A

DISSERTATION REPORT

ON

EFFECT OF COMPRESSION RATIO ON PERFORMANCE AND EMISSION CHARACTERISTICS OF SI ENGINE FUELED WITH BLENDS OF N-BUTANOL AND GASOLINE

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF

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CERTIFICATE

This is to certify that the dissertation report entitled ***“Effect of compression ratio on performance and emission characteristics of SI engine fueled with Blends of n-butanol and Gasoline*”** submitted by ***Mr. Ankit Kumar Agarwal*** (ID No. 2012PME5214) to the Malaviya National Institute of Technology Jaipur for the award of the degree of Master of Technology in Energy Engineering is a bonafide record of original work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirement for the submission of this thesis, which has reached the requisite standard.

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DECLARATION

I, ***Ankit Kumar Agarwal*** hereby declare that the dissertation entitled ***“Effect of compression ratio on performance and emission characteristics of SI engine fueled with Blends of n-butanol and Gasoline***” being submitted by me towards the partial fulfillment of the degree of M. Tech (Energy Engineering) is a research work carried out by me under the supervision of Dr. S. L. Soni, and has not been submitted anywhere else. The thesis has been checked for Plagiarism. I will be solely responsible if any kind of plagiarism is found.

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(Ankit Agarwal)

Abstract

The consumption of petroleum is increased drastically. About 72% of crude oil will be imported for fulfill the requirements. The sources for the crude oil are also limited and depleted very soon. Along with the fuel, emission exhausted by the fuel burning in the engine is a very vital problem. The gases emitted from the engine are very health hazardous to the human being and the animals also. For this situation, it is necessary to find a new fuel which is renewable and can be develop easily.

A new alcoholic fuel n-butanol, which is completely renewable made by the lignocellulose, is used for the testing of the spark ignition engine. In this research, the engine is running with the fuel blends of n-butanol and gasoline and find out the engine performance and emission parameters.

In this dissertation report, engine performance and emission characteristics of single cylinder four stroke spark ignition engine have been experimentally studied for gasoline and gasoline/n-butanol blends in a wide range of applied load without any tuning and modification of the engine. The performance characteristics such as brake thermal efficiency and brake specific fuel consumption have been evaluated for gasoline and blends of gasoline/n-butanol such as B0 (100% gasoline), B5 (gasoline 95% + 5% n-butanol) by volume, B10 (gasoline 90% + 10% n-butanol), B15 (gasoline 85% + 15% n-butanol), B20 (gasoline 80% + 20% n-butanol) and B25 (gasoline 75% + 25% n-butanol) at the compression ratio of 4.67:1, 6:1 and 8:1. Similarly emission characteristics such as CO, CO_2, HC and NO_x have also been evaluated and analysed.

Results of test engine indicated that using n-butanol, the brake thermal efficiency is increased and brake specific fuel consumption decreased as a result of proper fuel combustion and higher oxygen content. As the compression ratio increased, the BTE was also increased by 18.63% and by adding 25% n-butanol, it was increased by 23.24%. The emissions of CO, CO_2, HC and NO_x were also decreased by 92.18%, 23%, 38.14% and 18.29% respectively by the fuel of B25 at CR 6:1 compared with those of gasoline at original CR.

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Abbreviations

BMEP	Brake Mean Effective Pressure
BSFC	Brake Specific Fuel Consumption (kg/kW-h)
BP	Brake Power (kW)
BTE	Brake Thermal Efficiency (%)
CI	Compression Ignition
CO	Carbon Monoxide (%)
CO_2	Carbon Dioxide (%)
CR	Compression Ratio
CV	Calorific Value (kJ/kg)
IC	Internal Combustion
I.P.	Indicated Power (kW)
m_f	Mass Flow Rate of Fuel (kg/h)
NO_x	Nitrous Oxide (ppm)
O_2	Oxygen (%)
SI	Spark Ignition
UHC	Unburnt Hydrocarbons (ppm)
VCR	Variable Compression Ratio

Nomenclature

B0	n-Butanol 0% + Gasoline 100%
B5	n-Butanol 5% + Gasoline 95%
B10	n-Butanol 10% + Gasoline 90%
B15	n-Butanol 15% + Gasoline 85%
B20	n-Butanol 20% + Gasoline 80%
B25	n-Butanol 25% + Gasoline 75%

Chapter 1

Introduction

1.1 General Introduction

Today, the fuel is produced from the fossil fuels. The reserves of these fossil fuels are limited and depleted soon, if the consumption is high. The population growth and technological development of the developing countries are the most of reason for increasing the demand of energy. In parallel with the growing world population, vehicle, industries equipment etc. requires a rise demand of energy. The production of these fuels and use of them, impact negatively on the environment is an important factor and cannot be ignored. These circumstances have been promoted for the research on alternative fuels. The experiments have concentrated on reducing fuel consumption and reducing the concentration of toxic components in exhaust emissions by renewable, sustainable, non-petroleum and non-polluting fuels [1]. The most of the energy consume today is produced from the fossil fuels. The demands of clean energy have also been increasing due to continuing increases in the cost of fossil fuels [2].

Energy diversity is a vibrant factor for commercial growth and environmental protection. Building a strong base of energy resources is required for concern the efforts which are made to search a potential alternate [3].

Emission are generated as a by products from combustion of the fuel in the engine. The main emissions of the engines are carbon monoxide (CO), hydrocarbons (HC), carbon dioxide (CO_2), and oxides of nitrogen (NO_x) (formaldehyde and particulate matter are also produced). As a compound hydrocarbon, gasoline is a particularly polluted-burning fuel [4]. The carbon dioxide becomes a potential health hazard in a confined area, if concentration exceeds 5000 ppm, otherwise it is not considered as pollutant as nature recycles it and produces oxygen [5].

In the developing countries, one of the most problem arises today is increasing air pollution. The air is mainly polluted by exhaust emissions from the motor vehicle. The idea of change the design of motor vehicle is not so sufficient to cope with the legal regulations; it is required to find the alternative fuel and doing the research on them.

These alternative fuels must be produced from renewable resources and must be directly used in the engine without modifying the structure of the engine [6].

The position of India in energy consumption has sixth in the world and it will by improved to third after USA and China by 2020 with increase in annual consumption rate of 6.8% from 1999 to 2020. India imports 72% of crude oil for fulfilled the requirement of crude oil. It will be planned to self-dependent on the crude oil by replace the gasoline/ diesel by alternative fuel. Table 1:1 represents the percentage consumption of petroleum in various sectors.

Table 1:1 Percentage consumption of petroleum in various sectors of India [7]

Sector	**Approximate Consumption**
Transport (Petrol, Diesel, CNG, Aviation fuel)	51%
Industry (Petrol, Diesel fuel oil, Naphtha, Natural Gas)	14%
Commercial & others	13%
Domestic (LPG & kerosene)	18%
Agriculture (Diesel)	04%

1.2 Spark Ignition Engine

Spark ignition engines are widely utilized in the two/three wheeler vehicles, light motor vehicles, sports utility vehicles, small water pump sets, as a vibrator, small electricity generator set ups etc. The engine used for the research purpose used as the small water pumps, electricity generators and as a vibrator. The motive of this research is to replace fully or partially the gasoline fuel by the renewable fuel and increase the engine performance to a certain extent and reduce the emission of pollutants from the engine running with renewable fuel.

1.3 Alternative fuels for SI Engines

Performance of SI engines is increased by adding the suitable additives to the fuel reduced with the present technology. Additives are integral part of today’s fuel. Together with carefully formulated base fuel composition they contribute to efficiency and long life. They are chemicals, which are added in small quantities either to enhance fuel performance, or to correct a deficiency as desired by the current legislation. They can have surprisingly large effects even when added in little amount. Additives are blended into fuel by refineries or end users. However use of metallic additives was subsequently discontinued mainly because of concern about the toxicity of the barium compounds in the exhaust emission. But the interest is revised recently to verify the possible use of additives to reduce emission level. Alcohol has been used as a fuel for Auto-engines since 19th century; it is not widely used because of it high price. Alcohol is one of the fuel additive has some advantage over gasoline such as better antiknock characteristics and the reduction of CO and HC emissions [5].

Lower molecular mass alcohols, in comparison, burn nearly pollution-free. Alcohols already contain oxygen integral with the fuel, which can lead to a more homogenous combustion. Alcohols burn with a faster flame speed than gasoline, and they do not contain additional elements such as sulphur and phosphorus. All these factors work in lower molecular mass alcohol's favour with regard to emissions [4].

The following alcohols are the most promising substitute for petroleum fuels used in SI engines are

i. Methanol
ii. Ethanol
iii. Butanol

Methanol can be produced from a wide range of abundantly available raw materials lignite or coal, municipal solid wastes and waste or specifically grown biomass. Ethanol can be produced from sugar and grain. Butanol can be biochemically produced from both agricultural crops and lignocellulosic biomass. The sources of production of these alcohols are mainly biomass and available abundantly in wide range. So these alcohols generally referred as an alternative fuels.

1.4 Production of Butanol

Butanol is a very attractive alternative fuel compared with gasoline besides ethanol because of end use in existing vehicle and gasoline blending. Butanol has more energy content i. e. 30% greater than ethanol and is closer to gasoline. It has additional properties like less volatile, low sensitivity to water, low vapour pressure and less flammable when compared with other biofuels.

In the alcohols, one of the carbon atoms is attached with the hydroxyl group (-OH). It has 4-carbon structure either in the form of straight chain or branched, resulting different properties. The location of –OH decides the different isomers of butanol. The carbon structure and their isomers are shown in the Figure 1:1. n-butanol also known as 1-butanol and sec-butanol also known as 2-butanol have straight chain structure differencing the position of –OH ion. In n-butanol, the –OH ion is at terminal carbon and in sec-butanol, -OH is attached with internal carbon. Iso-butanol and tert-butanol are branched isomers with the –OH ion at the terminal carbon and at internal carbon respectively. The physical properties of the butanol such as boiling point, octane number, viscosity etc. are largely dependent on the structure of butanol. Although the main applications like industrial cleaners, solvents, gasoline additives are common for all structures. All the different structure of butanol / isomers can be produced from fossil fuels but, straight chain structure of butanol i.e. n-butanol usually derived from biomass.

