality deteriorates, e.g., with very lean mixtures HC emissions can rise rapidly due to incomplete combustion or misfire in a fraction of the engine's operating cycles.

The possible HC emission formation mechanisms for spark-ignition engines (where fuel-air mixture is essentially premixed) have been proposed [6].

1. **Crevice flows:-** The crevice mechanism where crevices in the combustion chamber are filled with a mixture of fuel and air. This mixture remains unburned after flame passage since the flame cannot propagate into the crevices. When the exhaust valve opens and the pressure drops in the combustion chamber the fuel in crevices is driven out in hot bulk gasses and are being partly oxidized. The UHC emissions from SI engines will normally increase with increasing compression ratio.

2. **Flame quenching:-** As the flame approaches the combustion walls it is extinguished (due to heat transfer to walls) thus, leaving a layer of unburned fuel-air mixture adjacent to the wall.

3. **Absorption/desorption in oil films: -** Hydrocarbons can be absorbed into the oil film on the cylinder bore during compression. These hydrocarbons are released again during expansion and often escape oxidation as a result. Absorption/desorption from in-cylinder deposits may also be considered as a reason for the UHC.

4. **Incomplete combustion: -** Incomplete combustion in a fraction of the engine's operating cycle (either partial burning or complete misfire), occurring when combustion

quality is poor (e.g. during engine transients when A/F, EGR, and spark timing may not be adequately controlled).

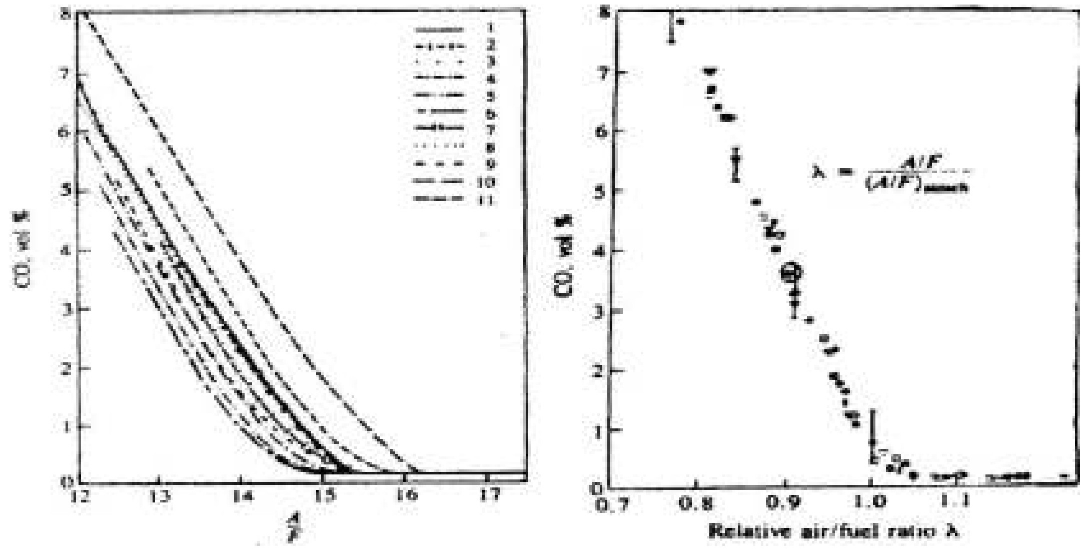
1.3.3 CO Emissions

Carbon monoxide (CO) is a colorless, odorless, flammable and highly poisonous gas this 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 hemoglobin. Exposure levels must be kept below 30 ppm to ensure safety. Apart from that, carbon monoxide also helps in the formation of greenhouse gases and global warming by encouraging the formation of NO_x.

Formation of CO

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 (λ). Figure 1.2 (a) shows the variation of CO emission for eleven fuels with different hydrocarbon contents and a single curve may be used to represent the data when using the relative air/fuel or equivalence ratio as represented in Figure 1.2 (b).



(a) (b)

Figure 1.2: Variation of CI engine CO emissions with various fuels (a) with air/fuel ratio; (b) with relative air/fuel ratio (λ) [6]

Both the graphs clearly show that the amount of CO emitted increases with decreasing air to fuel ratio. Spark ignition gasoline engines which normally run on a stoichiometric mixture at normal loads and fuel-rich mixtures at full load shows significant CO emissions. On the other hand, diesel engines which run on a lean mixture only emit a very small amount of CO which can be ignored. Additional CO may be produced in lean-running engines through the flame-fuel interaction with cylinder walls, oil films and deposits. Direct injection diesel engines also emit more CO than indirect-injection engines. However, the CO gas emission increases with increasing engine power output for both engines. [7]

CO formation is one of the principle reaction steps in the hydrocarbon combustion mechanism, which may be summarized by

$$\mathrm{RH}\text{----›}\ \mathrm{R}\text{----›}\ \mathrm{RO_2}\text{----›}\ \mathrm{RCHO}\text{----›}\ \mathrm{RCO}\text{----›}\ \mathrm{CO}$$

Where ‘R’ stands for the hydrocarbon radical.

The CO formed from hydrocarbon radicals can be oxidized to form carbon dioxide in an oxidation reaction, in an equilibrium condition:

$$CO+OH=CO_2+H$$

The emission of CO is a kinetically-controlled reaction since the measured emission level is higher than equilibrium condition for the exhaust. Three-body radical recombination reactions such as:

$$H+H+M=H_2+M \quad H+OH+M=H_2O+M \quad H+O_2+M=H_2O+M$$

Above reaction is found to be rate-controlling reactions for emission of CO gas.

Reduction of carbon monoxide in internal combustion engines can be achieved by improving the efficiency of combustion process or utilization of oxidation catalysts to oxidize carbon monoxide to carbon dioxide. Engine modifications such as improved cylinder head design, controlled air intake and electronic fuel injection can help to maintain a lean air/fuel mixture which is favorable.

1.3.4 Carbon Dioxides

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 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, engine with higher thermal efficiency that are able to operate at the lowest level of excess air is used.

1.3.5 Sulphur Dioxide (SO_2)

Sulfur dioxide (SO_2) belongs to the family of sulfur oxide gases (SO_X). These gases dissolve easily in water and are produced when sulfur or fuels containing sulfur are oxidized:

$$S + O_2 = SO_2$$

SO_2 dissolves in water vapors to form acid, and interacts with other gases and particles in the air to form sulfates and other products that can be harmful to the people and environment. Moreover, oxidation of SO_2 will further produce SO_3 in the atmosphere under the influence of sunlight:-

$$2SO_2 + O_2 = 2SO_3$$

Some of the SO_3 will also be introduced directly from the combustion processes alongside SO_2. SO_3 will react rapidly with moisture from the atmosphere to form sulfuric acid, which is the main element in acid rain:-

$$SO_3 + H_2O = H_2SO_4$$

It had been proven that even with sophisticated combustion techniques; there had been no significant improvement of reduction in the emission of sulphur dioxide. Therefore the best way to solve this problem is the selection of low sulphur content fuels such as Ethanol, LPG, and CNG etc.

1.4 Emission Control Strategies for C.I. Engines

The following techniques are used to control the harmful emission coming through engine exhaust.

1.4.1 After Exhaust Treatment Devices

Catalytic converters are used on both spark ignition and compression ignition engines. For spark ignition engines, the most commonly used catalytic converter is the three-way converter which converts the three main pollutants of concern-CO, HC, and NO_x to less-toxic substances [8]. The control of NO_x involves a *reduction* process that releases oxygen and the control of CO and HC involves an *oxidation* process that consumes oxygen. Therefore, a catalytic converter contains two catalyst-coated stages: The first catalyst stage encountered by the exhaust is for reduction of NOx, which produces oxygen employed by the second stage to oxidize CO and HC.

Catalytic converters work most efficiently with exhaust from engines operated on a stoichiometric air-fuel mixture. Generally, such engines are equipped with closed-loop feedback fuel mixture control employing one or more oxygen (lambda) sensors. While a catalyst can be used in an open-loop system, NO_x reduction efficiency is low. Since NO_x emissions are now regulated throughout the world, open-loop fuel systems are obsolete in many jurisdictions. Closed-loop maintenance of the stoichiometric air-fuel ratio is most often attained by means of an engine management system with computer-controlled fuel injection, though early in the deployment of catalytic converters, carburetors equipped for feedback mixture control were used during the transition to fuel injection [9].

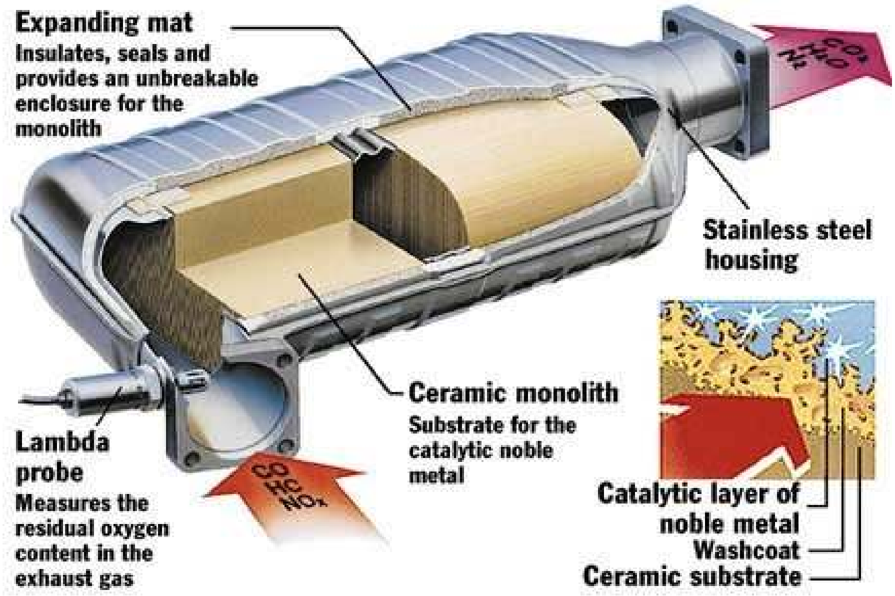


Figure 1.3: Schematic diagram of a Catalytic Converter

At the correct stoichiometric ratio, conversion of all three pollutants is very complete sometimes approaching 100%. However, outside of that ratio conversion efficiency falls off very rapidly. Two-way (or oxidation) converters act only to control CO and HC, and have therefore been abandoned on conventional spark ignition engines in most jurisdictions due to an inability to control NO_x.

1.4.2 Advanced Engine Technologies

In addition to using alternative fuels and exhaust gas treatment there are advanced engine technologies which can aid in reducing engine exhaust emissions. Some of them are listed as follows-

(i) Conversion of Two Stroke Engines to Four Stroke Engines

In Delhi, two-wheelers account for about two thirds of the total vehicular population. The big proportion of overall automobile pollution is due to large number of two-wheelers /three wheelers fitted with 2-stroke engines. Because of the inherent drawbacks in the design of 2- stroke engines, 2-wheelers emit about 20-40% of the fuel un-burnt/partially burnt. At present, two-wheelers generate more than 70% of the hydrocarbon emissions and nearly 40% of the CO emissions in Delhi.

As these emissions are less visible than SPM, the general public is not aware of the role of 2-wheelers in the deteriorating air quality. To reduce pollution scenario from such vehicles 2-stroke engines need to be replaced by 4-stroke engines. It is one of the alternative technologies for reducing vehicular pollution and aimed to reduce pollutants from exhaust of smaller 2-stroke engine fitted vehicles such as scooters and motorcycles /three wheelers (Table 1.5). Relative to carbureted 2-stroke engines, the main benefits offered by carbureted 4-stroke engines are:

- Misfire-free operation.
- Reduced fuel consumption and CO_2 emissions,
- Reduced HC emissions.
- Improved drivability

Table 1.5: Two and Four-Stroke Engine Powered Motorcycles (Driving Cycle Test)

Motor Cycle	Engine Type	Engine Displacement	Fuel Economy Km/l	Emission g/km		
				CO	HC	NO_X
Kawasaki KE-175	2-stroke	174	24.2	24.16	7.48	0.02
Suzuki TS-100	2-stroke	98	29.2	13.19	7.09	0.03

-	2-stroke	200	30.0	12.2	4.8	-
Honda XL-125	2-stroke	124	42.3	11.60	0.78	0.13
-	4-stroke	150	36.2	15.8	0.98	-

(ii) Exhaust Gas Recirculation

The Exhaust Gas Recirculation (EGR) system's purpose is to reduce NO_x emissions that contribute to air pollution. The first EGR systems were added to engines in 1973, and today most engines have an EGR system. Exhaust gas recirculation reduces the formation of NO_X by allowing a small amount of exhaust gas to "leak" into the intake manifold. The amount of gas leaked into the intake manifold is only about 6 to 10% of the total, but it's enough to dilute the air/fuel mixture just enough to have a "cooling effect" on combustion temperature. This keeps combustion temperatures below 1500°C (2800° F) to reduce the reaction between nitrogen and oxygen that forms NO_x.

When the engine is idling, the EGR valve is closed and there is no EGR flow into the manifold. The EGR valve remains closed until the engine is warm and is operating under load. As the load increases and combustion temperatures start to rise, the EGR valve opens and starts to leak exhaust back into the intake manifold. This has a quenching effect that lowers combustion temperatures and reduces the formation of NOx.

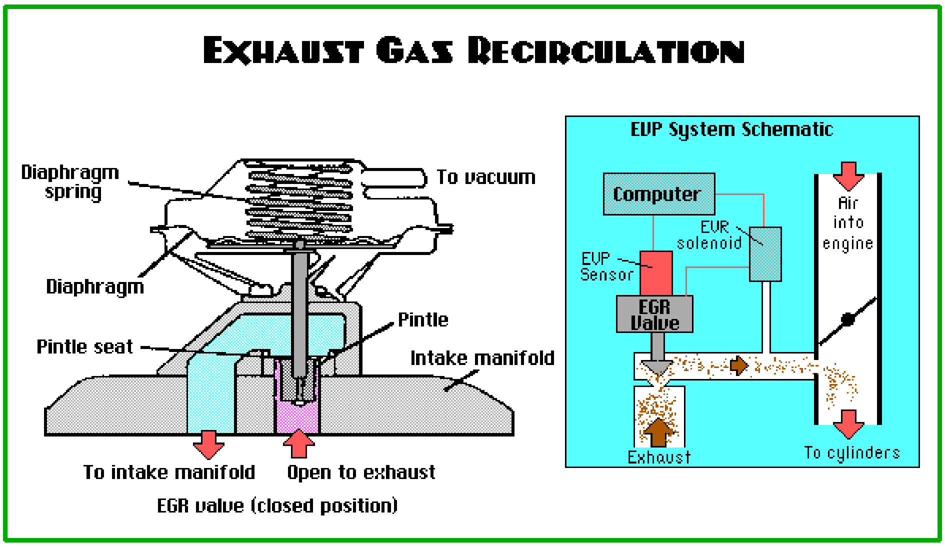


Figure 1.4: Exhaust Gas Recirculation System

(iii) Stratified Charge Engines

The stratified charge engine is a type of internal-combustion engine similar in some ways to the Diesel cycle, but running on normal gasoline. The name refers to the layering of fuel/air mixture, the charge inside the cylinder. It uses a direct-injection system, like the Diesel, with its inherent ability to be run at efficient high compressions. However, like the Otto, it relies on gasoline's ability to mix quickly and cleanly in order to avoid the poor combustion found in older direct injection Diesels.