1-Butanol/n-butanol 2-butanol/sec-butanol iso-butanol tert-butanol

Figure 1:1 Carbon structures of n-butanol & their isomers

Butanol is very competitive biofuel for the engines. By alcoholic fermentation of the biomass feedstocks, butanol can be obtained as a biomass based renewable fuel. Methanol and ethanol have 1 and 2-carbon structure while butanol has 4-carbon structure, having more complex structure than others. Butanol can be blend with gasoline and diesel. Due to higher heat of vaporization, NO_x emissions can be reduced resulting lower the combustion temperature [8]. The butanol has more advantages because of more oxygen content than ethanol and other fuels. The butanol has disadvantage of quite low production, however higher production rate has become possible in recent years with the development of butanol fermentative process.

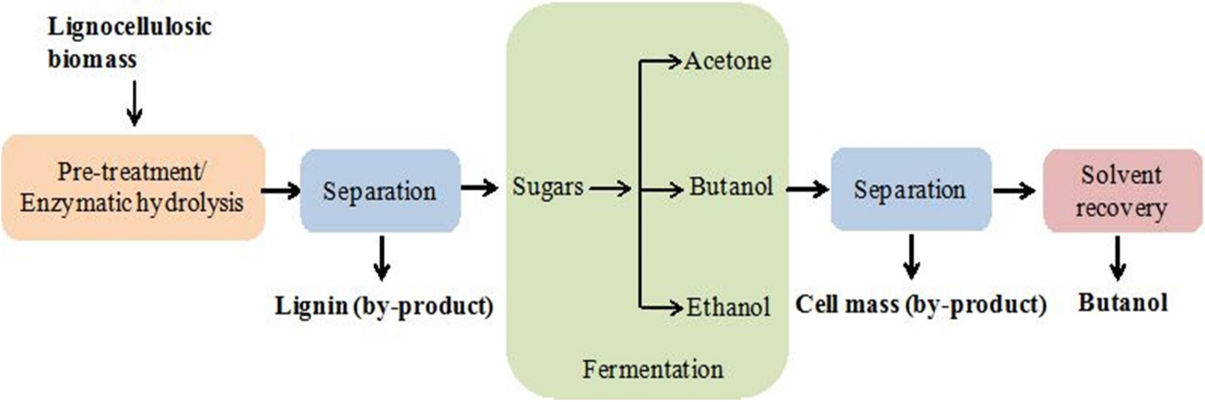

Figure 1:2 Schematic diagram for butanol production, from biomass [9]

By the agricultural crops and lignocellulosic biomass, butanol can be produced using Clostridium acetobutylicum or C. beijerinckii to ferment lignocellulosic hydrolysate sugars to butanol [9]. For large scale production of butanol, sugar-rich agricultural crops e.g. cane molasses, corn and whey permeate have been successfully used as feedstock. As the price of these crops rises, butanol is produced by the lignocellulosic biomass which becomes most popular substrate. The pre-treatment using cellulase and cellubiose are required prior to enzymatic hydrolysis. The fermentation is done on resulted lignocellulosic hydrolysate by microorganisms via Acetone-butanol-ethanol (ABE) fermentation. The schematic diagram for production of butanol from biomass is shown in the Figure 1:2. The produced butanol is toxic to the producing bacterium, substrate to product conversion efficiency. Due to long leg phase, product inhibition and downtime, the productivity in batch reactors is often low. Using fed-batch techniques and continuous culture with product removal techniques, this problem can be eliminated. To improve the solvent production and butanol production ratio, genetic modification is a viable method. The key enzymes Clostridia and their genes acting on the butanol synthetic pathway in C. aectobutylcum provide the facility to breakdown the polymetic carbohydrates into monomers [10].

At low butanol concentration, this procedure uses a lot of energy and is the cost-intensive since butanol has higher boiling point than water. Lignocellulose substrate is the best potential substrate than corn fibre hydrolysate, starch-based packaging materials, soy molasses, whey permeate and fruit processing industry waste. For large scale production of butanol, lignocellulose is the most efficient bioconversion of cellulose and hemicellulose which is crucial to economic success [11].

1.5 n-butanol: Merits & Demerits

The merits of n-butanol are given as follows.

i. Higher heating value: The heating value of alcohol is dependent on the carbon atom number in the structure. As the carbon atom increased, rise in the heating value. n-butanol have 4-carbon atom, 2 more carbon atom than ethanol having 25% more energy than ethanol. Resulted low fuel consumption rate and better mileage.
ii. Lower volatility: As the carbon atom increases, the volatility of alcohols decreases. For n-butanol, tendency towards vapour lock problem and cavitation will be very low.
iii. Higher oxygen content: n-butanol contains 21.6% of oxygen molecules. [12]
iv. Less ignition problem: The heat of vaporization of butanol is lower than half of that of ethanol. Due to this, the engine will be start easier in cold weather than running on methanol and ethanol.
v. Inter-solubility: Butanol can easily blend with gasoline without any solvent due to more carbon atoms containing alkyl and hydroxyl ions.
vi. Higher viscosity: As the carbon chain increases, the viscosity of alcohols increases. The viscosity of butanol is higher than gasoline, but it can be easily dissolve in the gasoline.
vii. More safer: due to very low vapour pressure and high flash point, in the high temperature, butanol is a much safer fuel.
viii. Easier distribution: Butanol has less corrosive property. There is no corrosion in the pipeline and it tolerate with water contamination, when it is distributed through the existing pipeline. If the fuel is contaminated with water, separation of butanol is impossible.

As the butanol have more advantages over the ethanol and methanol, the low carbon alcohols, still some potential issue will remaining with the use of butanol in the engine. These potential issues (demerits) are as follows:

i. As the heating value of butanol is greater than that of ethanol and methanol, but comparing with gasoline, it is still lower than gasoline. It is required to increase the fuel flow of butanol as a substitute of gasoline to match the engine performance.
ii. Butanol has lower octane number than ethanol and methanol. For higher compression ratio and engine efficiency, higher octane number is required. There is no effect of higher energy density of butanol.
iii. Higher viscosity of butanol incurred a potential aggradation or corrosive problems with direct use of blend of butanol and gasoline in SI engine.

The above advantages and disadvantages of the properties show that n-butanol has the potential to overcome the drawback brought by the low carbon alcohols. The comparison of various physical and chemical properties between gasoline and n-butanol is given in Table 1:2.

1.6 Performance characteristics of engine

Engine performance is an indication of the degree of success with which it is doing assigned job, i.e. the conversion of chemical energy contained in the fuel into the useful mechanical work.

In the evaluation of the engine performance certain parameters are chosen and the effects of various operating conditions, design concepts and modifications on these parameters are studied.

1.6.1 Thermal Efficiency

Thermal efficiency of an engine is defined as the ratio of the output to that of the chemical energy input in the form of fuel supply. It may be based on brake or indicated output. It is the true indication of the efficiency with which the chemical energy of fuel (input) is converted into mechanical work. Thermal efficiency also accounts for combustion efficiency, i.e., for the fact that whole of the chemical energy of the fuel is not converted into heat energy during combustion [13].

$$\text{Brake thermal efficiency} = \frac{\text{b.p.}}{\text{m}_\text{f} * \text{C.V.}}$$

Where, Cv = Calorific value of fuel, kJ/kg, and

m_f = Mass of fuel consumption rate, kg/sec.

Table 1:2 Physical and chemical properties of Gasoline and n-butanol [12], [14], [15]

S. No.	Property	Gasoline	n-Butanol
1	Chemical formula	$C_4 - C_{12}$	C_4H_9OH
2	Molecular weight	95-120	74.12
3	Composition by weight-% Carbon Hydrogen Oxygen	 84.0 16.0 0	 65 13.5 21.5
4	Viscosity (mm^2/s) at 40°C	0.8	2.63
5	Boiling point or range °C	25 - 215	118
6	Latent heat of vaporization KJ/kg	380 - 500	716
7	Density (kg/m3) at 28°C	740	810
8	Lower calorific value (kJ/kg)	44200	33100
9	Stoichiometric Air/fuel ratio	14.7	11.2
10	Self-ignition temperature °C	250-450	300 - 385
11	Octane number	91	87

1.6.2 Brake Specific Fuel Consumption

Specific fuel consumption is defined as the amount of fuel consumed for each unit of brake power developed per hour. It is a clear indication of the efficiency with which the engine develops power from fuel.

$$\text{Brake specific fuel consumption (bsfc)} = \frac{\text{Fuel consumed in kg/hr}}{Brake\ Power}$$

This parameter is widely used to compare the performance of different engines.

1.7 Emission Characteristics

Tail pipe exhaust emissions are the major source of automotive emissions. Petrol consists of a mixture of various hydrocarbons and if we could get perfect combustion then the exhaust would consist only of carbon dioxide and water vapours plus air that did not enter the combustion chamber process. Hence, for several reasons combustion is incomplete and hence we also get carbon monoxide, a deadly poisonous gas, and un-burnt hydrocarbons in exhaust. Hydrocarbon plays an important role in the formation of smog. The two important reasons for incomplete combustion of the fuel are cool metal surfaces of the combustion chamber and imperfect mixture ratio.

In addition to CO and HC, third main pollutant is oxides of nitrogen. The air supplied for combustion contains about 77% nitrogen. At lower temperature the nitrogen is inert but the temperature higher than 1100°C nitrogen reacts with oxygen. During the combustion process some of the nitrogen in the fuel air mixture due to the high temperature in the combustion chamber, unites with oxygen to form various oxides of nitrogen. Some oxides of nytrogen are very toxic and harmful.

NO_x and CO are formed in the burned gases in the cylinder.

- NO_x is formed by oxidation of molecular nitrogen. During combustion at high flame temperatures, nitrogen and oxygen molecules in the inducted air breakdown into atomic species which react to form NO. Some NO_2 is also formed and NO and NO_2 together are called as NO_x.
- CO results from incomplete oxidation of fuel carbon when insufficient oxygen is available to completely oxidize the fuel. CO rises steeply as the air-fuel (A/F) ratio is decreased below the stoichiometric A/F ratio.
- HC originates from the fuel escaping combustion primarily due to flame quenching in crevices and on cold chamber walls, fuel vapour absorption in the oil layer on the cylinder and in combustion chamber deposits, and presence of liquid fuel in the cylinder during cold start.

Main sources of hydrocarbon emissions in the four-stroke, homogeneous charge spark ignition engines are:

(i) Flame quenching on the cylinder walls

(ii) Flame quenching in crevices

(iii) Absorption and desorption in oil film on cylinder walls

(iv) Absorption and desorption in carbon deposits in the chamber

(v) Misfired combustion or bulk gas quenching

(vi) Liquid fuel in the cylinder

(vii) Exhaust valve leakage, and

(viii) Crankcase blow by gases

Air-fuel ratio is one of the most important parameter that affects the engine exhaust emissions. The SI engine is operated close to stoichiometric air-fuel ratio as it provides a smooth engine operation. Nitric oxide emissions are maximum at slightly (5-10%) leaner than stoichiometric mixture due to combination of availability of excess oxygen and high combustion temperatures at this point. Carbon monoxide and HC emissions reduce with increase in the air-fuel ratio as more oxygen gets available for combustion.

1.8 Effect of compression ratio over efficiency

Improving internal combustion (IC) engine efficiency is a prime concern today. A lot of engineering research has gone into the improvement of the thermal efficiency of the (IC) engines, so as to get more work from the same amount of fuel burnt. Of the energy present in the combustion chamber only a portion gets converted to useful output power.

All the methods of increasing the power output of an engine bring with them a host of problems. For example, increasing engine speed imposes dynamic loads and increased wear, thereby, reducing reliability and life. High speed also increases the pumping losses which may become unacceptable especially for part load operation. Use of high pressure turbo-charging results in very high peak cycle pressure and also imposes higher thermal loads.

One method of solving the high peak pressure problem encountered when the specific output is increased due to reduce the compression ratio at full load but at same time keeping the compression ratio sufficiently high for good starting and part load operation. Thus, it is clear that a fixed compression ratio engine cannot meet these requirements of high specific output, hence, the development of variable compression ratio (VCR) engine.

Compression ratio is the ratio of the total volume of the combustion chamber when the piston is at the bottom dead centre to the total volume of the combustion chamber when piston is at the top dead centre. Theoretically, increasing the compression ratio of an engine can improve the thermal efficiency of the engine by producing more power output. The ideal theoretical cycle, the Otto cycle, upon which spark ignition (SI) engines are based, has a thermal efficiency, η_T, which increases with compression ratio, r_c and is given by [5].

$$\eta_T = (1 - \frac{1}{{r_c}^{\gamma-1}})$$

However, changing the compression ratio has effects on the actual engine for example, the combustion rate. Also over the load and speed range, the relative impact on brake power and thermal efficiency varies. Therefore, only testing on real engines can show the overall effect of the compression ratio. Knocking, however, is a limitation for increasing the compression ratio.

1.9 Objective of the work

The objective of this dissertation is to study the performance and emission characteristics of SI engine fuelled with different blends of n-butanol and gasoline at different compression ratios. For the purpose, following subjectives are being decided.

- To review the literature of alternative fuels for SI engine
- To conduct load test on SI engine with blended alternative fuels.
- To draw various performance and emission curves.
- To analyze the curves and find best suitable blend.

1.10 Organization of Chapters

The chapters of this reports contains the following information:

Chapter: 2 named literature review represent the past studies on the gasoline engines running on the various alternative fuels. These studies describe the behaviour of the engine running with different alternative fuels at different compression ratios. Finally conclusion is derived for the progress and motive of this research work.

Chapter 3 named materials and methods introduces the various equipment used here for the research work, with working principle, schematic and pictorial diagrams. And lastly experiment procedures are described.

Chapter 4 named results and discussion contains the results obtain form the engine performance and exhaust emissions and their analyses. Some comments are made on the results by the researchers to explain the trends of results obtain from the engine.

Chapter 5 named conclusion presents the summery of the results and tell about the preference of the alternative fuel and optimum compression ratio on which engine perform with better efficiency and emits less pollutions.

Chapter 2

Literature Survey

This chapter deals with the past research done and published in field of four stroke spark ignition engine using alcoholic fuels/alternative fuels. It represents the variations in the engine performance and exhaust emissions with different alternative fuels compared with gasoline at different compression ratios. The previous work done with butanol blends has been shown here to prepare a better background. Finally, problem formulation is shown in the latter part of this chapter.

2.1 Methanol/Ethanol as an Alternative Fuel

Aina et al. [16] performed an experiment on Ricardo four stroke single cylinder spark ignition variable compression ratio engine. To increase the compression ratio, lowering the cylinder head down, and to decrease, rose the head up. The test CRs were taken as 5, 6, 7, 8 and 9 and the test speeds were 1100 to 1600 rpm, in increment of 100 rpm. Results reported that with increasing in the compression ratio, the BSFC decreases by 7.75%, brake power and brake thermal efficiency improves by 1.34% and 8.49% respectively. The optimum compression ratio was 9:1, where brake power, brake thermal efficiency and brake mean effective pressure were obtained maximum and minimum BSFC.

Celik et al. [17] experimented on variable compression ratio engine whose original CR was 6:1. For changing compression ratio of the engine, modified cylinder head was used. The test CR was 6:1, 8:1 and 10:1 and test fuel was methanol and gasoline. The base line reading was taken at CR of 6:1 with gasoline and methanol at full load and various speeds. The knock was observed using gasoline, at the CR 8:1 while using methanol, knock was not observed at the CRs of 8:1 and 10:1. The comparative results between gasoline and methanol showed that with use of methanol, at the CR of 6:1, CO, CO_2 and NO_x emissions were reduced without any power loss. With methanol, the BSFC values were higher than those of gasoline at all the CRs. The engine power and BTE were increased up by 14% and 36% when CR is increased from 6:1 to 10:1. While CO, CO_2 and NO_x emissions were decreased by 37%, 30% and 22% respectively. The value of HC was increased by 12% with increasing in the CR from 6:1 to 10:1 with methanol.

Celik [1] investigated the results on a four stroke single cylinder small engine of CR 6:1 was used. The test CRs was 6:1, 8:1 and 10:1. Modified cylinder heads were used to change the compression ratio from 6:1 to 10:1. 1.5 to 1.8 times more ethanol was used to got same energy output because of ethanol have lower heating value than gasoline. E0, E25, E50, E75 and E100 were the test fuels for the investigation. The engine was tested with E0 at CR 6:1 only because of observation of knocking at higher CRs. The results reported that at CR 6:1, brake power increases when increases the volume of ethanol in the gasoline. The increment in power was obtained 3%, 6% and 2% with E25, E50 and E75 fuels respectively. The reason is that heat of evaporation of ethanol ios greater than gasoline and it provide increased density and cool fuel air charge. Brake power starts to decrease with blend B50 and above. There was a decrement of 4% in power, when running with E100. The value of BSFC was increased as the increase in the volume of ethanol in the blend because of lower heating value of the ethanol. Results also reported that when engine was running with E50 fuel, the power is increased by 29% compared to the running with E0 fuel. The emission parameters like CO, CO_2, HC and NO_x emissions were decreased by 53%, 10%, 12% and 19% respectively. Engine power was increased when increased in the compression ratio from 6:1 to 10:1 and SFC decreases.

Koç et al. [6] investigated the experiments on Hydra brand, four stroke single cylinder spark ignition engine with variable compression ratio of 5:1 to 13:1. The test CRs were taken as 10.0:1 and 11.0:1 and the test fuels were E0, E50 and E85at variable speeds. The results reported that there was an increment in engine torque of 2% with E50 and E85 at CR 10.0:1 and about 2.3% and 2.8% with E50 and E85 at CR 11.0:1 as compared with E0 at test CRs. There were increment of 20.3% and 45.6% in BSFC when tested with E50 and E85 at CR 10.0:1 as compared with E0 blend. At CR 11.0:1, BSFC was increased by 16.1% and 36.4% with blend E50 and E85 respectively, when compared with E0. The emissions of CO, HC and NO_x were lower with E50 and E85 as compared with E0 at all test CRs. Reduction in NO_x is higher at CR 11.0:1 as compared with NO_x emission at CR 10.0:1.

Balki & Sayin [18] carried out the test on single cylinder four stroke spark ignition engine whose original CR was 8.5:1. For increase the compression ratio, then volume of combustion chamber was reduced by grounded cylinder head. The test CRs were 8.0:1, 8.5:1, 9.0:1 and 9.5:1. Results reported that the engine running with ethanol and methanol, BTE and BMEP had increased with increased CRs. But engine running with gasoline, these values were decreased after reached the maximum value along with increasing the CRs. At original CR, the BTE rose about 3.65% with ethanol and 4.51% with methanol. At CR of 9.5:1, ethanol and methanol produced maximum BTE about 30.22% and 30.47% respectively and gasoline produced maximum BTE of 29.73% at 9.0:1 CR. The BSFC was decreased with the increasing in the CR of test fuels of ethanol and methanol, but it was greater than those of gasoline at all CRs. At original CR for ethanol, the BSFC rose about 58.9% and for methanol, BSFC rose about 30.22% as compared with those of gasoline. Emission parameters like CO, HC, CO_2 and NO_x are improved compared with gasoline. However, it will be lower than those of gasoline at all CRs. As comparison with gasoline, reduction of minimum values of HC emissions was 29.01% and 40.12% for ethanol and methanol respectively at CR 8.5:1. At the same time, the CO emission was about 44.88% for methanol and 34.65% for ethanol. The CO_2 emission was increased to about 2.19% with methanol and 1.46% with ethanol at CR of 9.0:1. However, the maximum values for NO_x emissions were decreased to about 22.97% with methanol and 18.1% with ethanol.

Canakci et al. [3] experimented on a vehicle having four stroke, four cylinder, MPFI SI engine whose compression ratio was 10.4:1. For load measurement, chassis dynamometer was mounted on vehicle. The tests were taken on two engine speeds of 80km/h and 100km/h at gear ratio 1:1. The different wheel powers 5kW, 10kW, 15kW and 20kW were selected for the test along with the test fuels E5, E10, M5 and M10. Results revealed that the BSFC was increased by 2.8%, 3.6%, 0.6% and 3.3%, with E5, E10, M5 and M10 with those of pure gasoline at speed 80km/h. At speed 100km/h, the BSFC was decreased, as compared with those at speed 80km/h. The emission of CO at 80km/h was compared with those of gasoline. There were an increment of 18%, 17%, 14% and 11% with E5, E10, M5 and M10 respectively. CO_2 emissions were decreased by 9.5%, 8%, 11.3% and 3% at 80 km/h as compared with pure gasoline. At 100km/h, CO_2 emissions were decreased by 4%, 3.7% and 7% with blends of E5, E10 and M5 respectively. The value of HC emissions were also decreased to a certain extant with the use of blends of ethanol and methanol at both test speeds. The average decrement was founded in the emission of NO_x as 11%, 15.5%, 9% and 1.3% with the blends as E5, E10, M5 and M10 as compared with those of gasoline at 80km/h test speed while, at 100km/h, the NO_x emissions were lower with blend of E5, E10 and M5 and higher with M10 as compared with NO_x of gasoline.