To do this the fuel injectors are aimed to inject the fuel into only one area of the cylinder, often a small "sub-cylinder" at the top, or periphery, of the main cylinder. This provides a rich charge in that area that ignites easily and burns quickly and smoothly. As the combustion process proceeds, it moves to a very lean area (often only air) where the flame-front cools rapidly and the harmful NO_x has little opportunity to form. The additional oxygen in the lean charge also combines with any CO to form CO_2, which is less harmful. This technology has also been applied to the latest electronically controlled direct injection diesels. The injection system on these engines delivers the fuel in multiple injection bursts to ensure better fuel/air mixing and reduced diesel knock.

(iv) 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. These trends arise mainly as a result of the poor flame propagation characteristics within the very lean gaseous fuel-air mixtures and originating from the various ignition centers of the pilot. Dual-Fuel is fitted onto a standard diesel engine which operates unchanged, except power is generated by mostly clean natural gas. 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.

(v) Common-Rail Fuel Injection System

Common rail fuel injection system is finding increasing use in diesel engines as it has the potential to drastically cut emissions and fuel consumption. This system provides control of many important parameters linked to the injection system. It has a wide range of applications, from small to heavy duty engines. Some important features are:

(i) Very high injection pressure of the order of 1500 bar.
(ii) Complete control over start, and end of injection
(iii) Injection pressure is independent of engine speed
(iv) Ability to have pilot, main and post injection
(v) Variable injection pressure.

The common rail injection system has a high pressure pump which operates continuously and charges a high pressure rail or reservoir or accumulator. Fuel is led from this rail to the injector mounted on the cylinder head through lines. The injector is solenoid operated. It received pulses from the ECU to open the same.

1.5 Emission standards

Emissions standards are requirements that set specific limits to the amount of pollutants that can be released into the environment. Many emissions standards focus on regulating pollutants released by automobiles (motor cars) and other powered vehicles but they can also regulate emissions from industry, power plants, small equipment such as lawn mowers and diesel generators. Frequent policy alternatives to emissions standards are technology standards (which mandate the use of a specific technology) and emission trading.

Standards generally regulate the emissions of NO_x, sulfur oxides, particulate matter (PM) or soot, carbon monoxide (CO), or volatile hydrocarbons (see carbon dioxide equivalent). Emission standards for vehicles in Delhi are shown in table 1.6.

Table 1.6: Emissions Standards for Vehicles in Delhi

	1991	1996	2000	2001	2005	2010

Petrol Vehicles: Passenger Cars			India 2000 (Euro 1)	Bharat II (Euro 2)	Bharat III (Euro 3)	Bharat IV (Euro 4)
CO (g/km)	14.3-27.1	4.5	2.72	2.2	2.3	1.0
HC (g/km)	2.0-2.9	-	-	-	0.2	0.1
HC+NO$_X$ (g/km)	-	3.00-4.36	0.97	0.5	-	-
NO$_X$(g/km)	-	-	-	-	0.15	0.08
Diesel truck and bus Engines			Euro I	Euro II	Euro III	
CO (g/km)	17.3-32.6	11.2	4.5	4.0	2.1	-
HC (g/km)	2.7-3.7	2.4	1.1	1.1	0.66	-
NO$_X$ (g/km)	-	14.4	8.0	7.0	5.0	-
PM (g/km)	-	-	0.36	0.15	0.1	-
2-wheelers			TA COP			
CO (g/km)	12-30	4.5	2.0 2.4	-	1.5	1.0*
HC (g/km)	8-12	-	-	-	-	-
HC+NO$_X$ (g/km)	-	3.6	2.0 2.4	-	1.5	1.0*
3-wheelers			TA COP			
CO (g/km)	12-30	6.75	4.0 4.8	-	2.25	1.25*
HC (g/km)	8-12	-	-	-	-	-
HC+NO$_X$ (g/km)	-	3.6	2.0 2.4	-	2.0	1.25*
3-wheelers: Diesel			TA COP			
CO (g/km)	12-30	5.0	2.72 3.16	-	1.0	0.5*
HC (g/km)	8-12	-	-	-	-	-
HC+NO$_X$ (g/km)	-	2	0.97 1.13	-	0.85	0.5
NO$_X$(g/km)	-	-	0.14 0.18	-	0.1	0.05*

Source: CPCB 2001, Aggarwal et al. [3]

1.6 Alternative Fuels

The Life of the automobile no longer seems to be under the control of its designers and manufactures. The benefits of the machine and the society's perception about the machine have ensured it survival. The time is changing and man is coming to a new crossroads that must be critically evaluated in light of new concerns and problems that were not pressing at the birth of the automobile more than a century ago.

Industry has brought the western world to a new frontier that is no longer about living by the sweat of our brow and by working the land. The industrial revolution and the modernization of the world has enabled us to remove ourselves from nature and to allow us to look the other way as our inventions and creations dirty our nest and foul our water.. Nature cannot take all of our garbage anymore we are approaching the pollution saturation point in which all the actions that we perform should be analyzed to take into account that we are not alone and that not only are we harming the creatures around us, we are harming ourselves.

The different type of pollutants can be broken down into categories based on the different areas that they affect. The automobile produces air, water, and noise pollution. The harmful Air pollution can be controlled by using Alternative fuels. Alternative fuels are of the following types:

- Liquefied petroleum gas
- Compressed natural gas
- Biodiesel
- Hydrogen gas
- Methanol
- Ethanol

1.7 Compressed Natural Gas (CNG)

Natural gas is abundantly available in nature and has a small and simple molecular structure and its carbon to hydrogen ratio is low resulting in much lower emissions.

Natural gas is a mixture of hydrocarbons-mainly methane (CH_4) and is produced either from gas wells or in conjunction with crude oil production. High Octane rating

of natural gas allows compression ratio and thereby efficiency to be increased.

Table 1.4: Properties of CNG

CNG Characteristics	Value
Vapor density	0.68
Auto Ignition temperature	700°C
Octane rating	130
Boiling point (Atm. Press)	-162°C
Air-fuel ratio (Weight)	17.24
Chemical reaction with rubber	No
Storage Pressure	20.6 MPa
Fuel air mixture quality	Good
Pollution CO-HC-NO_X	Very low
Flame speed m sec-1	0.63
Combust. ability with air	4-14%

Properties of CNG are shown in Table 1.4. High energy content (weight wise) of natural gas results in more efficient vehicle operation. But Natural gas requires large infrastructure for its transportation, distribution and refueling. Moreover as natural gas is compressed to very high pressures approx 200 bar for automotive applications it requires use of heavy and strong storage tanks [11]. Moreover low volumetric efficiency results in power loss and restricts natural gas vehicle (NGV) range.

1.7.1 Properties of CNG as Alternative Fuel

The octane rating of natural gas is about 130, meaning that engines could operate at compression ration of up to 16:1 without knock or detonation [14]. In the CNG application policy, many of the automotive makers already built transportation with a natural gas fuelling system and consumer does not have to pay for the cost of conversion kits and required accessories.

Most importantly, natural gas significantly reduces CO_2 emissions by 20-25% compare to gasoline because simple chemical structures of natural gas (primarily methane-CH_4) contain one Carbon compare to diesel ($C_{15}H_{32}$) and gasoline (C_8H_{18})[14].

CNG as alternative fuel characteristics are shown in Table 1.4. Natural gas composition varies considerably over time and from location to location [14]. Methane content is typically 70-90% with the reminder primarily ethane, propane and carbon dioxide. At atmospheric pressure and temperature, natural gas exists as a gas and has low density. Since the volumetric energy density is so low, natural gas is often stored in a compressed state at high pressure stored in pressure vessels.

That natural gas has a high octane rating, for pure methane the RON = 130 and enabling a dedicated engine to use a higher compression ratio to improve thermal efficiency by about 10% above that for a petrol engine, although it has been suggested that optimized CNG engine should be up to 20% more efficient, although this has yet to be demonstrated. Compressed natural gas therefore can be easily employed in spark ignited internal combustion engines.

1.8 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.

These trends arise mainly as a result of the poor flame propagation characteristics within the very lean gaseous fuel-air mixtures and originating from the various ignition centers of the pilot.Dual-Fuel is fitted onto a standard diesel engine which operates unchanged, except power is generated by mostly clean natural gas. 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.

1.9 concluding Remark

In this chapter according to the current scenario alternative fuels are the best option in place of fossil fuels. The use of these alternative fuels is also a major concern, performance wise, as well as safe environment point of view. CNG is one of the best alternatives of fossil fuels. The effective use of CNG is also a necessary task. Diesel-CNG Dual fuel mode is also a good technique for effective use of CNG.

CHAPTER-2

LITRATURE REVIEW

2.1 Objective

The literature review contains two sorts of studies. The first part of the literature review is related to the studies on importance of CNG and its use in internal combustion engines. Second part of the literature review contains the work carried out on dual fuel engine.

2.2 Studies on CNG

Natural Gas: Natural gas is produced from gas wells or tied in with crude oil production. Natural Gas (NG) is primarily made up of methane (CH_4) but frequently contains trace amounts of ethane, propane, nitrogen, helium, carbon dioxide, hydrogen sulfide and water vapor. Compressed natural gas is a largely available form of fossil energy and therefore non-renewable.

According to **Srinivasan [16]** natural gas contains more than 98% methane. Natural gas can be compressed, so it can be stored and used as Compressed Natural Gas (CNG). NG requires a much larger volume to store while at high pressure, about 200 bar the same mass of natural gas can be stored in a smaller volume in the form of Compressed Natural Gas (CNG). CNG is safer than gasoline in many respects and ignition temperature for natural gas is higher than gasoline and diesel fuel. Additionally, natural gas is lighter than air and will dissipate upward rapidly if a rupture occurs. Gasoline and diesel will pool on the ground, increasing the danger of fire. Compressed natural gas is non-toxic and do not contaminate groundwater if spilled. Advanced CNG engines guarantee considerable advantages over conventional gasoline and diesel engines.

2.3 Studies on the use of CNG in SI Engines

Kumarappa [17] 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. Experiments were carried out at the constant speed of 3500 rpm with a compression ratio of 12:1. This indicates the 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.

In the study of **Bhandari [18]** 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. It was estimated that a CNG with range and power equivalent to the gasoline model would be less efficient (25%). This tradeoff 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 NMHC and NO_X emission impacts depended upon conversion techniques. Emission benefits in CNG engine would be greater in dedicated vehicle. The maximum level of CO emission was 0.325 percent. Results showed an improvement in the performance and emission characteristics of CNG fueled SI engines using specially designed Electro Mechanical Fuel system.

Fleming [19] investigated single cylinder and a multi cylinder engines and showed Light-load, lean-limit misfire region of NG begins at an air fuel ratio between 140-150 percent of stoichiometric value. Changes in ignition timing significantly influenced emission of

NOx and HC but had little effect on CO emissions. Lower emissions can be achieved in current design engines but with heavy penalty to engine performance. Emissions from vehicles fueled with NG are virtually unaffected between 6 to 38° C. NG exhaust are estimated to be 22-25% as reactive as gasoline exhaust. 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.

2.4 Studies on the use of CNG in CI Engines

The diesel engine is a compression ignition engine, in which the fuel is ignited solely by the high temperature created by compression of the air-fuel mixture. The engine operates on diesel cycle. The direct injection compression ignition engines are those in which fuel is injected by the fuel injection system into the engine cylinder toward the end of the compression stroke, just before the start of combustion. The liquid fuel, usually injected at high velocity as one or more jets through small orifices or nozzles in injector tip, atomizes into small drops and penetrates into the combustion chamber. The fuel vaporizes and mixes with high temperature and high pressure cylinder air. The air is supplied from intake port of engine. Since the air temperature and pressure are above the fuel's ignition point, spontaneous ignition of portions of the already-mixed fuel and after air a delay period of a few crank angle degrees. The cylinder pressure increases as combustion of the fuel-air mixture occurs. The major problem in compression ignition engine combustion chamber design is achieving sufficiently rapid mixing between the injected fuel and the air from intake port in the cylinder to complete combustion in the appropriate crank angle interval close to top center. Horsepower output of an engine can be dramatically improved through good intake port design and manufacture.

There are two methods of converting Diesel Engine into CNG Engine

1. First is a dual-fuel engine. This refers to diesel engines operating on a mixture of natural gas and diesel fuel. Natural gas has a low cetane rating so it is not suited to compression ignition engine, 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. The engine can also revert to 100% diesel operation.

2. The second is dedicated natural gas engines. Dedicated natural gas engines are optimized for the natural gas fuel. They can be derived from petrol engines. The practice of converting diesel engines to spark ignition will continue, which involves the replacement of diesel fuelling equipment by a gas carburetor and the addition of an ignition system and spark plugs.

2.4.1 Studies on Dedicated CNG conversion

Semin [20] 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 500 rpm. Results shows that that increasing engine speed of the diesel engine increased the maximum combustion temperature in the engine cylinder contrary to this Increasing engine speed of CNG engine will decrease the maximum combustion temperature in the engine cylinder. Decreasing engine speed of diesel engine will decrease the maximum combustion temperature in the engine cylinder. The highest maximum combustion temperature in the engine cylinder in combustion process was not at highest engine speed. 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 most excellent than the other condition and unburned fuel is lowest, so the temperature product from the combustion is the highest.

In diesel engine converted to CNG engine, the maximum engine cylinder temperature at the 1000 rpm engine speed has increased by 9.94%. In the 1500 rpm the temperature increased by 5.40%. At 2000 rpm the engine cylinder temperature increased by 0.52%. At 2500, 3000, 3500 and 4000 the temperature increased by 3.77%, 13.57%, 21.72% and 26.72% respectively.

Ismail [21] developed a gaseous fuel injector for port injection CNG engine converted from diesel engine. Advantages of CNG as a fuel are octane number is very good for SI engine fuel/engines can be operate with a high compression ratio/less engine emissions/ less aldehydes. In the diesel engines converted or 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 engine parts load operations. The system was able to diminish the cyclic variations and to expand the limit of lean operation of the engine. The flexibility of gas pulse timing offers the potential advantage of lower emissions and fuel consumption. There are several advantages of port injection. To increase the power and decrease the exhaust gas emissions, the CNG engine needed some improvements. The converting of diesel engine to port injection CNG engine and improve the gaseous fuel injector nozzle holes geometries which operated in variation injection pressure and injection timing will be give better performance and exhaust gas emissions.