2.2 Butanol as an Alternative Fuel

Elfasakhany [15] experimented on single cylinder spark ignition engine whose compression ratio was 7. The test fuels were neat gasoline and gasoline/butanol blends (B3, B7 & B10). The results reported that using gasoline, the exhaust emissions were greater by 32%, 43% and 26% for carbon monoxide, carbon dioxide and unburned hydrocarbons respectively compared to the blended fuels. When the speed was increased, the difference between exhaust emission of gasoline and blended fuels was reduced. At the maximum speed, the CO_2 emissions by gasoline was 27% higher than the blended fuel and the value of CO and HC emissions was of same magnitude as the blended fuels. Results also reported that with increasing the volume of butanol in the gasoline, the performance parameters were decreases. The engine torque, brake power, in-cylinder pressure, volumetric efficiency and exhaust gas temperature were lower than gasoline by 2.5%, 6.6%, 8.3%, 3.5% and 5.6%, respectively. This means that increasing the volume of butanol in the gasoline blend, the performance characteristics are inferiors and emissions characteristics are improved as compared to those of gasoline. The future scope reported that with increasing in compression ratio of the engine, the engine performance could be improved since butanol has more resistance to knock than gasoline.

Deng et al. [19] performed the experiment on 4 stroke single cylinder spark ignition engine whose compression ratio was 9.2. Test were taken with the two fuels as pure gasoline and B35 butanol/gasoline blend at full load from 3000 rpm to 8500 rpm with the interval of 500 rpm. Results reported that at optimum ignition timing, with addition of butanol, improved results were obtained for brake power, energy consumption and HC & CO emissions. But NO_x emissions deteriorated largely.

Gu et al. [20] studied the results on three cylinder, spark ignition, port fuel injection engine whose CR was 9.6. There were five test fuels namely pure gasoline (B0), three blends of gasoline and butanol (B10, B30 and B40) and pure butanol (B100). The engine was operated on three different loads (full, part and low loads) at engine speed of 3000 rpm. The results showed that the BSFC was higher with B10, B30, B40 and B100 than those of gasoline due to lower heating value of the butanol. The small quantity of n-butanol in the blend was reduced the quantity of HC emissions compared to those of gasoline at different loads. With increasing the quantity of butanol, the emissions of HC was going to be increased. The HC formation was decreased with addition of butanol because of decrement in the fraction of hydrocarbons. Same in the CO emissions, the CO emissions were decreased with blend of gasoline and butanol, while with pure butanol; it gives high specific CO emissions. The NO_x emissions were reduced with butanol at different loads due to the lower heat value and adiabatic temperature as compared with gasoline.

Feng et al. [12] was conducted experimental study on motorcycle single cylinder engine for two load condition of full load and partial load at 6500rpm and 8500 rpm with B35 and pure gasoline. There were improved results in the engine torque, BSFC, HC and CO emission with B35. NO_x and CO_2 emissions were go up with B35 at increasing loads. The role of operating parameters was very high in the engine torque and NO_x emissions. The CO, CO_2 and HC emissions are highly depend on fuel properties and BSFC is affected by the heating value of the fuel and engine operating parameters. With the addition of H2O with B35, the torque was increased by 1.2%, BSFC was decreased by 11.5%, HC and CO emission was decreased by 11.8% and 13.8% respectively. The NO_x and CO_2 emissions were increased by 38.3% and 7.7% respectively on average.

Venugopal & Ramesh [21] used a four stroke single cylinder air cooled engine for experiments whose compression ratio was 9.4:1. The test fuel blends were the proportional of butanol and gasoline by mass as mB0, mB20, mB40, mB60, mB80 and mB100 injected in the engine through dual injection system. The experiment was conducted at different blends by varying throttle position as 15%, 25%, 35% and 100%. Results revealed that as increasing the mass of butanol in the blend, the BTE of the engine was increased as compared with gasoline. The BTE was lower with the blends of mB60, mB80 and mB100 because of higher fraction of butanol in the blends. As the fuel ratio was increased, the NO_x emissions were reduced to a certain extant while emissions of UHC increased.

Jin et al. [22] concluded the performance and emission characteristics based on the literature review. The results reported that the engine power drops as the blending ratio of butanol increased to 30% by volume and BSFC was increased due to lower heating value as compared to gasoline. When the butanol content was below 40%, the change in BSFC was about only 10%. Results also reported that n-butanol had lower specific fuel consumption rather than ethanol blend due to higher heating value. As the butanol rate was higher in the gasoline, higher the unburned alcohol emission. The aldehyde emissions were higher with formaldehyde as the main constituent for n-butanol whereas with addition of ethanol, formaldehyde does not increase significantly.

Siwale et al. [23] et al. carried pout the experiment on Suzuki RS-415 engine with in-line sixteen valves and four stroke multi point fuel injection system whose compression ratio was 11.1. The test fuels for the experiment were M0, M20, M70 and M53B17. Due to high volatilely problem by single alcohol gasoline, duel alcohol gasoline blends were specially used here. Results reported that as the increase in the BMEP, the BTE was increased at all pressures. The higher BTE was obtained with blend M70 at all pressures. The BSFC of all blends was greater than those of gasoline and with increase in pressure, the BMEP of all blends were reduced. The NO_x emissions from the engine for all the test blends were lower than those of gasoline. As the BMEP increases, NO_x emissions were increase, but lower than gasoline at that particular pressure. The lowest emission of NO_x was obtained from engine running with blend M70. The UHC emissions were improved with the blends of methanol and gasoline as compared with pure gasoline. The highest decrement was obtained in HC emission with blend M53B17. The CO_2 emissions were obtained higher with blend M53B17 at higher pressure.

Zhang et al. [14] experimented on four-cylinder DISI engine whose compression ratio was 9.6 with exhaust gas recirculation. Unleaded gasoline, ethanol /gasoline blends (E10 and E20) and n-butanol /gasoline blends (B10 and B20) were the test fuels for the engine with purity of 99.5% of ethanol and butanol. The results reported that octane number and LH/LHV plays important role in anti-knock ability. Higher the octane number, higher the anti-knock ability. The anti-knock ability of all test fuels were in the order as the order of octane number which was arranged as E20 > E10 > Gasoline > B10 > B20 and LH/LHV order was E20 > E10 > B20 > B10 > Gasoline. BSFC of all test blend E20 and B20 was higher than those of gasoline at all test loads. Results also showed that the BSFC was decreases for all the test fuels by about 4.9 - 6.1% with increasing in EGR rate. Due to the reduced heat transfer loss and combustion temperature, the BTE was increased with addition of EGR at high load conditions.

Balaji et al. [5] carried the experiment on four stroke single cylinder spark ignition engine whose compression ratio was 7.4:1. The test fuel was the gasoline with additives of ethanol and ethanol-isobutanol. The results reported that using fuel additives, the performance and emission characteristics were improved. With the addition of 5%

isobutanol and 10% ethanol to gasoline, the BP, BTE and fuel consumption were increased by 6.2%, 8.2% and 6.7% respectively. In addition, BSFC was decreased by 3.4%. Results also revealed that there were reduction in emissions of HC & CO and increment in NO_x emission.

Sayin & Balki [24] experimented on single cylinder four stroke variable compression ratio engine whose compression ratio was varied by the milled cylinder head. The combustion chamber for each CR was corrected by filling it with liquid through spark plug orifice. The test CRs were 9:1, 10:1 and 11:1 and the test fuel were B0, B10, B30 and B50. The results revealed that the negative results of butanol on the BSFC was recovered on the increasing CR. 13% difference was obtained in BSFC, between engine running on CR 9:1 and CR 11:1, as compared with engine running on gasoline at test CRs. There was also an increment in BTE of 2.34%, 5.54%, and 49.91% with B10, B30 and B50 respectively compared to B0. The maximum decrement was observed at CR of 11:1 for the CO and UHC emission was 27.62% and 28.13% respectively while maximum increment was observed for CO_2 as 30.56% with blend B50 as compared to B0.

2.3 Suggestion based on literature review

From the literature review, it is suggested that when we use the alternative fuel in SI engine, the brake power, BMEP and BSFC slightly affected while the exhaust emitted from the engine was reduced to a large extent compared with those of gasoline. If we increase the compression ratio, the torque and BMEP was increased and BSFC was reduced. There is also reduction in emission of HC, CO. Whereas the CO_2 and NO_x were increased because of improved combustion and high cylinder temperature with increase in the compression ratio. From the previous research, it has been observed that effect of compression ratio on performance, combustion and emission characteristics of SI engine fueled with n-butanol is yet to be discovered.

Chapter 3

Materials and Methods

This chapter contains the details of equipment e. g. engine, exhaust gas analyzer, data logger, bomb calorimeter and redwood viscometer etc. to be used for the experimental study, their authentication, calibration and accuracy with schematic and pictorial diagrams. Experimental procedures are also reported in this chapter.

3.1 Introduction

For conducting the experiment, the single cylinder four stroke spark ignition engine manufactured by Greaves is modified by the Technical Teaching (D) Equipments, Banglore, India. The cylinder head is replaced by an auxiliary head for changing the compression ratio. Eddy current dynamometer is provided for apply the load. For data acquisition and computer interface, a data logger is provided for collection of data and calculation of different engine performance and combustion characteristics. Various sensors are mounted at different places for the measurement of temperature, in cylinder pressure, speed, fuel flow rate, water flow rate and air flow rate. A 5 gas analyser is used to evaluate the emission characteristics of the engine.

The fuel blends of n-butanol and gasoline are made for the experiment.

3.2 Experiment Set-Up

The schematic diagram of experiment set up is shown in the Figure 3:1 and Figure 3:2. It consist of engine, couples with eddy current dynamometer, computer interface, data logger, exhaust gas analyser and various sensors for measure the in-cylinder pressure and for measure the temperature at the different points of the engine.

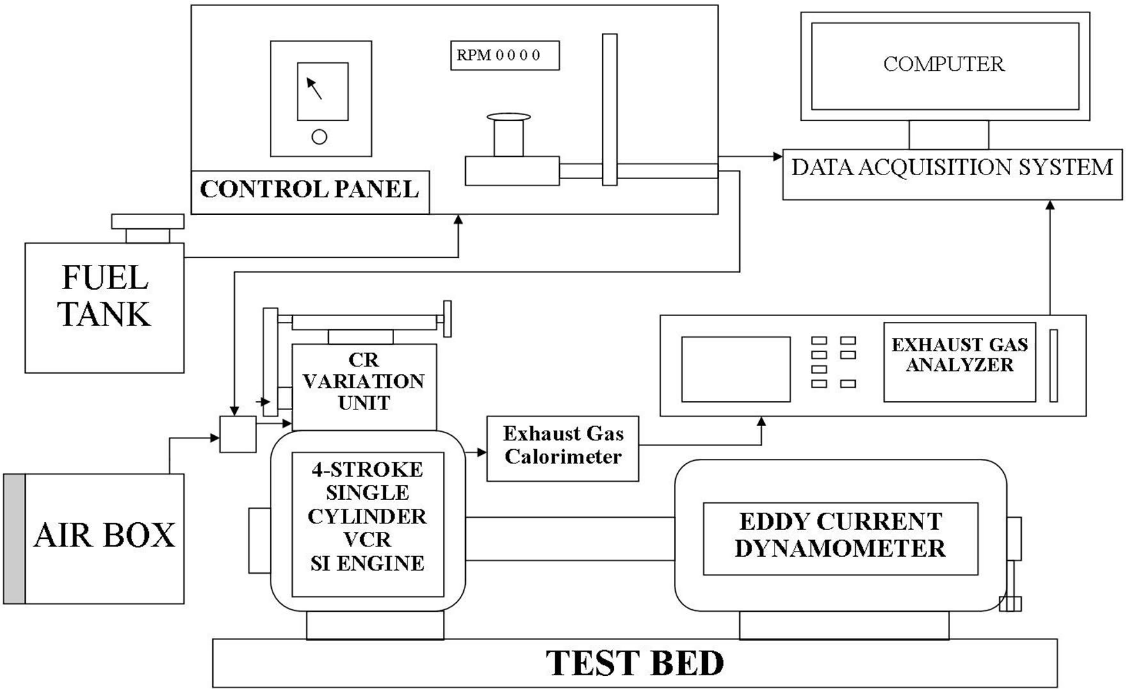

Figure 3:1 Schematic diagram of the engine test rig

1. Engine	2. Air Box	3. Auxiliary Cylinder
4. Dynamometer	5. Exhaust Syphon	6. Battery
7. Gas Analyser	8. Torque Controller	9. Burette
10. Computer Interface	11. Data Logger	12. Fuel Tank

Figure 3:2 Realized engine test rig

3.2.1 Engine

A four stroke single cylinder spark ignition engine manufactured by Greaves is used for the experiment whose original compression ratio is 4.67:1 is shown in the Figure 3:3. This engine is used widely in the country as a portable pump-set for the farmers, small electricity generator, vibrator etc. The specification of the engine is given in the Table 3:1. The engine is then modified by the Technical Teaching (D) Equipments, Bangalore for the research purpose.

Figure 3:3 Single cylinder four stroke SI engine (Greaves make)

3.2.2 Auxiliary Head

An auxiliary cylinder head has been mounted on the engine cylinder to vary the compression ratio as shown in the Figure 3:4. The variation in the clearance volume is done by the piston mounted in the auxiliary cylinder head. When the piston is lowered, the clearance volume is decreased hence compression ratio gets increased as shown in the Figure 3:5. For decrease the compression ratio, piston mounted in the auxiliary head moved upward by the wheel attached with the piston link resulting in increased the clearance volume.

Table 3:1 Specification of the engine

Make & Model	Greaves Cotton & MK-25
Type of the Engine	Vertical, four stroke cycle, single acting, totally enclosed, high speed, SI engine
Fuel	Petrol(Gasoline)
No. of Cylinders	1
Bore x Stroke (mm)	70 x 66.7
Clearance Volume (CC)	54.800
Total Displacement (CC)	256
Compression ratio	4.67:1
Rated Power	2.2 kW/ 3 HP @ 3000 rpm
Max. Torque (Nm)	14
Weight (Kg)	26
Ignition Timing	28 Deg. BTDC
Ignition System	Electronic
Spark Plug	Micro W95T2 / M45Z8
Fuel Capacity (l)	4.5 (Petrol)
Lubrication Method	Splash Type
Engine Oil	20 W 40
Sump Capacity (ml)	1100
Governor Type	Centrifugal Fly
Starting Method	Rope and Pulley - (Recoil Optional)
Direction of Rotation	Anticlockwise @ Drive End

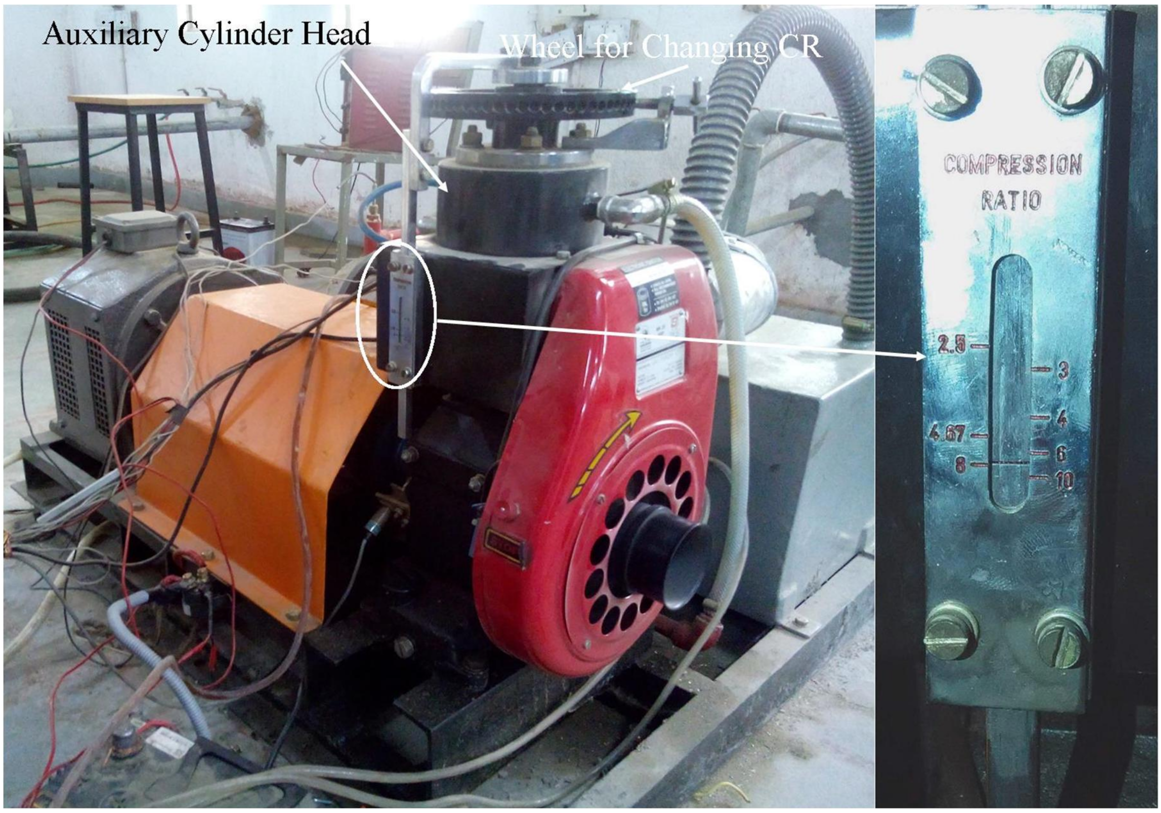

Figure 3:4 Components used for change the compression ratio

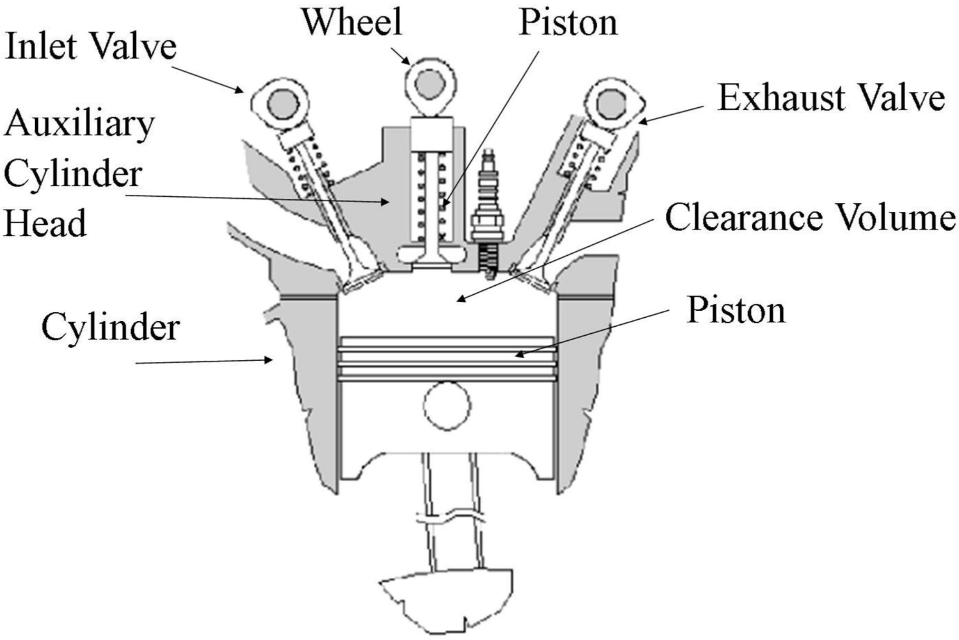

Figure 3:5 Method of change the compression ratio of the engine cylinder

3.2.3 Data logger

Analysis of the engine performance has been computerized with the help of data logger system. A Unitech Data Logger software and hardware arrangement has been used here for engine analysis. The system uses NI6210 high speed data logging card from National Instrument having the capability of logging 250 ks/sec. The power supply to the sensors for all necessary signals is inbuilt. To interface the data logger to the computer, USB communication is provided. EngineTest_10CChPV.exe software developed by LabVeiw Software is provided for data logging and excel printing. The software works on any IBM compatible computer loaded with Window XP or Window 7.

3.2.4 Eddy Current Dynamometer

The Powermug eddy current dynamometer has the components of a tachometer, eddy current clutch and a separate solid state controller. With a hytersics braking system, the dynamometer absorbs power and torque of the engine shaft. The dynamometer provides the torque by the use of two components, one of reticulated pole structure with output shaft and a speciality steel rotor drum fitted with input shaft. The rotor drum can spin freely on shaft bearing until the pole structure is energized.

When the magnetic force is applied to the pole structure, the air gap becomes a flux field and the rotor is magnetically restrained, providing a braking action between pole structure and rotor drum. Powermug torque controller, a solid state electronic controller is used to excite the field coil. Figure 3:6 Shows the eddy current dynamometer coupled to the engine and Table 3:2 represents the technical specification of the dynamometer.