Awang Idris [22] has investigated the fluid characteristic effect in the engine cylinder of four-stroke direct injection diesel engine converted to port injection dedicated compressed natural gas (CNG) engine spark ignition. The investigation and simulation of the engine cylinder flow performance characteristic profile based on engine computational model. The engine computational model has developed based from the diesel engine converted to port injection dedicated compressed natural gas (CNG) engine spark ignition. The simulation of engine model has simulated in variations engine speeds. The simulation results of fluid characteristics are shown the characteristics of in cylinder volumetric. The air-fuel characteristics results shown that increasing engine speed in port injected CNG engine will be decrease the air-fuel characteristics such as cumulative mass fuel injected, cylinder volumetric efficiency, Fuel flow past intake valve to cylinder, total fuel consumption per cycle and total fuel energy entering cylinder, efficiency profile, percent burned mass, fuel/air ratio, fuel flow profile, total fuel consumption and total fuel energy entering to cylinder in variations engine speeds. Increasing engine speed in port injected CNG engine will increase the air-fuel characteristics such as mass flow rate from intake valve, percent burned mass at cycle start and fuel/air ratio in cylinder. The air-fuel performance characteristics in cylinder of port injection CNG engine commonly is lower than the base diesel engine, but the percent burned mass at cycle start is higher than diesel engine. It means that conversion of diesel engine to port injection CNG engine commonly will reduce the air-fuel characteristics in cylinder and increase the percent burned mass at cycle start.

Kaleemuddin [23] found that due to lower specific weight of CNG there was drop in engine volumetric efficiency in CNG mode also lower compression ratio. To get Maximum Braking Torque (MBT) engine has to achieve peak combustion pressure which is possible if its ideal burning duration has achieved. With advance in ignition timing ideal burn condition of fuel mixture increases which improves engine torque. With retarded ignition timing there was increase in exhaust temperature there was drop in torque at higher engine speed as charge density is function of gas pressure and gas temperature. Higher engine speed lean down air /fuel ratio and combustion temperature increases. Since Natural gas has 1/3 of the volumetric energy density of gasoline and diesel also alternative fuels exhibit longer ignition delay, with slow burning rates due to its high auto ignition temperature. The ignition delay was reduced through advanced injection timing which has shown in improvement in bsfc.

2.4.2 Studies on the use CNG in Dual fuel Engines

The dual-fuel engines refer to diesel engines operating on a mixture of natural gas and diesel fuel. Natural gas has a low cetane rating and is not therefore 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. The engine can also revert to 100% diesel operation.

Pal et al. [24] In their work on a Kirloskar, four stroke, 7.35kW, twin cylinder, DI diesel engine operated in dual fuel mode (with substitution of up to 75% diesel with CNG). For the smooth entry of CNG in combustion chamber, a venturi was introduced in the passage of air inlet. The results of this experiment of substituting the diesel by CNG at different loads showed significant reduction in smoke, 10 to 15 % increase in power, 10 to 15 % reduction in fuel consumption and 20 to 40 % saving in fuel cost (considering low cost of CNG). The most exciting result was about 33 % reduction in engine noise which prolong the engine life significantly and the consequent sound levels of giant diesel engine reduction to that of a similar sized gasoline engine.

When a diesel engine operates at its maximum power and torque, the output of oxides of nitrogen (NO_x) increases because of higher combustion temperature and pressure. It has been observed that the thermal efficiency of a dual fuel engine is better than that of a dedicated diesel engine. At full load, increase in CNG flow rate results in improvement of thermal efficiency up to 35 %. In emission analysis of dual fuel engine, the amount of diesel consumed is reduced due to its replacement with combustion of CNG – air mixture. Hence smoke is reduced with the use of CNG in a diesel engine.

Ehsan [25] investigated the performance of a dual mode CNG engine. Compressed natural gas has used as main fuel and diesel as pilot fuel. A low pressure CNG system with an integrated pressure reduction device is being developed. Easily de-touchable low pressure hosing was used for gas delivery, while standard high pressure dispensing nozzle used for refilling CNG. This allowed easy and safe refilling of the system without disturbing the engine. Gas fumigation technique was used to run the unit with minimum possible hardware modifications. Performance tests were carried out for the entire range of engine loads running the engine with diesel only and in dual fuel mode. Comparison of the performance results and optimization of the natural gas replacement in dual fuel mode were carried out.

In his study **LIU Zhen Tao et al. [26]** found that compressed natural gas (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 not require prior knowledge. Studies showed that the predicted results were according to experimental data over a large range of operating conditions from low load to high load. The developed emissions model based on the RBF neural network could be used to successfully predict and optimize the emissions performance of DFE. The effects of the DFE main performance parameters, such as rotation speed, load, pilot quantity and injection timing, were also predicted by means of this model. An emission prediction model for CNG/diesel DFE based on RBF neural network was built for analyzing the effect of the main performance parameters on the CO, NOx emissions of DFE. The predicted results showed the reduction of NO_X and CO when dual fuel engine was compared with dedicated diesel engine.

Lyford et al. [27] compared the Emissions from two diesel and two natural gas tractor-trailers. These two types of engines were compared using the UDDS and ad hoc Viking cycles. Compared with the diesel trucks, carbon monoxide (CO) emissions from the dual mode CNG trucks were reduced by 87% for the UDDS and 93% for the Viking cycle. Compared with the diesel trucks, NOx emissions from the dual mode CNG trucks were reduced by 24% for the UDDS and 45% for the Viking cycle. The larger NOx reduction for the Viking cycle (versus the UDDS) could result from leaner operation of the dual mode CNG engine in that cycle. Compared with the diesel trucks, total particulate matter (TPM) from the dual mode CNG trucks was reduced by more than 90%. These results agreed with other researchers who have shown that dual mode CNG tractors significantly reduce NOx and particulate matter (PM) emissions relative to their conventional diesel counterparts.

Non-methane organic gases constituted less than 5% of the total hydrocarbon (THC) mass for the natural gas trucks. Hydrocarbon (HC) emissions from the diesel trucks were also very low and were of the same order of magnitude as the non-methane hydrocarbon (NMHC) emissions from the natural gas dual mode CNG trucks.

Patrick Coroller [28] checked the performance of a dual fuel diesel-CNG engine. In comparison with Diesel-powered buses, dual mode CNG -powered buses shows 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 by injection systems rather than older technology using a carburetor. To date the reliability of control systems of fuel mixture is not yet perfected.

Fuel consumption depends very much on the use of technology conditions which shows fuel consumption varied between 20 and 45 per cent. Incidents occurring on vehicles concerned the ignition and gas-compression system. Numerous "teething" technical problems were resolved.

In the case of Diesel-powered bus, the use of adapted after-treatment can decrease exhaust emission 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 for some filter technologies) constant filter maintenance.

Kumar [29] studied various types of dual fuel engines working on diesel-CNG dual mode. 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 have 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. Emission testing indicated NO_x reduced by 48%, CO_2 greenhouse gas reduced by at least 24% (as compared to 12% with a dedicated CNG engine). Visible “smoke” was eliminated after startup.

Wannatong [30] investigated the combustion and knock characteristics of DDF engine fueled by natural gas. A single cylinder direct injection diesel research engine was modified to operate as the DDF engine. A gas mixer was installed on the intake manifold to supply natural gas to the engine. Test runs of normal and abnormal conditions were investigated.

The combustion and knock characteristics of DDF engine fueled by natural have been investigated experimentally. From the test data, it can be summarized as:

- If the intake mixture temperature and the amount of supply gas can be controlled for the similar power output, the engine knock reduced.
- If amount of pilot diesel fuel in DDF mode was less than amount of diesel fuel which utilized in the premixed combustion diesel mode, the longer ignition delay time will be observed.
- In the case of keeping constant engine speed and torque while varying the mixing ratio of natural gas and diesel fuel, amount of added natural gas enhanced the heat release rate. It fastened the combustion process and decreased the exhaust temperature
- Engine knocks when the intake temperature reached the certain value that decreased with the engine speed.
- Engine knock took place by gradually increase the amount of natural gas. In the case of sudden increase, the rough combustion (partially burned) was observed instead.

2.5 Concluding Remarks

From the above literature important findings are as follows:

- Lower performance of was caused by the effect of lower engine cylinder temperature.
- In diesel engine highest maximum combustion temperature is at 3500 rpm because at this time the combustion is most excellent and the unburned fuel is lowest.
- In case of CNG maximum engine cylinder temperature is at 1000 rpm.
- The flexibility of gas pulse timing offers the potential advantage of lower emission and fuel consumption.
- On increasing the engine speed in port injected CNG engine air-fuel characteristics such as cumulative mass fuel injected, cylinder volumetric efficiency, total fuel consumption per cycle and total fuel energy entering the cylinder will decrease. While there will be increase in mass flow rate from intake valve, percentage burned mass at cycle start and F/A ratio in cylinder.
- Less wear on engine parts with reduced maintenance and oil charges were reported with CNG fueled engines.
- Emission testing indicates NOx reduction by 48%, CO_2 greenhouse gas is reduced by at least 24% (as compared to 12% with a dedicated CNG engine)

CHAPTER-4

DEVELOPMENT OF EXPERIMENTAL SET UP

4.1 Objective

The main objective of this chapter to show the necessary modifications made to convert the diesel engine into diesel CNG dual mode engine. The accessories and their specifications are also explained in this chapter.

4.2 Engine Test Setup

The setup consists of four cylinders, four strokes, Diesel engine connected to eddy current type dynamometer for loading. It is provided 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 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.

Figure 4.1: Experimental setup

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.

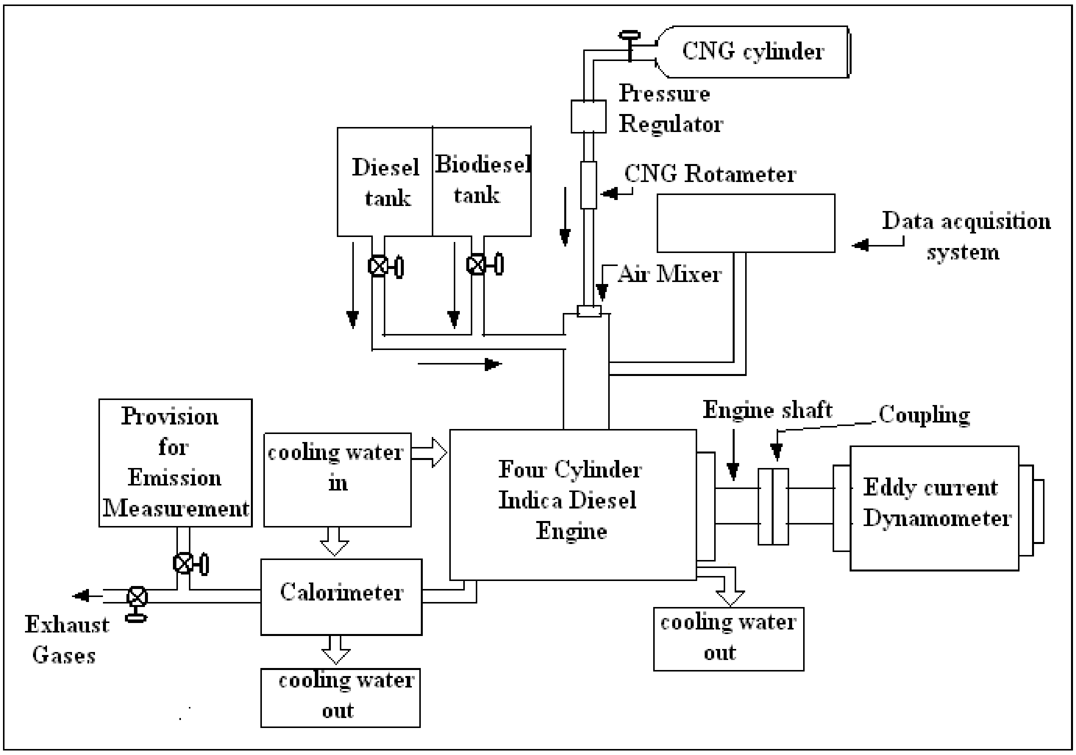


Figure 4.2: Schematic diagram of experimental set up

Windows based Engine performance analysis software package "Engine soft" is provided for on line performance evaluation. Emissions are measured with the help of smoke meter and gas analyser.

4.3 Engine Modification

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 not therefore 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 [14]. The engine can also revert to 100% diesel operation.

To use the diesel-CNG in dual mode we have introduced CNG from a cylinder of 60 liters. capacity shown in figure 4.3 in which CNG is stored at a high temperature about 200 bar. A pressure regulator CNG kit shown in figure 4.4 is used to convert the pressure of CNG from 200 bar to 4 bar. A CNG flowmeter is used to check the flow of CNG.

Figure 4.3: CNG cylinders

Figure 4.4: CNG kit

CNG is then supplied to the CI engine with the help of a CNG-air mixer shown in figure 4.6 through the suction pipe. This mixture of air and CNG is compressed in compression stroke. Here we have not used spark plug to ignite the mixture of air and CNG, but diesel is use as a pilot fuel at the end of the compression stroke. Diesel is first ignited as primary fuel when the combustion takes place this help to ignite our mixture of air-CNG. This method is one of the easy and cheep conversions of the diesel engine into diesel-CNG engine. The method of necessary modification made to convert diesel engine into diesel-CNG dual mode is shown in Figure 4.5.

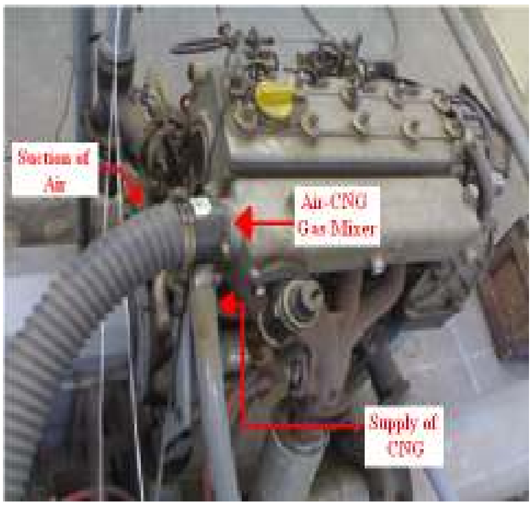


Figure 4.5 Attachment of Air-CNG gas mixer on diesel engine

Figure 4.6: Gas-air Mixer

The smoke meter and gas analyser used to measure the emissions are shown in figure 4.7 and 4.8 respectively.

Figure 4.7: Smoke Meter used

Figure 4.8: Gas Analyser used

4.4 Test Setup Specifications

Product	Engine test setup 4 cylinder, 4 stroke, Diesel (Computerized)
Engine	Make Telco, Model Tata Indica, Type 4 Cylinder, 4-stroke, Diesel water cooled, Power 39Kw at 5000 rpm, Torque 85 NM at 2500 rpm, stroke 79.5mm, Bore 75mm, 1405 cc, CR-22
Dynamometer	Type eddy current, water cooled, with loading unit
Air box	M S fabricated with orifice meter and manometer
Fuel tank	Capacity 15 lit with glass fuel metering column
Calorimeter	Type Pipe in pipe
Piezo sensor	Range 5000 PSI, with low noise cable
Crank angle sensor	Resolution 1 Deg, Speed 550 RPM
Engine indicator	Input Piezo sensor, crank angle sensor, No of channels 2, Communication RS232
Digital milivoltmeter	Range 0-200mV, panel mounted
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Temperature transmitter	Input RTD PT100, Range 0–100 ^{0}C, Output 4–20 mA and Type two wire, Input Thermocouple, Range 0-1200 ^{0}C, Output 4–20 mA
Load indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Fuel flow transmitter	DP transmitter, Range 0-500 mm WC
Air flow transmitter	Pressure transmitter, Range (-) 250 mm WC

Rota meter	Engine cooling 100-1000 LPH; Calorimeter 25-250 LPH
Add on card	Resolution12 bit, 8/16 input, mounting PCI slot
Software	“Engine soft” performance analysis software
Overall dimensions	W 2000 x D 2750 x H 1750 mm
Smoke meter	Make AVL, for opacity measurement
Gas Analyser	Make AVL, (AVL DIGAS) for emissions measurement

4.5 Concluding Remark

The existing multi-cylinder diesel engine is converted into diesel-CNG dual mode engine for the measurement of various performance and emission parameters.. In which CNG gas is supplied to the engine using a CNG kit and CNG-air mixer through the air suction pipe. The performance of this dual mode engine is tested with the help of different sensors and shown on the computer using software “Engine Soft”. For emission measurement an AVL make smoke meter and a gas analyser is used.