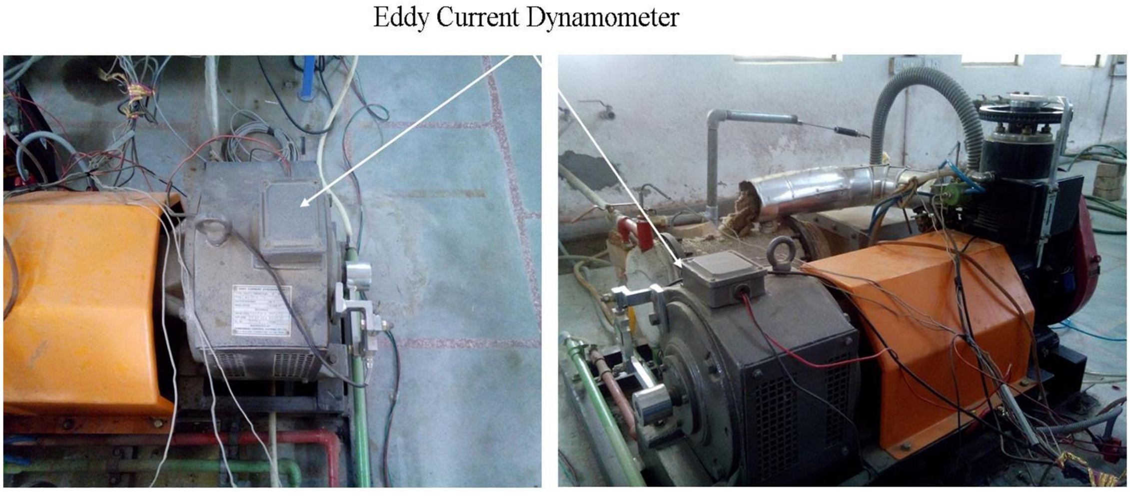

Figure 3:6 Realized Eddy current dynamometer

Table 3:2 Technical specification of eddy current dynamometer

Dynamometer	
Make	Powermag Control Systems (P) Ltd.
Type	FTAC
Duty	S-1
Torque	1.0 kg-m
Speed	3000 rpm
Excitation Max.	80 V
Insulation	Class F
Bearing	
Drive End	6206ZZ / 6306ZZ
Opposite End	6306ZZ / 6305ZZ
Sl. No.	04054
Month/Year	03/2014

3.2.5 Exhaust Gas Analyser

Emission characteristics are measured using ‘five gas’ gas analyser made by INDUS Scientific Pvt Ltd as shown in the Figure 3:7. It is certified by “Automotive Research Association of India (ARAI)”. EPM1601, a gasoline engine exhaust measurement system designed and manufactured by i3sys based on Crestline 7911 NDIR bench.

EPM1601 measures Carbon monoxides (CO), Carbon dioxides (CO_2), Oxygen (O_2), Hydrocarbons (HC), and Oxides of nitrogen (NO_x). The NDIR bench measures CO, CO_2 & HC based on non-dispersive infra-red principle. O2 and NO_x are measured by Electro Chemical Principle. The principle of measurement of these gases are presented in the Table 3:3.

Table 3:3 Principle of measurement of various gases in exhaust gas analyzer

Measurement Parameters	**Principle of Measurement**	**Range**
CO	NDIR	0 – 15 %
HC	NDIR	0 – 20000 ppm

Measurement Parameters	**Principle of Measurement**	**Range**
CO_2	NDIR	0 – 20 %
O2	Electrochemical	0 - 25 %
NO_x	Electrochemical	0 – 5000 ppm

Figure 3:7 Exhaust gas analyser

3.3 Evaluation & Measurement

3.3.1 Measurement of fuel flow rate:

Two capacitive sensors have inbuilt with a glass burette to measure the rate of fuel flow that is controlled by solenoid valve. The solenoid valve is controlled by the digital output of the NI6210 card. When the solenoid stops the fuel inside the burette, fuel will start goes down and when it goes down just below the top sensor, timer starts. Timer stops when the fuel goes just down from the bottom sensor. The fuel flow rate is then calculated using the time required for the volume of fuel consumed (50 ml) between the top sensor and bottom sensor. These arrangements are shown in the Figure 3:8

Figure 3:8 Arrangement of fuel flow measurement

3.3.2 Measurement of load

The engine is coupled to an eddy current dynamometer for loading the engine. The loading end of the shaft of the dynamometer is mounted with a load cell and arm. As the dynamometer is loaded, the load cell senses the load in kg. Multiplying with the arm length, the load is applied on the shaft of the engine can be calculated. Figure 3:9 shows the arrangement of applying the loads.

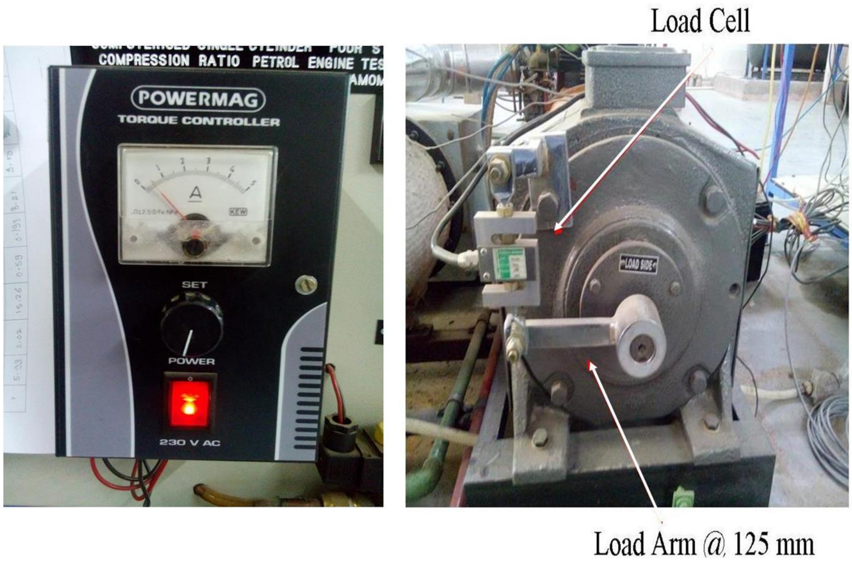

Figure 3:9 Arrangement of applying load on the engine

3.3.3 Measurement of air flow rate

Rate of air flow is measured using orifice with differential pressure transmitter. The orifice is fitted to a 2ft X 2ft metal enclosure, whose coefficient of discharge is 0.62 and diameter is 20.00mm. The metal enclosure is connected to the suction of carburettor. As the engine starts, it starts sucking the air from metal enclosure chamber. The vacuum created in the chamber will starts sucking the air through the orifice. The differential pressure built due to suction of the air inside the chamber is measured. Then air flow rate is calculated based on the coefficient of discharge and diameter of the orifice.

3.3.4 Measurement of water flow rate

Using flow sensors, the water flow rate is measured. At the inlet of the cylinder, the flow formers generate a controlled and constant swirl that causes the rotor to float in the flow stream of the metered fluid. The free rotation of the rotor is almost without friction and proportionate to the fluid throughout. The rotation interrupts an infrared signal that provides a direct pulse output. The infrared beam is generated by a diode and detected by a phototransistor on integrated electronics. Based on the frequency, flow rate is calculated.

3.3.5 Measurement of temperature

Using K type thermocouples, the temperature at four different places like inlet water temperature, outlet water temperature, room temperature and exhaust temperature are measured.

3.3.6 Measurement of engine speed

The engine speed is measured using encoder fitted to measure the angle position of the piston inside the cylinder. The encoder pulse frequency is measured and RPM of the engine calculated.

3.3.7 Measurement of cylinder pressure

To measure the cylinder pressure of the engine, quadrature encoder is fitted to the engine of shaft. The encoder gives 360 pulses per revolution in A and also in B. Z pulse is matched to the TDC of the engine. M/S Kister Instrument make combustion pressure sensor is used to measure the pressure inside the cylinder as shown in the Figure 3:10. The system starts taking the pressure reading when the TDC is detected. The readings are taken for every0.25° of rotation of the engine up to 720° (i. e. around 28809 readings for 2 rotation of the engine.

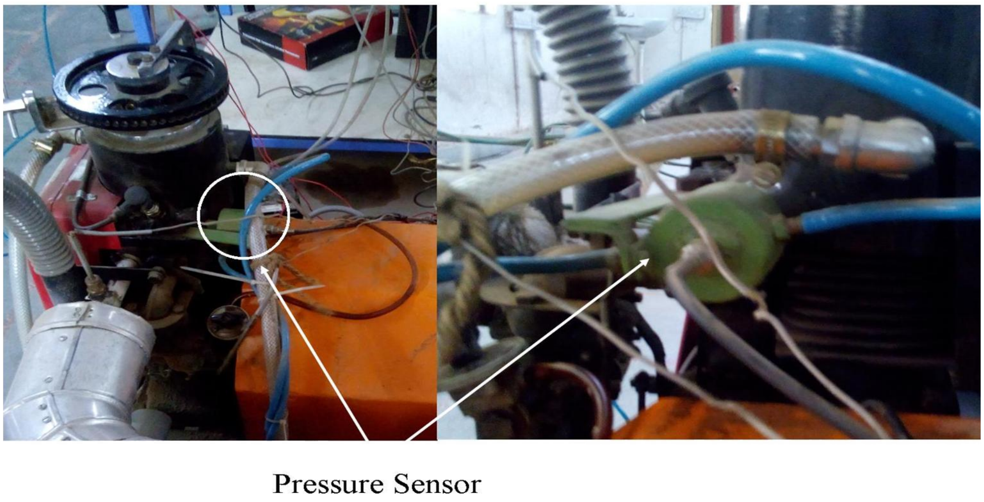

Figure 3:10 Pressure sensor for measuring the In-cylinder pressure

3.3.8 Measurement of Emission Characteristics

INDUS five gas analyzer is used to measure the emission characteristics of engine. Exhaust gases such as CO (carbon monoxide), CO_2 (carbon dioxide), HC (hydrocarbons) and NO_x (oxides of nitrogen) have been measured. Before each test, gas analyzer goes through self-checking process. It is calibrated by ARAI.

3.3.9 Measurement of Calorific Value

For measurement the calorific value of the gasoline and n-butanol, Bomb Calorimeter made by "Aditya" has been used. The instrument is designed according to the I.P.12 and I. S. 1350-1959. Figure 3:11 shows the bomb calorimeter.

Figure 3:11 Bomb calorimeter for measuring calorific value of the fuel

3.3.10 Measurement of Viscosity

Viscosity of the gasoline and n-butanol are measured by Red-wood viscometer No. 1. The red wood viscometer is shown in the Figure 3:12

Figure 3:12 Redwood Viscometer for measuring viscosity of the fuel

3.4 Error Analysis

The accuracy of various instruments used for experiments are shown in the Table 3:4. This includes the engine performance and emission characteristics of the engine. For error analysis, base line readings were taken three times and find out the standard deviation. These are in the satisfactory limit. The errors in the emission parameters are than checked from the manufacture catalogue and found the errors are in within limit.

Table 3:4 Uncertainty of Instruments

Parameters	Uncertainty
Speed	$\pm 5\ RPM$
Load	0.05 kg
BTE	2.5%
BSFC	2.5%
CO	3%
CO2	3%
HC	5%
NOx	3%

3.5 Experimental procedures

A planning is made for conducting the experiments on the different blends of n-butanol and gasoline at different compression ratio with increasing the load. The maximum load on the engine according to the rated power, engine speed and load arm, is 6 kg. The performance and emission characteristics have been calculated on increasing each 1kg of load.

The various tests have been taken here at various loads with different blends of gasoline and n-butanol with different compression ratios. The different blends are B5 (5% n-butanol by volume + 95% gasoline by volume), B10 (10% n-butanol+ 90% gasoline), B15 (15% n-butanol + 85% gasoline), B20 (20% n-butanol + 80% gasoline) and B25 (25% n-butanol + 75% gasoline) and the different compression ratios are 4.67:1 (original CR), 6:1 and 8:1.

When the engine is running on the CR of 9:1 with gasoline, the cylinder pressure rises to 110 bar. The engine is very noisy and vibration of the engine reaches very high. These conditions are representing the detonation of the engine. So the all tests are made up to 8:1 CR.

Calculate the calorific value and density of each fuel blend. These values are shown in the Table 3:5.

Table 3:5 Calculated properties of the fuel blends

S. No.	Property	Gasoline	n-Butanol	B5	B10	B15	B20	B25
1	Density (kg/m3) at 28°C	740	810	744	747	751	754	758
2	Lower calorific value (kJ/kg)	44200	33100	43645	43090	42535	41980	41425

The engine speed is governed by the governor and all tests have been made with wide open throttle (WOT).

The reading of the engines performance and emission characteristics have taken, after 15 minutes running the engine at particular test condition.

First, base line readings are taken with gasoline at original CR with increasing the load of 1kg to 6 kg. Than the test readings are taken at CR of 6:1 and 8:1. In second part, blend of B5 (95% gasoline + 5% n-butanol) has been prepared by volume. The test readings have taken at all test CRs with this blend of B5. Same process is adopted for the fuel blends of B10, B15, B20 and B25. A comparison is made for the data obtain in the experiments for all the test fuels at the CR of 4.67:1 with increasing the load. Similarly, for the CR of 6:1 and 8:1, the data of performance characteristics and emission characteristics have been evaluated and compared.

From this comparison, most suitable fuel blend on which engine is running, give higher performance and lesser emission, is found out at each CR. Then, the data of these suitable blends at particular CRs are compared and evaluated the engine performance.

The performance characteristics have been identified as brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC). CO, CO_2, HC and NO_x emissions have been involved in emission measurement.

3.5.1 Starting the engine

i. Turn on the computer system, power in data logger and eddy current dynamometer
ii. Insert the calorific value and density of fuel in the system software
iii. Turn on the gas analyser
iv. Prepare a fuel blend on which test will be conducting by adding n-butanol in the gasoline with particular quantity.
v. Fill the fuel tank by the test fuel.
vi. Switch on the solenoid valve for the fuel supply in the engine and burette also.
vii. Supply the cooling water to the calorimeter as well as auxiliary cylinder head.
viii. Connect the battery to starter.
ix. Start the engine and check the exhaust line
x. Now, leave the engine in running state for 15 minutes to achieve stabilize condition.

3.5.2 Collection of data at various loads

i. After achieving stabilize condition, emission parameters are tested by gas analyser at zero laod.
ii. Increase the load to 1 kg with torque controller and leave the engine running for 10 minutes to stabilize

iii. Click “Start” tab in the software and off the solenoid valve.
iv. Then, note down the reading of performance parameters
v. Press “F1” for zeroing the gas analyser
vi. After zeroing, take the reading of emission parameters
vii. While unloading, load is decreased slowly to avoid failure due to high speed.

3.5.3 Method of making fuel blend

i. For making blend B5, take the 95% of gasoline and 5% n-butanol by volume in the measuring cylinder
ii. Add them. For B10, check the quantity of remaining B5 blend.
iii. Calculate the percentage of gasoline and n-butanol in that blend.
iv. Calculate the quantity of gasoline and n-butanol for converting it to B10 blend.
v. Take the gasoline and n-butanol of calculating quantity and mix with B5.
vi. Similar procedure is followed for making blend of B15, B20 and B25.

Chapter 4

Results & Discussions

In this chapter, performance and emission characteristics of Spark Ignition engine are shown for different fuel blends such as B0, B5, B10, B15, B20 and B25 at different compression ratios of 4.67:1, 6:1 and 8:1 with increasing the loads. Engine ran well on all set of fuels blends and compression ratios without any engine modifications and without any failure. All results have been shown, discussed and analysed for each test condition.

First, performance and emission characteristics of SI engine are compared at each CR with all test fuels of B0, B5, B10, B15, B20 and B25 at increasing the loads. Analyze the graph and select the best blend at that particular CR.

After that, comparisons are made between the best blends selected at CRs of 4.67:1, 6:1 and 8:1.

4.1 Performance and emission characteristics (CR 4.67:1)

4.1.1 Effect of n-butanol blends on BTE

Figure 4:1 represents the comparison of BTE for engine running with all test fuels at CR of 4.67:1. When the load on the engine increases, the BTE also increases. As the quantity of n-butanol is increased from zero percentage to 25 percentages in the gasoline, the BTE is also increased for all test loads. This is due to proper combustion of the air/fuel mixture in the combustion chamber as n-butanol contains higher oxygen molecules. When the BTE of these test fuels were compared with neat gasoline at full load, it was found that the BTE is increased by 5.4%, 9.44%, 8.63%, 13.96%, and 12.83% for the engine running with test fuels of B5, B10, B15, B20 and B25 respectively. Maximum efficiency is obtained by the fuel B20.

4.1.2 Effect of n-butanol blends on BSFC

The variation in the BSFC for all the test fuels with increasing the load at CR 4.67:1 is shown in the Figure 4:2. As the load is increased, the BSFC is decreased continuously for all the test fuels. It is concluded from the figure that the variation in BSFC between the test fuels is large at low loads of 1 kg to 3 kg, and after that load, variation is very small for all test fuels. When the BSFC of test fuels were compared with that of neat gasoline, it was observed that the BSFC is reduced from the neat gasoline. It is 7.46%, 8.95%, 14.92%, 8.95% and 7.46% for the test fuels of B5, B10, B15, B20 and B25 respectively. This is due to the higher density of n-butanol and proper burning of the fuel because of higher oxygen content. Engine running with blend B20 gives minimum BSFC at full load.