CHAPTER-5

OBSERVATIONS

5.1 Methodology

In this a four cylinder C.I. engine was converted to Dual fuel mode. The engine was used to run on pure diesel mode as well as dual fuel mode. Pure diesel, Biodiesel blends (B10, B20 and B30) were used as fuel with CNG in dual fuel mode.

First the engine was used to run at different speeds varying form 1000 rpm to 5000 rpm with pure diesel. Performance characteristics were recorded with the help of "ENGINESOFT" software. The emissions were recorded for each speed by using Gas Analyser AVL Di Gas 444 and opacity was recorded by smokemeter (AVL437).

Further the same experiment was performed on speed varying from 1000-5000 rpm in Dual fuel mode with diesel-CNG with variation of CNG flow from 75 lpm to 175 lpm with speed. Performance and emission characteristics were recorded similarly. Then the above experiments were repeated on different blends of Biodiesel (B10, B20 and B30) and performance and emission characteristics were recorded.

The effects of different fuel modes on engine knocking were analysed by recording the engine sound with multimedia recorders and then these sounds are converted to graphical format by MATLAB program.

The performance parameters recorded are as follows:

1. Torque
2. Break Power (BP)
3. Break Thermal Efficiency (BThE)
4. Specific Fuel Consumption (SFC)
5. Specific Energy Consumption (SEC)

The Emissions Recorded are follows:

1. Smoke Opacity
2. Carbon Monoxide Emission (CO)
3. Hydrocarbon Emission (HC)

4. Oxides of Nitrogen (NO_X)

5.2 Observations tables

Experimental data and observations are given below:

5.2.1 Observations for Pure Diesel

Engine performance parameters obtained from performance testing in 4 cylinder CI engine against different speeds for pure diesel are given in table 5.1. Emission characteristics of the engine against speed for pure diesel are shown in table 5.2

Table 5.1: Performance parameters for pure diesel

S. No.	SPEED (rpm)	TORQUE kgm	BP kW	FP kW	IP kW	BThE %	IThE %	MechE %	SFC kg/kW-h	SEC kJ/kW-h
1.	1000	2.74	4.2	4.7	8.9	19.77	41.92	47.16	0.434	5.058
2.	2000	6.2	12.57	5.68	18.27	22.53	32.69	68.89	0.381	4.439
3.	3000	7.38	26.79	13.29	40.09	22.34	33.43	66.84	0.384	4.476
4.	4000	7.25	30.14	13.95	44.09	22.27	32.58	68.35	0.385	4.490
5.	5000	6.27	31.86	20.2	52.08	19.76	32.28	61.21	0.434	5.061

Table 5.2: Emissions for pure Diesel

S. no.	Speed (rpm)	CO (%)	HC (ppm)	CO_2 (%)	NO_X (ppm)	OPACITY (%)
1.	1000	.036	3	9.1	276	19
2.	2000	.037	5	8.9	284	23
3.	3000	.053	16	7.1	445	49.4
4.	4000	.07	20	6.0	575	56.2
5.	5000	.12	29	4.2	573	58.3

5.2.2 Observations for B10

Engine performance parameters obtained from performance testing in 4 cylinder CI engine against different speeds for 10% Biodiesel (B10) are given in table 4.3. Emission characteristics of the engine against speed for B10 are shown in table 5.4.

Table 5.3: Performance parameters for B10

S. No.	SPEED (rpm)	TORQUE kgm	BP kW	FP kW	IP kW	BThE %	IThE %	MechE %	SFC kg/kW-h	SEC kJ/kW-h
1.	1000	3.07	4.81	5.91	10.72	20.55	45.18	44.89	.421	4.87
2.	2000	5.61	11.52	7.83	19.35	23.29	39.13	59.52	.372	4.29
3.	3000	7.41	22.92	8.76	31.67	22.65	31.29	72.35	.383	4.42
4.	4000	7.46	30.96	15.88	46.84	22.31	33.75	66.09	.389	4.48
5.	5000	6.67	32.26	22.87	57.13	20.23	33.74	59.95	.429	4.94

Table 5.4: Emissions with B10

S. No.	Speed (rpm)	CO (%)	HC (ppm)	CO_2 (%)	NO_X (ppm)	OPACITY (%)
1.	1000	.038	4	8.4	239	18.5
2.	2000	.06	7	7.8	276	18.2
3.	3000	.06	15	7.2	433	44.6
4.	4000	.09	19	4.7	568	51.3
5.	5000	.13	22	4.1	574	58.8

5.2.3 Observations for B20

Engine performance parameters obtained from performance testing in 4 cylinder CI engine against different speeds for 20% Biodiesel (B20) are given in table 5.5. Emission characteristics of the engine against speed for B20 are shown in table 5.6.

Table 5.5: Performance parameters for B20

S. No.	SPEED (rpm)	TORQUE kgm	BP kW	FP kW	IP kW	BThE %	IThE %	MechE %	SFC kg/kW -hr	SEC kJ/kW-h
1.	1000	2.96	4.6	3.62	8.22	20.5	36.64	55.95	.428	4.88
2.	2000	5.7	11.86	5.93	17.79	24.22	36.33	66.66	.362	4.13
3.	3000	7.56	23.15	6.87	30.02	23.42	30.37	77.11	.375	4.27
4.	4000	7.33	30.06	14.13	44.2	23.17	34.07	68.02	.379	4.32
5.	5000	5.99	30.71	23.52	54.23	19.87	35.09	56.63	.442	5.03

Table 5.6: Emissions with B20

S. no.	Speed (rpm)	CO (%)	HC (ppm)	CO_2 (%)	NO_X (ppm)	OPACITY (%)
1.	1000	.043	11	8.4	226	20.4
2.	2000	.04	13	7.5	324	17.9
3.	3000	.06	17	7.1	458	45.9
4.	4000	.08	19	4.7	576	50.1
5.	5000	.11	23	3.8	614	57.8

5.2.4 Observations for B30

Engine performance parameters obtained from performance testing in 4 cylinder CI engine against different speeds for 30% Biodiesel (B30) are given in table 5.7. Emission characteristics of the engine against speed for B30 are shown in table 5.8.

Table 5.7: Performance parameters for B30

S. No.	SPEED (rpm)	TORQUE kgm	BP kW	FP kW	IP kW	BThE %	IThE %	MechE %	SFC kg/kW -hr	SEC kJ/kW-h
1.	1000	3.55	5.67	4.7	10.37	19.53	35.74	54.66	.455	5.12
2.	2000	5.54	11.5	6.82	18.32	26.26	41.82	62.78	.339	3.81
3.	3000	7.37	22.88	8.53	31.41	25.54	35.03	72.85	.348	3.92
4.	4000	7.16	29.67	15.51	45.18	24.8	37.77	65.67	.358	4.03
5.	5000	6.1	31.25	26.97	58.23	20.5	38.2	53.67	.436	4.88

Table 5.8: Emissions with B30

S. no.	Speed (rpm)	CO (%)	HC (ppm)	CO_2 (%)	NO_X (ppm)	OPACITY (%)
1.	1000	.05	5	8.4	215	15.2
2.	2000	.06	8	7.9	318	17.5
3.	3000	.07	12	7.5	391	49.87
4.	4000	.08	17	4.9	546	51.4
5.	5000	.11	24	4.1	611	59.6

5.2.5 Observations for Diesel-CNG Dual Fuel Mode

Engine performance parameters obtained from performance testing in 4 cylinder CI engine against different speeds for Diesel-CNG Dual fuel mode are given in table 5.9. Emission characteristics of the engine against speed for B10 are shown in table 5.10.

Table 5.9: Performance parameters for Diesel-CNG

S. No.	SPEED (rpm)	TORQUE kgm	BP kW	FP kW	IP kW	BThE %	IThE %	MechE %	SFC kg/kW -hr	SEC kJ/kW-h
1.	1000	3.68	4.8	4.5	9.3	20.45	33.47	51.6	.423	4.89
2.	2000	6.12	13.2	5.72	18.92	23.32	32.22	69.76	.375	4.29
3.	3000	7.68	21.88	13.34	39.22	24.36	32.87	65.98	.336	4.11
4.	4000	7.49	29.54	13.87	43.44	24.46	32.34	68.12	.348	4.09
5.	5000	5.78	30.72	20.73	51.43	22.64	32.09	59.69	.443	4.42

Table 5.10: Emissions with Diesel-CNG

S. no.	Speed (rpm)	CO (%)	HC (ppm)	CO_2 (%)	NO_X (ppm)	OPACITY (%)
1.	1000	.06	9	8.2	223	16.2
2.	2000	.076	13	7.8	243	18.4
3.	3000	.08	16	7.2	365	42.1
4.	4000	.11	27	4.7	478	45.3
5.	5000	.15	32	4.1	482	61.3

CHAPTER-6

RESULTS AND DISCUSSION

In this chapter the results of obtained by tests are discussed with figures. The results obtained for different fuels are compared and then their variations are discussed below. The results are as follows.

6.1 Knock Analysis

The comparison of knock for pure diesel and diesel with CNG in Dual fuel mode obtained by converting the sound wave to graphical form by using MATLAB software recorded at different speeds are shown below.

The Noise levels for pure Diesel and Diesel CNG Dual fuel mode at 1000 rpm are shown in figure 6.1(a) and 6.1(b) respectively. At initial speed 1000 rpm there is no major difference is observed. The curves of noise level for pure diesel and diesel-CNG are almost identical. The Noise levels at 2000 rpm are shown in figure 6.1(c) and 6.1(d) respectively. The noise level at 2000 rpm in pure diesel is less than the diesel-CNG dual mode because in diesel-CNG dual mode there is diesel knock and erratic knock due to spontaneous ignition of the CNG. The dual fuel engine knock was seen to depend on engine load and speed, combustion temperature, pilot fuel/gas ratio and turbulence in the cylinder. Therefore with increase in CNG flow at 2000 rpm the diesel-CNG dual fuel has higher noise level.

The Noise levels at 3000 rpm are shown in figure 6.1(e) and 6.1(f) respectively. At 3000 rpm the noise level is similarly as previous case. In case of 3000 rpm diesel-CNG dual fuel has higher noise level. The Noise levels at 4000 rpm are shown in figure 6.1(g) and 6.1(h) respectively. The operating condition is improved by increasing pilot fuel with increase in engine speed. Therefore at 4000 rpm the noise level in diesel-CNG dual fuel has improved in comparison to pure diesel.

The Noise levels at 5000 rpm are shown in figure 6.1(i) and 6.1(j) respectively. Similarly as previous case noise level is low in case of dual fuel because further increase in engine speed causes increase in pilot fuel. Therefore noise level has improved in case of diesel-CNG dual fuel.

6.1.1 Graphical Representation of Noise levels at 1000 rpm:

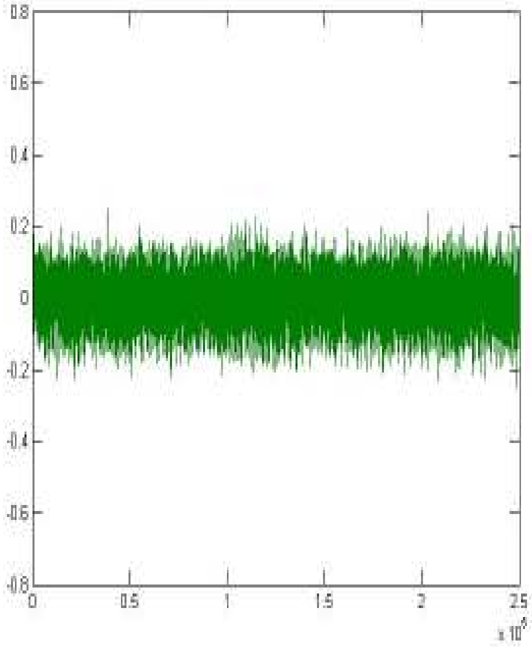


Figure 6.1(a): For pure Diesel at 1000 rpm

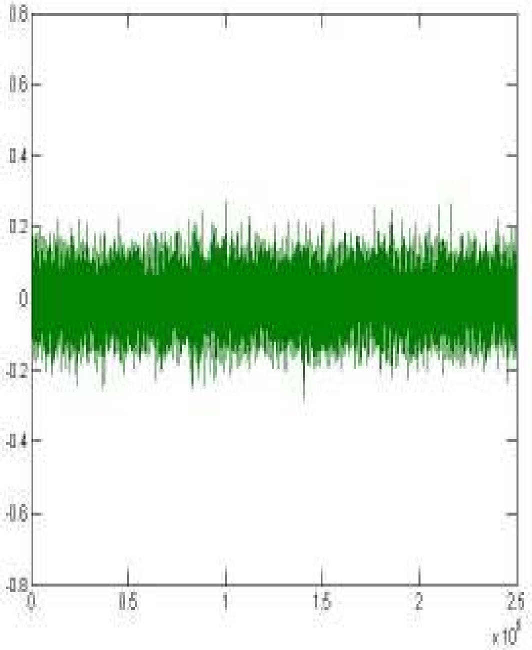


Figure 6.1(b): For DCNG at 1000 rpm

6.1.2 Graphical Representation of Noise levels at 2000 rpm:

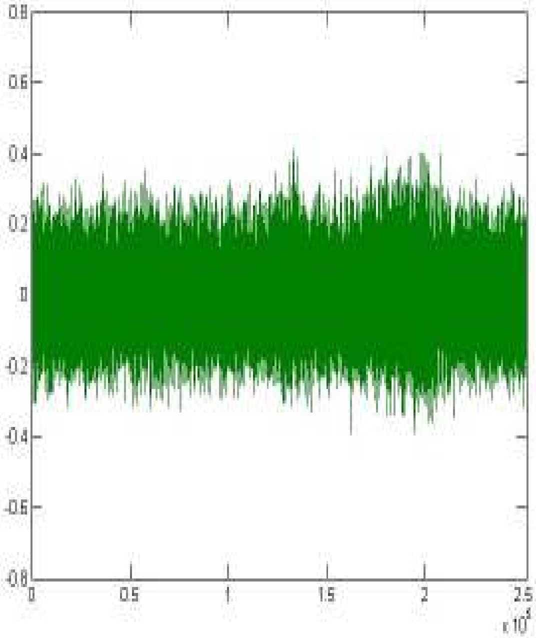


Figure 6.1(c): For pure Diesel at 2000 rpm

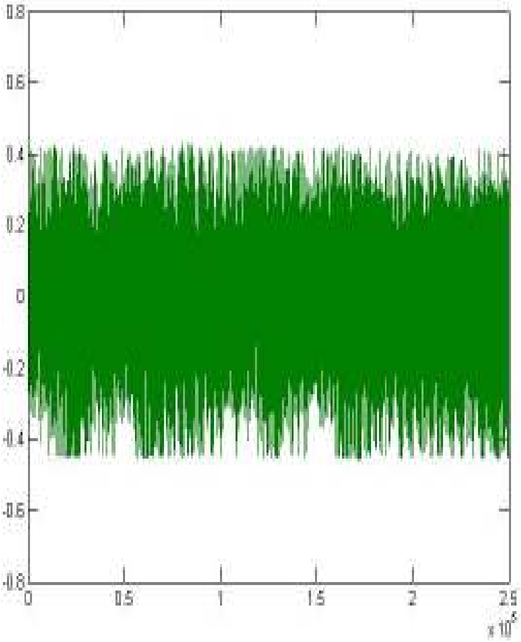


Figure 6.1(d): For DCNG at 2000 rpm

6.1.3 Graphical Representation of Noise levels at 3000 rpm:

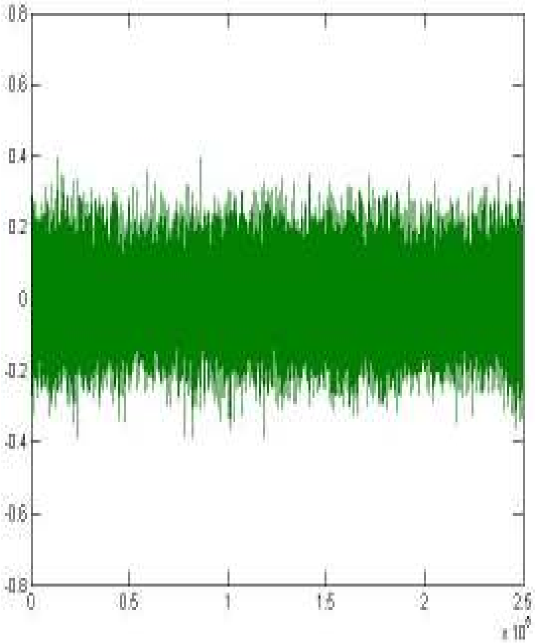


Figure 6.1(e): For pure Diesel at 3000 rpm

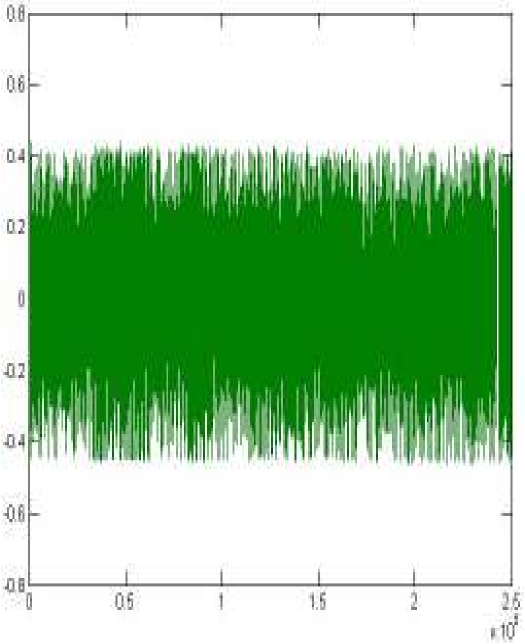


Figure 6.1(f): For DCNG at 3000 rpm

6.1.4 Graphical Representation of Noise levels at 4000 rpm:

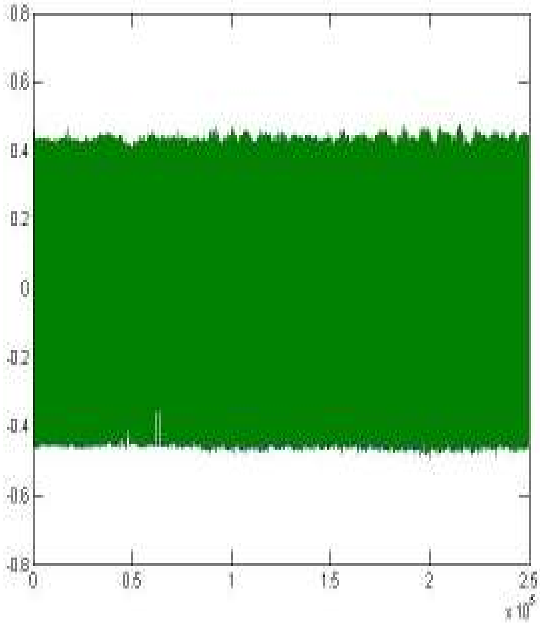


Figure 6.1(g): For pure Diesel at 4000 rpm

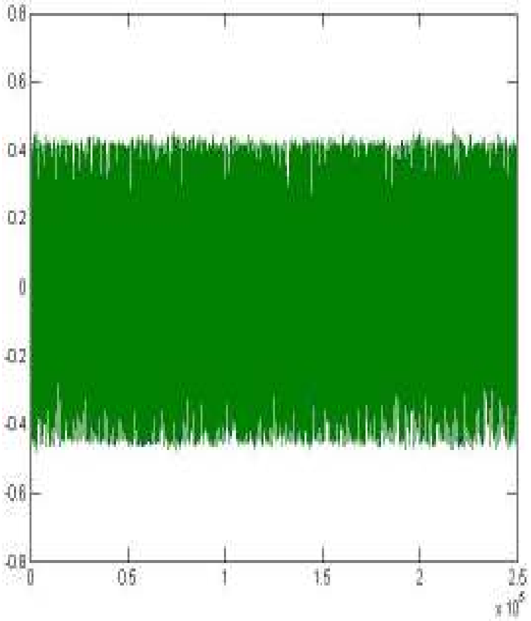


Figure 6.1(h): For DCNG at 4000 rpm

6.1.5 Graphical Representation of Noise levels at 5000 rpm:

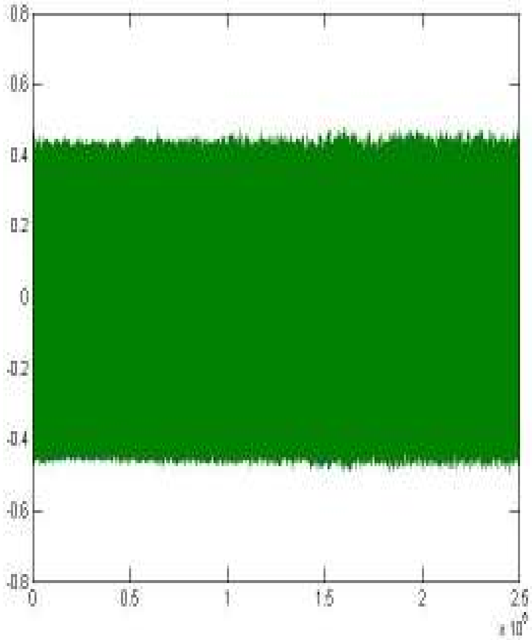


Figure 6.1 (i): For pure Diesel at 5000 rpm

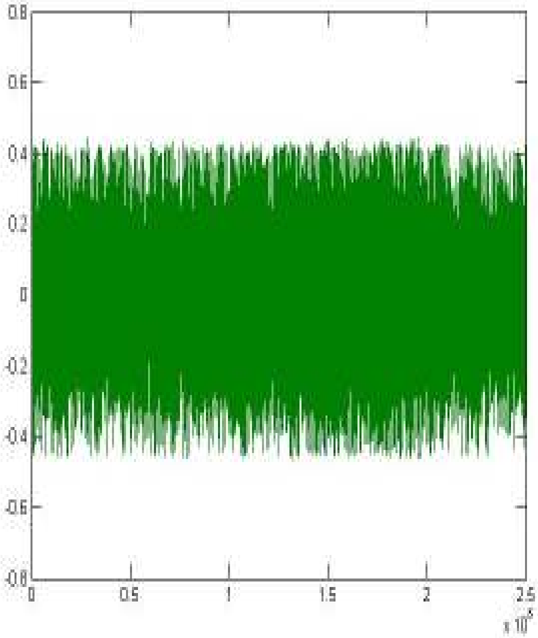


Figure 6.1 (j): For DCNG at 5000 rpm

6.2 Variation in Pressure Angle (P-θ) Curves

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. Different P-θ curves for different fuels at various speeds are shown below.

Figure 6.2(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 the 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 6.2(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 53 bar than after dual mode pressure is maximum in case of diesel is 52 bar. For the blends of B1O diesel the pressure is lower than 50 bar and it is lowest in case of B30.

Figure 6.2(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 change. 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 6.2(d) shows the P-θ curve for pure diesel, Biodiesel and diesel-CNG dual fuel mode at 4000 rpm. At 4000 rpm changes in pressure obtained was different from previous cases. 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 pressure (54 bar) was recorded is diesel-CNG dual fuel.

Figure 6.2(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 discussion of P-θ curves at different speeds varying from 1000-5000 rpm is that the maximum cylinder pressure in diesel-CNG always remains lower than the pure diesel. 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.

6.2.1 Variation in P-θ Curves at 1000 rpm

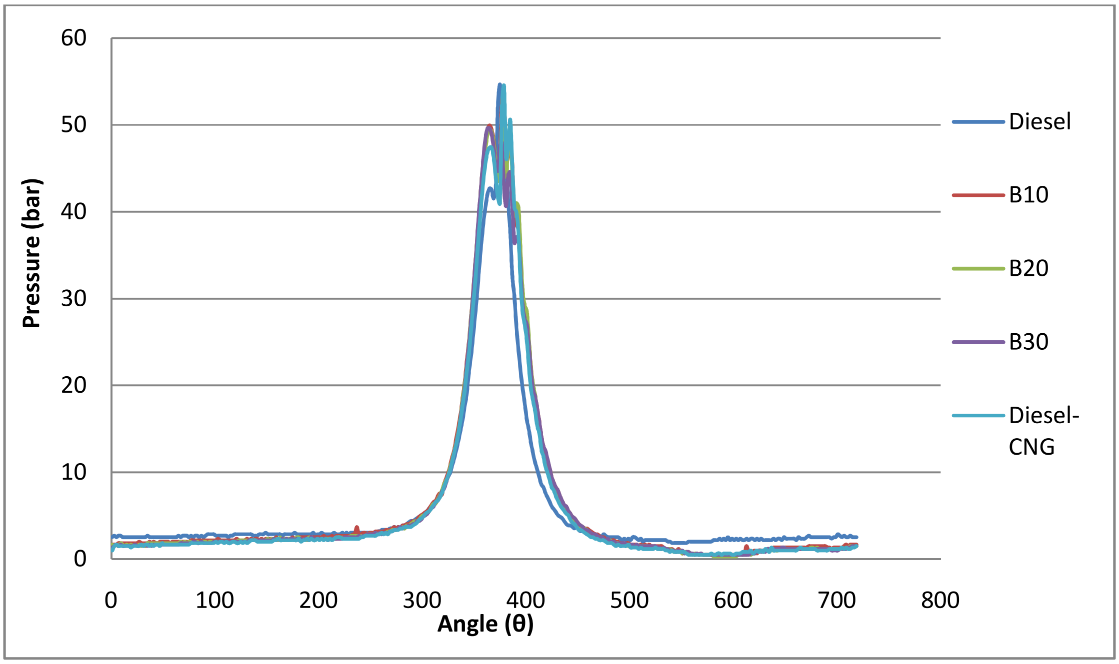


Figure 6.2(a): P-θ curves at 1000 rpm

6.2.2 Variation in P-θ Curves at 2000 rpm

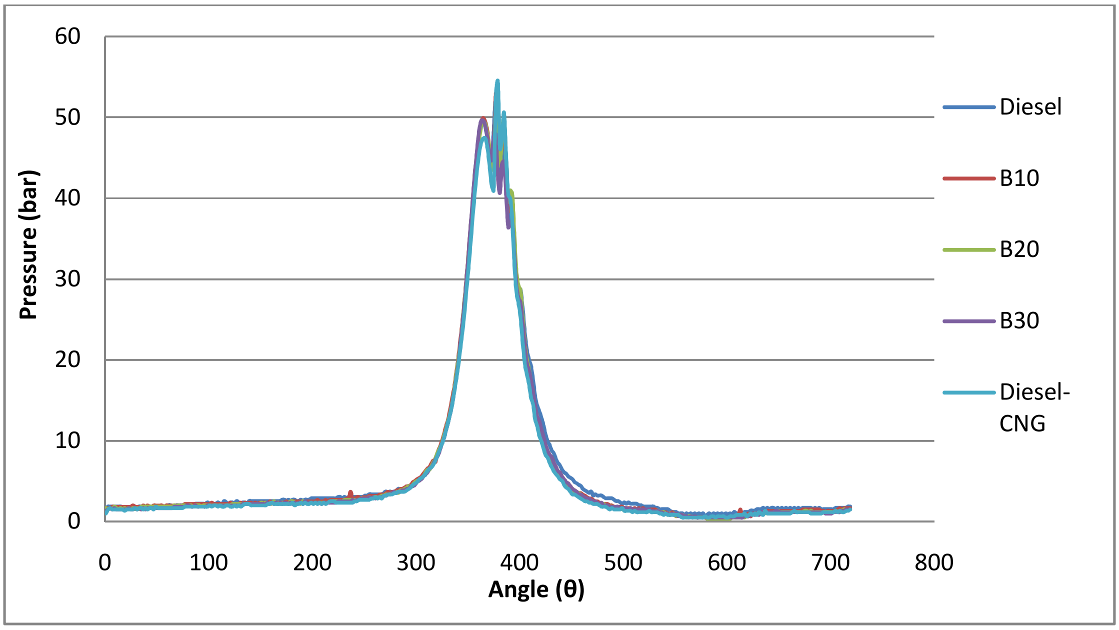


Figure 6.2(b): P-θ curves at 2000 rpm

6.2.3 Variation in P-θ Curves at 3000 rpm

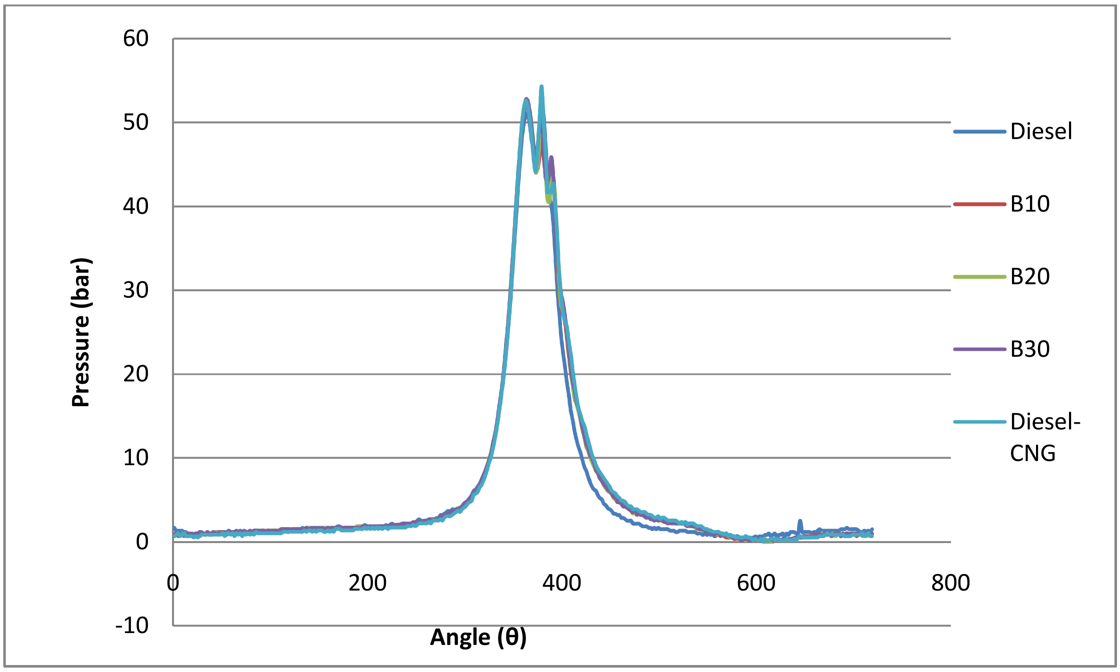


Figure 6.2(c): P-θ curves at 3000 rpm

6.2.4 Variation in P-θ Curves at 4000 rpm

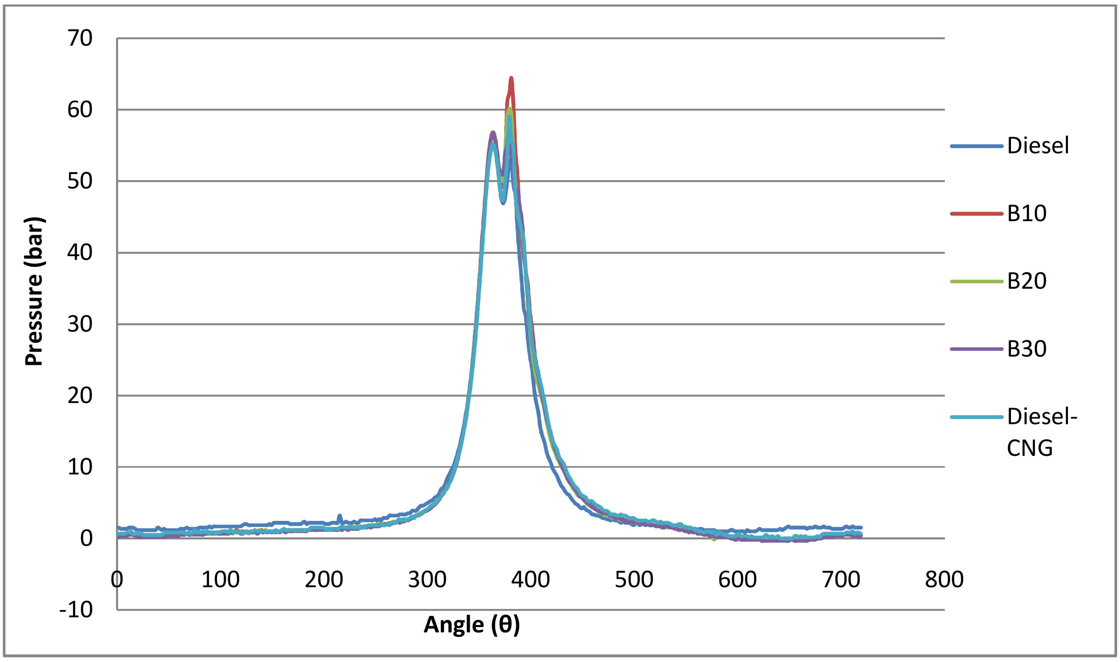


Figure 6.2(d): P-θ curves at 4000 rpm

6.2.5 Variation in P-θ Curves at 5000 rpm

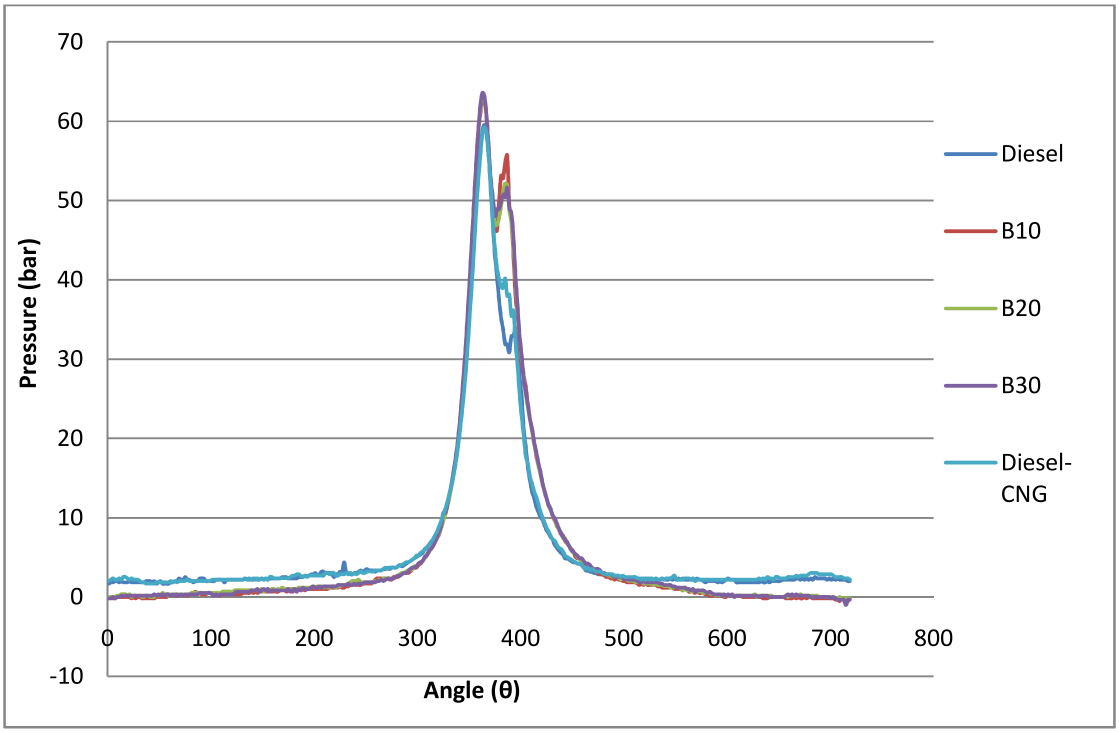


Figure 6.2(e): P-θ curves at 5000 rpm

6.3 Variation of Performance Parameters

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

Figure 6.3(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.

Similarly the figure 6.3(b) shows the percentage change in Torque for the blends of Biodiesel and diesel-CNG dual fuel mode considering diesel as a reference fuel. At the initial speed diesel-CNG dual fuel has more Torque. Maximum change in Torque is obtained in case of DCNG dual fuel at 1000 rpm which is 35% more than the pure diesel. Minimum change in Torque is obtained in case of B20 at 4000 rpm.

Figure 6.3(c) shows the Break Power for pure diesel, blends of Biodiesel and for diesel-CNG dual fuel. The variation of Break Power for different fuels is almost similar. Initially for all fuels the Break power increases sharply up 4000 rpm except pure diesel. In pure diesel it increases sharply upto 3000 rpm than increases slowly. After 4000 rpm the Break power increases slowly. Between 4000 rpm to 5000 rpm break power remains almost constant. In starting at 1000 rpm B30 has the maximum power. Between 2000 rpm to 4000 rpm Break Power is maximum in case of pure diesel. At higher speed 5000 rpm B10 has the maximum power. The Break 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 Break Power remains lower than other fuels. The maximum power obtained in case of B10 and pure diesel is 32 kW.

Figure 6.3(d) shows change in Break Power w.r.to speed considering pure diesel as reference. Here pure diesel is taken at base line. At initial speed 1000 rpm B30 has the maximum Break Power. At higher speed 4000 rpm and 5000 rpm the percentage change in Break Power is lower than in initial speeds. The minimum Percentage change in Break Power is at 4000 rpm which is just equal to Break Power in pure diesel.

Figure 6.3(e) shows the variation of Break Thermal Efficiency (BThE) for pure diesel, blends of Biodiesel and for diesel-CNG dual fuel. The pattern of variation of Break Thermal Efficiency for different fuels is almost similar. At initial speed Break Thermal Efficiency is almost same for all the fuels. In starting Break Thermal Efficiency 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.

Figure 6.3(f) shows the percentage change in BThE w.r.to speed. With increase in speed the change in BThE also increases. The maximum change in BThE 14.5 % is obtained in diesel-CNG dual fuel at 5000 rpm. The minimum change in BThE is obtained in B30 at 1000 rpm. There was a decrease in BThE at 1000 rpm for B30 only while in all the cases it increases with speed.

Figure 6.3(g) Specific Fuel Consumption (SFC) w.r.to 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.

Figure 6.3(h) shows that the percentages change in SFC with speed taking diesel at reference line. 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.

6.3.1 Variation of Torque with Speed

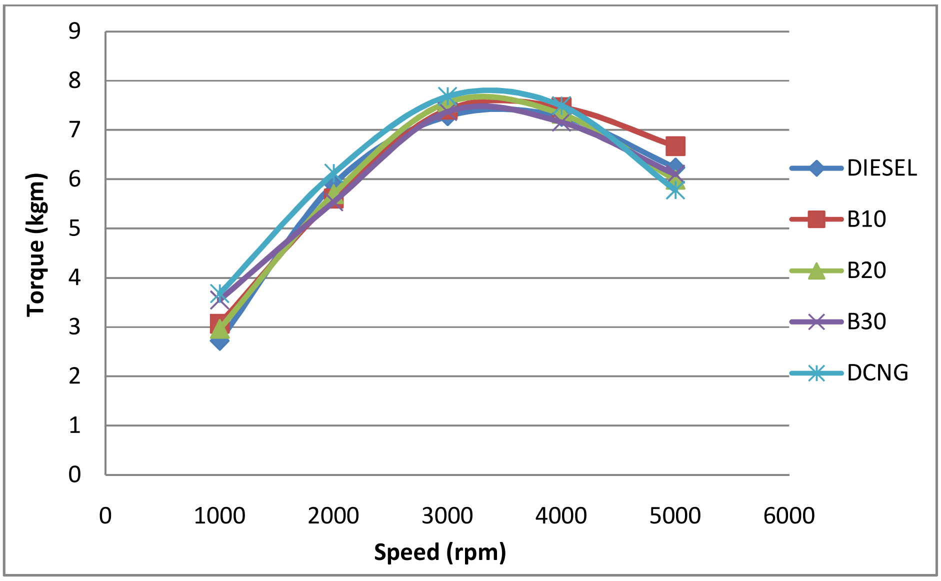


Figure 6.3(a): Comparison of Torque Vs Speed for different fuels

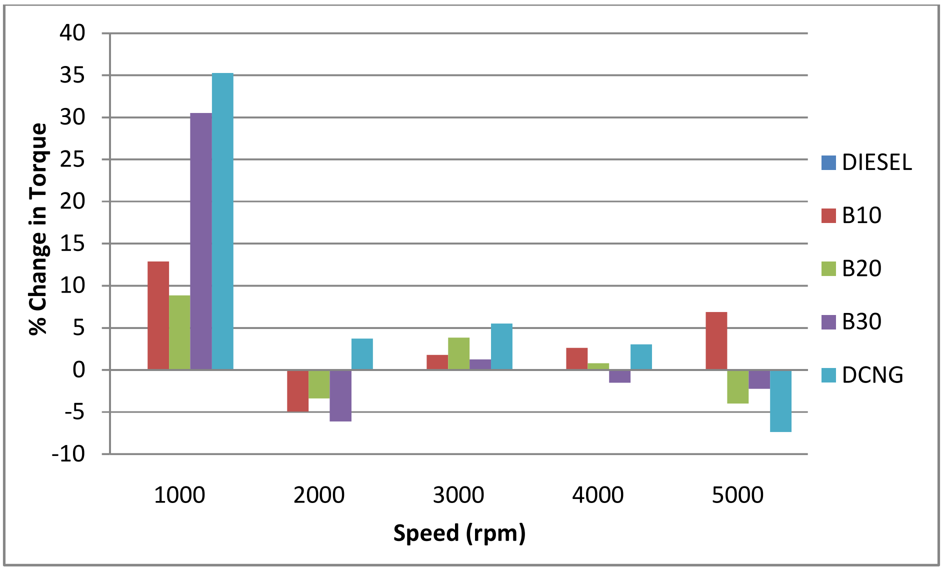


Figure 6.3(b): % Change in Torque with different fuels compared to pure diesel as baseline

6.3.2 Variation of Break Power with Speed

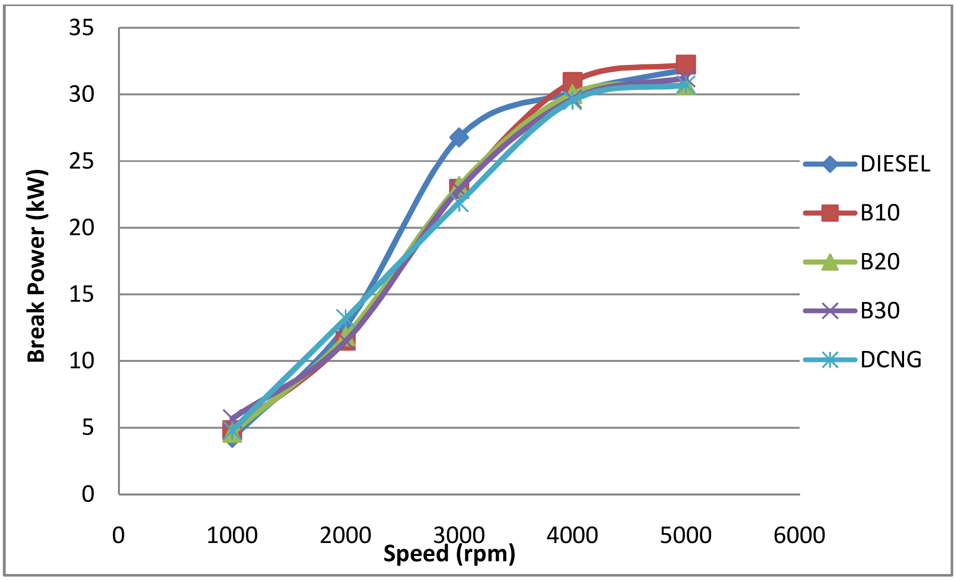


Figure 6.3(c): Comparison of BP Vs Speed for different fuels

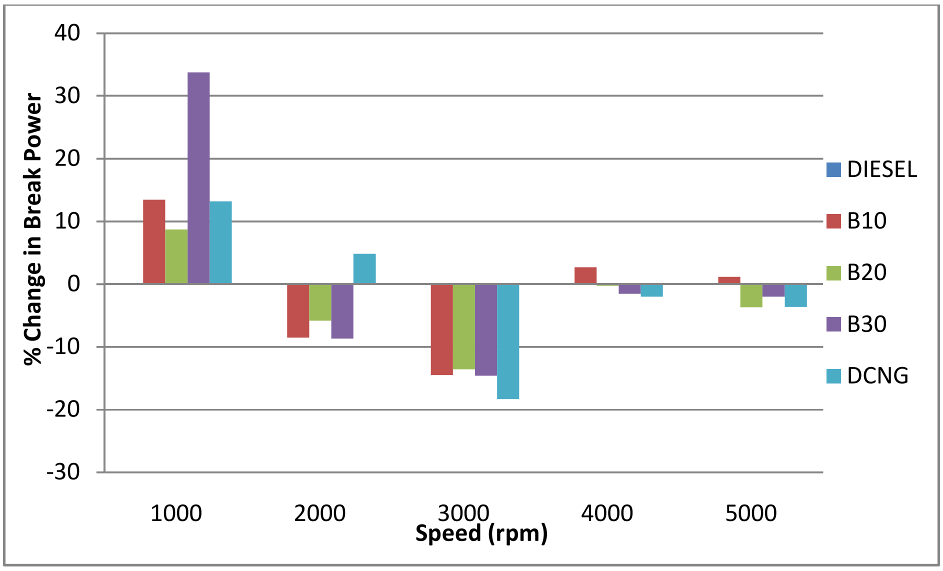


Figure 6.3(d): % Change in BP with different fuels compared to pure diesel as baseline

6.3.3 Variation of Break Thermal Efficiency with Speed

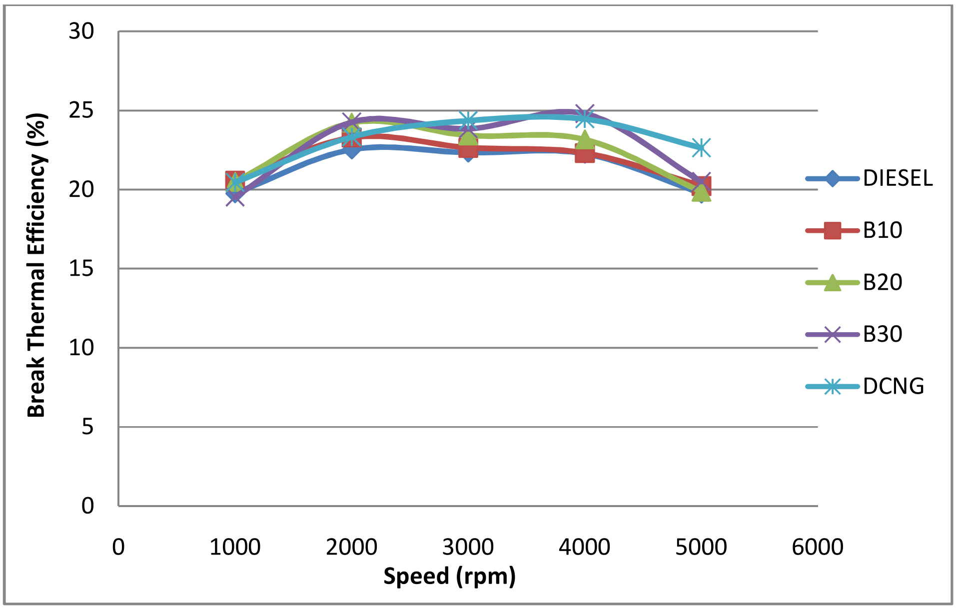


Figure 6.3(e): Comparison of BThE Vs Speed for different fuels

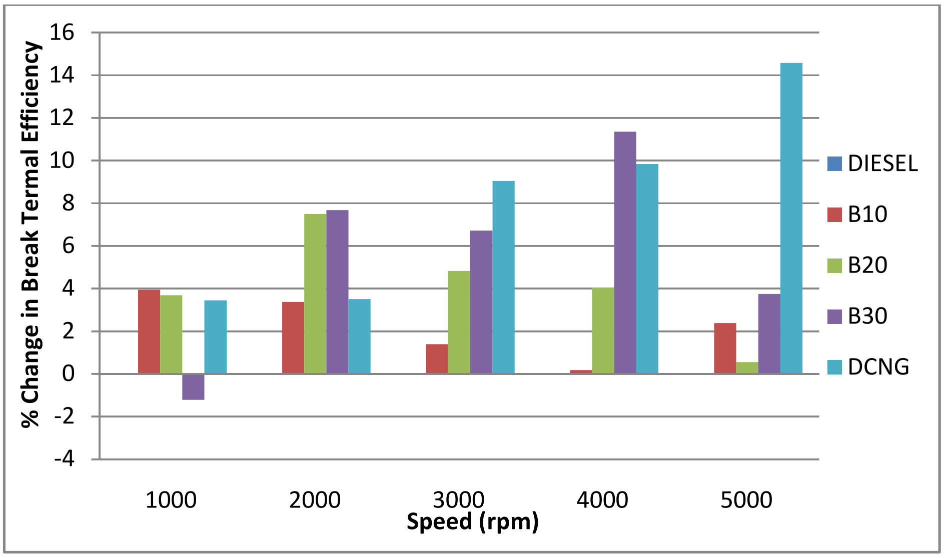


Figure 6.3(f): % Change in BThE with different fuels compared to pure diesel as baseline

6.3.4 Variation of Specific Fuel Consumption with Speed

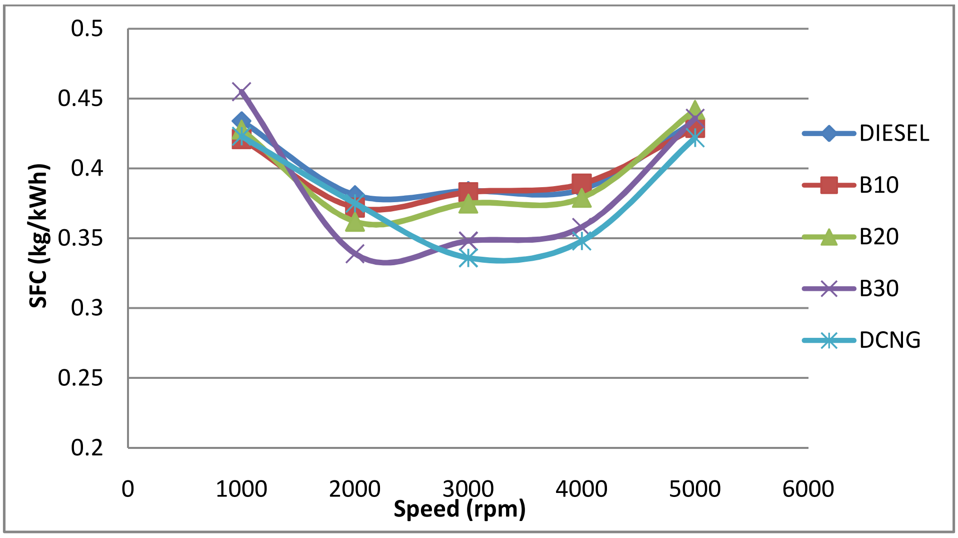


Figure 6.3(g): Comparison of SFC Vs Speed for different fuels

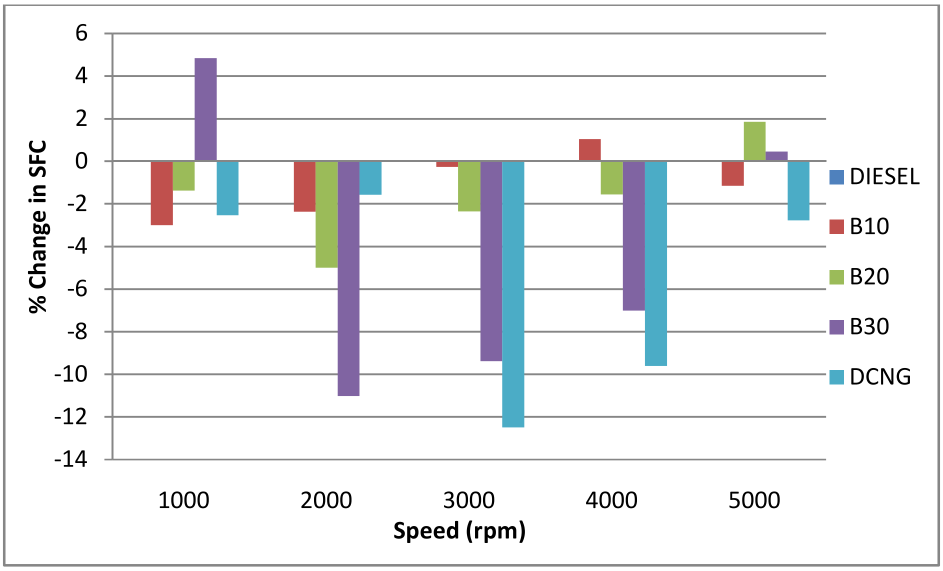


Figure 6.3(h): % Change in SFC with different fuels compared to pure diesel as baseline

6.4 Variation in Emissions

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

Figure 6.4(a) shows the variation of smoke opacity w.r.to speed. The pattern of variation in opacity is same for all the fuels. The opacity in case of pure diesel always remains higher than the other fuels this shows the advantage of using alternative 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 higher speed 5000 rpm there is little increase in opacity due to improper A/F mixture. Maximum Opacity is in case of pure diesel throughout the test.

Figure 6.4(b) shows the percentage change in opacity w.r.to speed taking diesel at 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. At 3000 rpm decrease in opacity is maximum 15% in case of diesel-CNG dual fuel. Similarly at 4000 rpm decrease in opacity is maximum 19% in case of diesel-CNG dual fuel. But opacity increases in all the cases as compared to diesel fuel at 5000 rpm.

Figure 6.4(c) shows the variation of CO emission w.r.to speed. The CO emission increases with increase in engine speed for all the fuels. The maximum CO emission is obtained at 5000 rpm in case of diesel-CNG dual fuel. CO emission is higher for diesel-

CNG dual fuel throughout the test. Therefore CO emission is higher in diesel-CNG dual fuel and lower in pure diesel throughout the test.
Figure 6.4(d) shows the percentage change in CO emission w.r.to speed taking diesel at base line. 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.

Figure 6.4(e) shows the variation of HC emission w.r.to speed. The pattern of increase in HC emission with speed is almost similar for all the fuels. The HC emission is lowest in Case of pure diesel at 1000 rpm and maximum HC emission is in case of diesel-CNG dual fuel at 5000 rpm. At 3000 and 4000 rpm minimum HC emission is in case of B30. 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.
Similarly figure 6.4(f) shows the percentage change in HC emission w.r.to speed taking diesel as reference fuel. Maximum increase in HC emission is obtained in case of B20 at 1000 rpm. At 5000 rpm increase in HC emission is highest in comparison to other fuels w.r.to diesel.

Figure 6.4(g) 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 for pure diesel and B10. NO_X emission is higher in case of B20.
Figure 6.4(h) shows the percentage change in NO_X emission w.r.to speed taking pure diesel as reference fuel on base line. The effective change in NO_X emission is observed in case of diesel-CNG which is decreasing throughout the test. 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.

6.4.1 Variation in Smoke Opacity

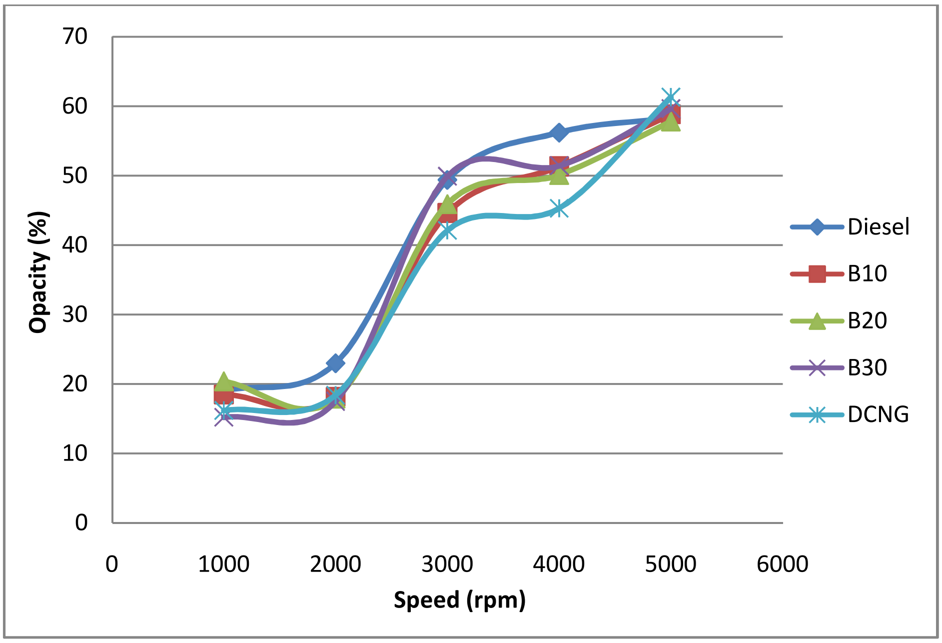


Figure 6.4(a): Comparison of Opacity Vs Speed for different fuels

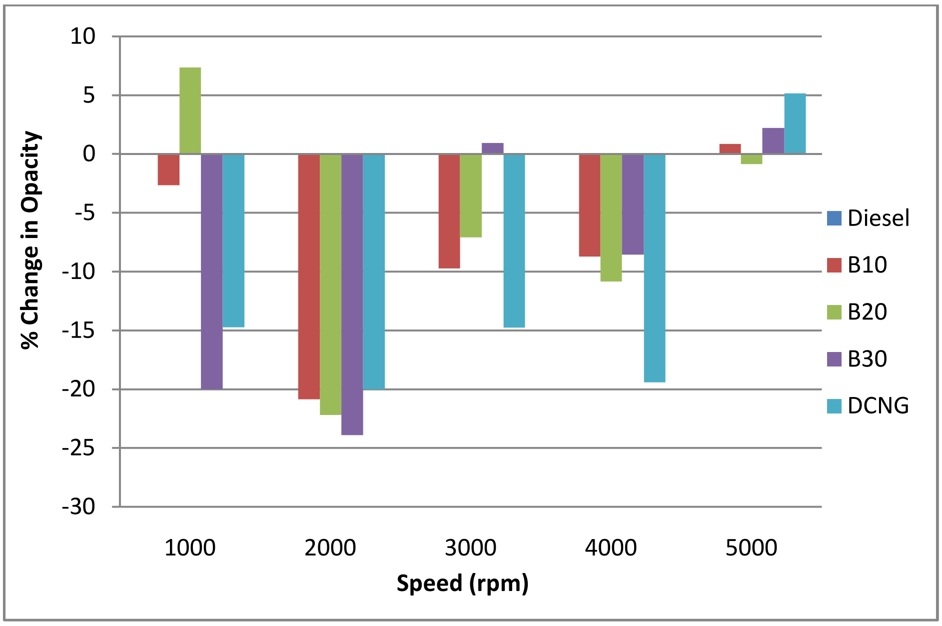


Figure 6.4(b): % Change in Opacity with different fuels compared to pure diesel as baseline

6.4.2 Variation in CO Emissions

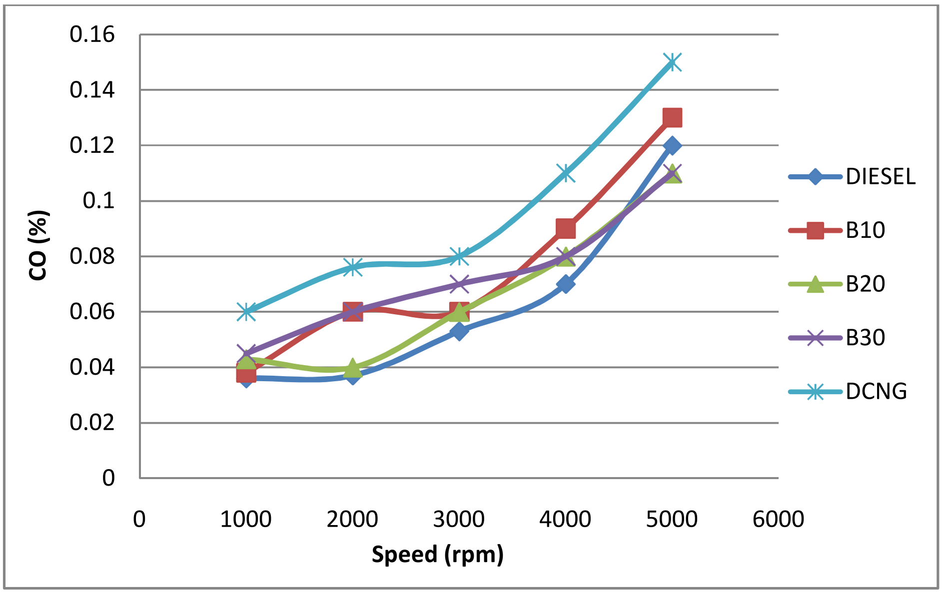


Figure 6.4(c): Comparison of CO Vs Speed for different fuels

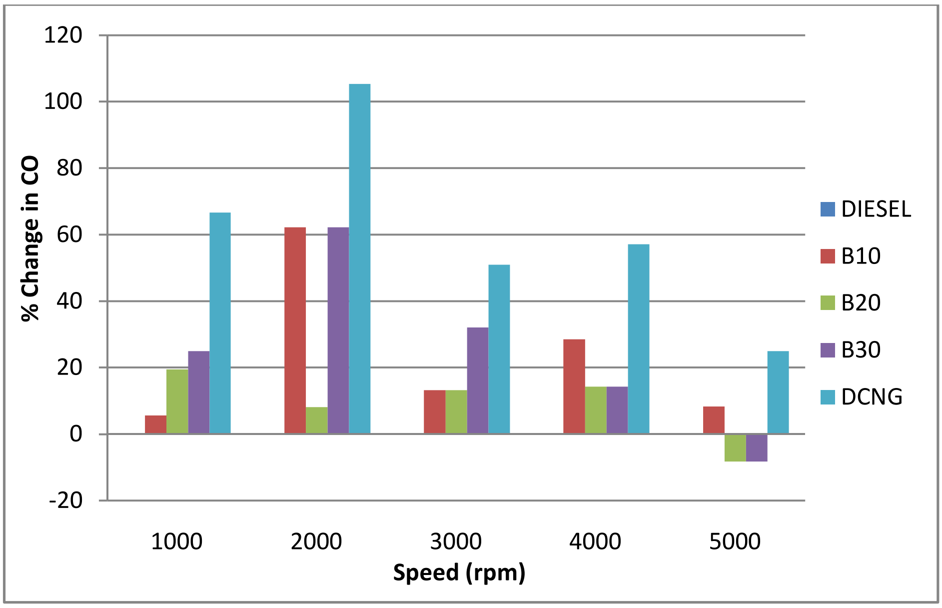


Figure 6.4(d): Change in CO with different fuels compared to pure diesel as baseline

6.4.3 Variation in HC Emissions

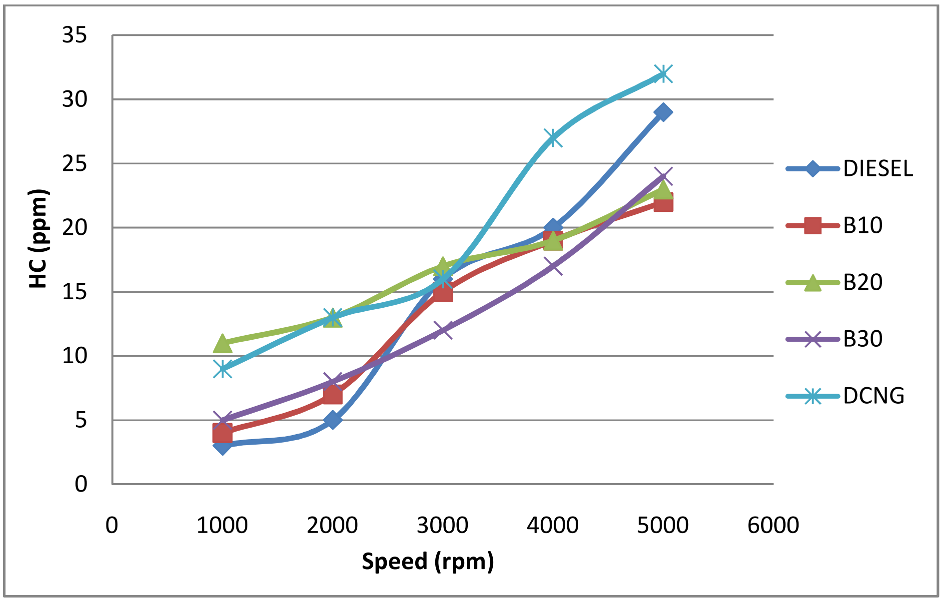


Figure 6.4(e): Comparison of HC Vs Speed for different fuels

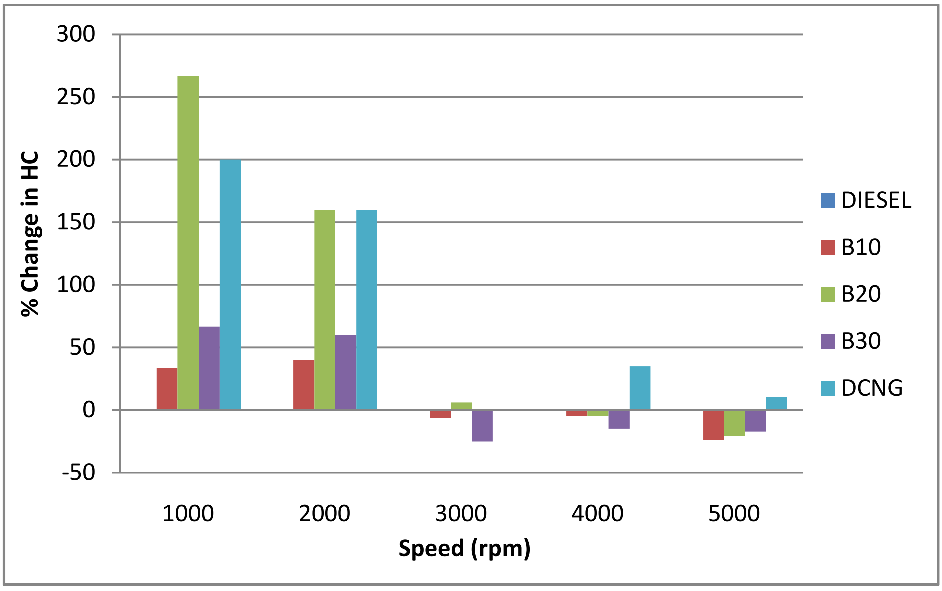


Figure 6.4(f): Change in HC with different fuels compared to pure diesel as baseline

6.4.4 Variation in Nitrogen Oxides

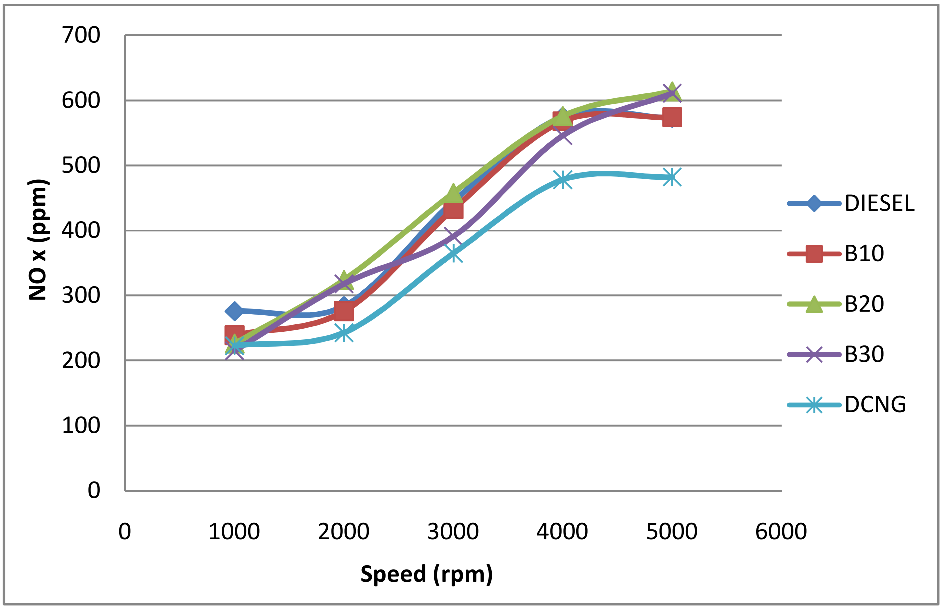


Figure 6.4(g): Comparison of NO_X Vs Speed for different fuels

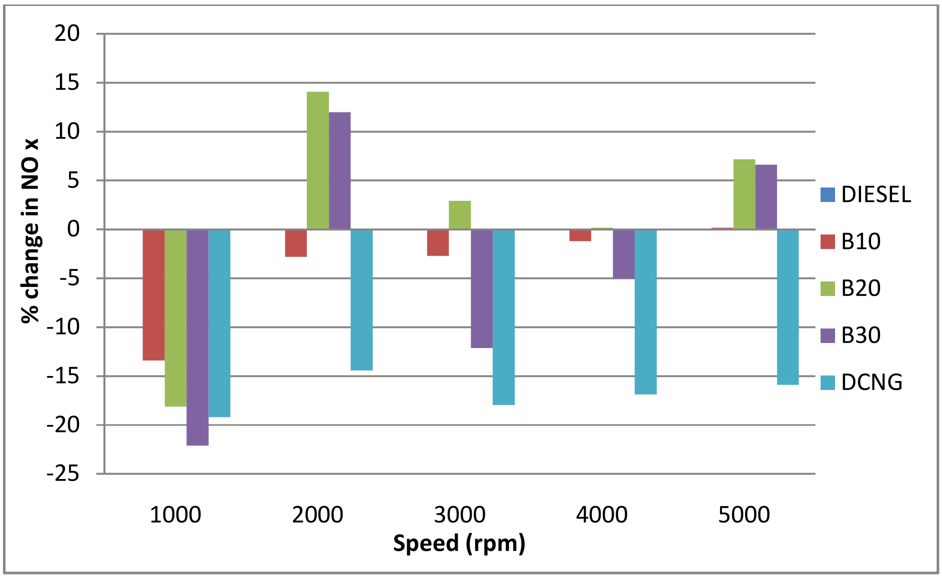


Figure 6.4(h): % Change in NO_X with different fuels compared to pure diesel as baseline

CHAPTER-7

CONCLUSION AND FUTURE RECOMMENDATIONS

7.1 Conclusion

The dual fuel technique is a good method to take the advantage of both the fuels, diesel and alternative fuel (CNG). It is observed that the diesel engine have some disadvantages over alternative fuels running at the higher speed like higher knocking tendency, higher specific fuel consumption and comparatively higher emissions. On the other hand dedicated CNG engines converted from diesel engines also have some drawbacks like higher conversion cost, low engine power etc. Therefore to take the advantages of both the fuels a bridge technology in between both the fuel is used. That's why diesel-CNG dual fuel mode is used by combining them through the arrangement of supplying of CNG in intake air suction pipe of the engine. The engine is tested with pure diesel, blends of Biodiesel (B10, B20 and B30) and diesel-CNG dual fuel mode.

The following conclusions have been made from the experiments:

1. Engine running on the diesel-CNG dual mode produced less knock at the higher speed comparatively to the pure diesel. In starting at slow speed in dual fuel mode knocking was higher but with increase of engine speed knocking was less in dual fuel case.
2. The performance parameters were also improved in case of duel fuel mode. Torque produced in duel fuel mode was higher upto 4000 rpm after that at high speed it will start decreasing. In starting torque produced was 30% more than produced diesel fuel. There was slight decrease in break power of the engine at higher speed.
3. The break thermal efficiency of engine has improved in diesel-CNG dual fuel mode as compared to other fuels. At higher speed BThE increased by 14% than pure diesel mode.

4. The specific fuel consumption has also reduced due to the use of CNG. The SFC first decrease up to 3000 rpm than becomes almost constant and after a specific speed it starts increasing at higher speed.
5. The smoke opacity is reducing in our alternative fuels. The main advantage of using alternative fuels is to reduce the exhaust emissions. The smoke opacity is decreasing in case of all the alternative fuels. At 5000 rpm there was slight increase in opacity which is negligible.
6. There is slight increase in CO and HC emissions in case of dual fuel mode. This is the disadvantage of diesel-CNG dual fuel mode. This problem can be resolved by using the emission control technologies or by after exhaust treatments.
7. The main advantage of using diesel-CNG dual fuel mode is reduction in oxides of nitrogen in engine exhaust emissions.

7.2 Scope for Future Work

The future work on this project can be as follows:

- The present setup suffers the problem of variation of the CNG flowrate with the variation of engine RPM, this can be eliminated with the help of Electronic fuel control (ECU) unit, That can be used to better control and effective utilization of the fuel.
- Multipoint fuel injectors can be used to inject the primary fuel.
- By using EGR system, further reduction of NOx emissions is possible.
- In place of CNG, Hythane (blend of 20% hydrogen and 80% CNG can be used) as an alternative fuel. This will increase the flame velocity of the CNG and gives better combustion with reduced emissions.

7.3 Recommendations

The CNG implementation 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 implementation has helped 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. In view of the above, the recommendations are as follows:

- Government and the regulating agencies need to aggressively advocate and promote the use of Public Transportation means. It also needs to increase the infrastructure of public transport.
- Emission norms for diesel cars need to be more stringent.
- Any city or authority thinking of implementing CNG as an automotive fuel must learn from the mistakes committed by agencies involved in CNG implementation in Delhi.
- Moreover as Safety is the most important parameter while handling CNG, therefore adequate infrastructure must be developed for inspection of CNG vehicles, especially public transport vehicles.

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