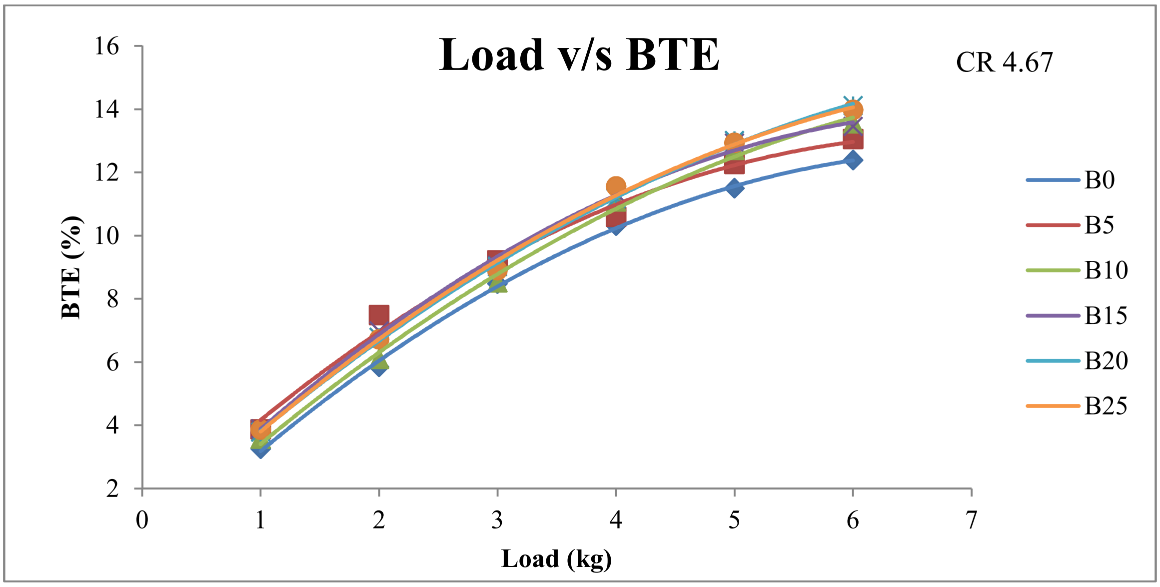

Figure 4:1 Comparison of BTE for fuel blends at CR 4.67:1

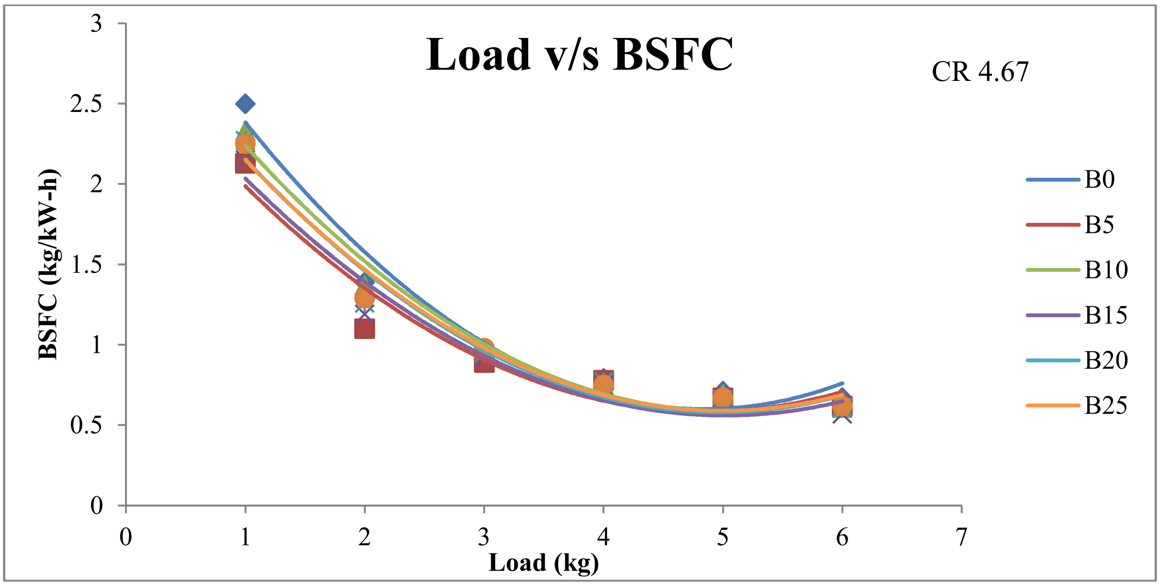

Figure 4:2 Comparison of BSFC for fuel blends at CR 4.67:1

4.1.3 Effect of n-butanol blends on CO

As the quantity of n-butanol is increased in fuel blends, oxygen content also increased. The formation of CO depends upon concentration of oxygen. As the concentration of oxygen is increased, carbon monoxide can oxidize and form CO_2. Higher combustion efficiency also causes the reduction of CO emissions. Figure 4:3 shows the variation of CO emission with increasing the loads. When the variation in the CO emissions of all test fuels were compared with pure gasoline at full load, the emissions are decreased by 48.98%, 84.22%, 78.22%, 88.41% and 89.11% for the engine running with test fuels of B5, B10, B15, B20 and B25 respectively. This is due to the fact that butanol has lower carbon content. The minimum emissions of CO exhausted from the engine are observed by B25 test fuel.

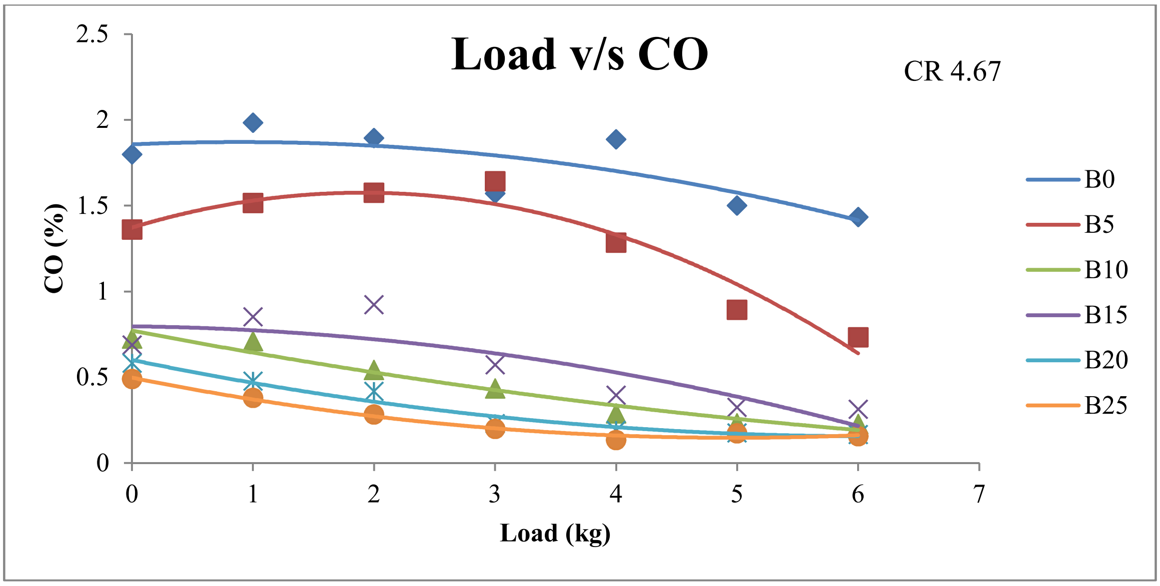

Figure 4:3 Comparison of CO emissions for fuel blends at CR 4.67:1

4.1.4 Effect of n-butanol blends on CO_2

Figure 4:4 represents the variation in the CO_2 with respect to increasing loads for all test fuels at CR of 4.67:1. As the load increases, CO_2 also increases due to proper combustion of fuel. The decrease in CO emissions leads to increase the formation of CO_2. The emissions of CO_2 are decreased at all test loads when compared these test fuels with those of gasoline. At full load, the CO_2 emissions are reduced by 10.83%, 14.38%, 20.87%, 25.93% and 21.66% for the test fuels of B5, B10, B15, B20 and B25 respectively. The engine emits minimum CO_2 with the fuel of B20.

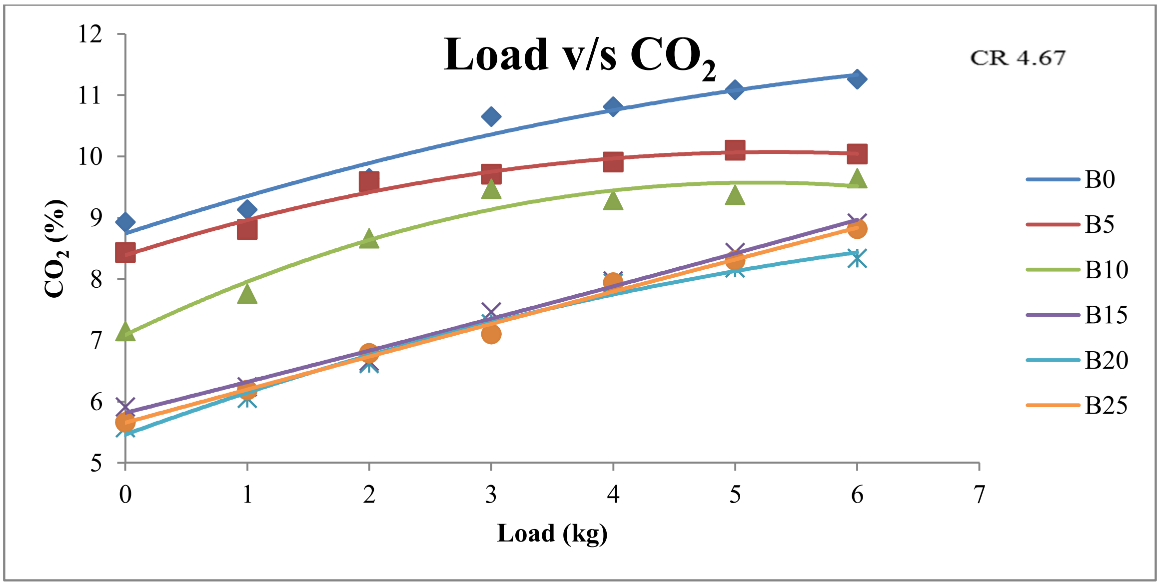

Figure 4:4 Comparison of CO_2 emissions for fuel blends at CR 4.67:1

4.1.5 Effect of n-butanol blends on HC

The variation in the HC emissions for all test fuels with increasing the load at CR of 4.67:1 are shown in the Figure 4:5. The UHC layers are formed because of quenching of flame by the cold surface of walls of the combustion chamber. As the load increases, temperature of the combustion chamber increases resulting formation of HC decreases. The HC emissions are reduced by 6.08%, 39.74%, 47.75%, 51.28% and 44.55% for the test fuels of B5, B10, B15, B20 and B25 respectively at full load when compared with those of gasoline. The fuel blends emits low HC due to the lower C/H ratio of n-butanol. The minimum emissions of HC are exhausted by the engine running with the test fuel of B20 at full load.

4.1.6 Effect of n-butanol blends on NO_x

Figure 4:6 represents the variation in NO_x emissions for all test fuels with increasing the load at CR 4.67:1. The NO_x is a by-product of combustion and depends upon the temperature for its rate of formation. At higher temperature, nitrogen molecules present in the air combines with the oxygen molecules and form oxides of nitrogen. As the load increases, more fuel burns and the temperature of cylinder rises resulted increase in NO_x formation. N-butanol has high latent heat of vaporization than gasoline. As the quantity of n-butanol is increased in the fuel blend, the cylinder temperature reduces resulted less formation of NO_x. When the NO_x emissions from all test fuels were compared with those of gasoline, it was observed that the NO_x is reduced at full loads by 12.06%, 35.18%, 7.03%, 30.36% and 30.09% for the test fuels of B5, B10, B15, B20 and B25 respectively.

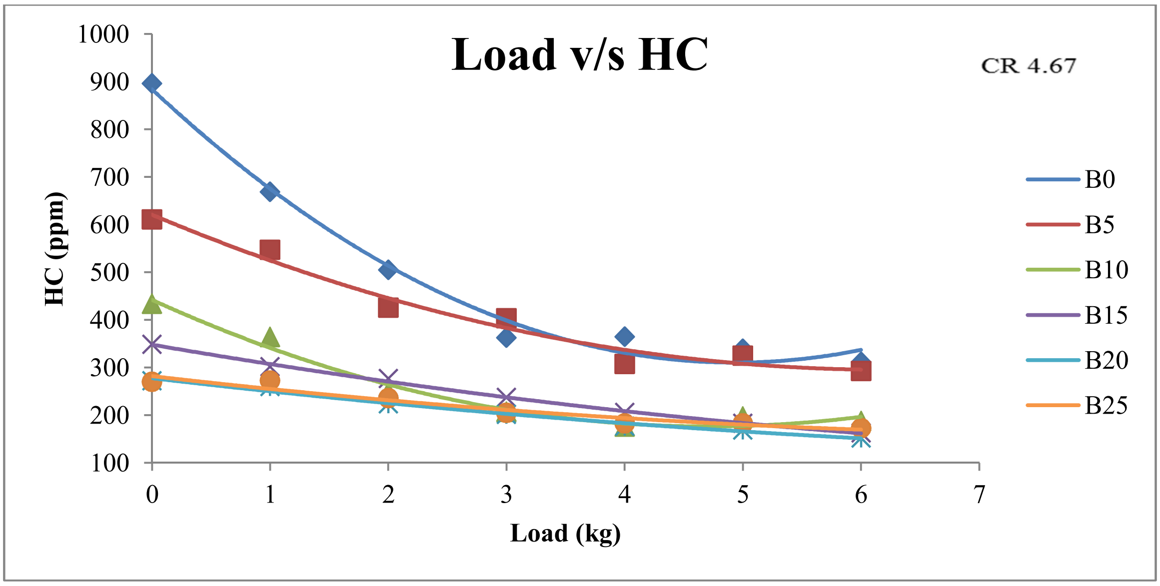

Figure 4:5 Comparison of HC emissions for fuel blends at CR 4.67:1

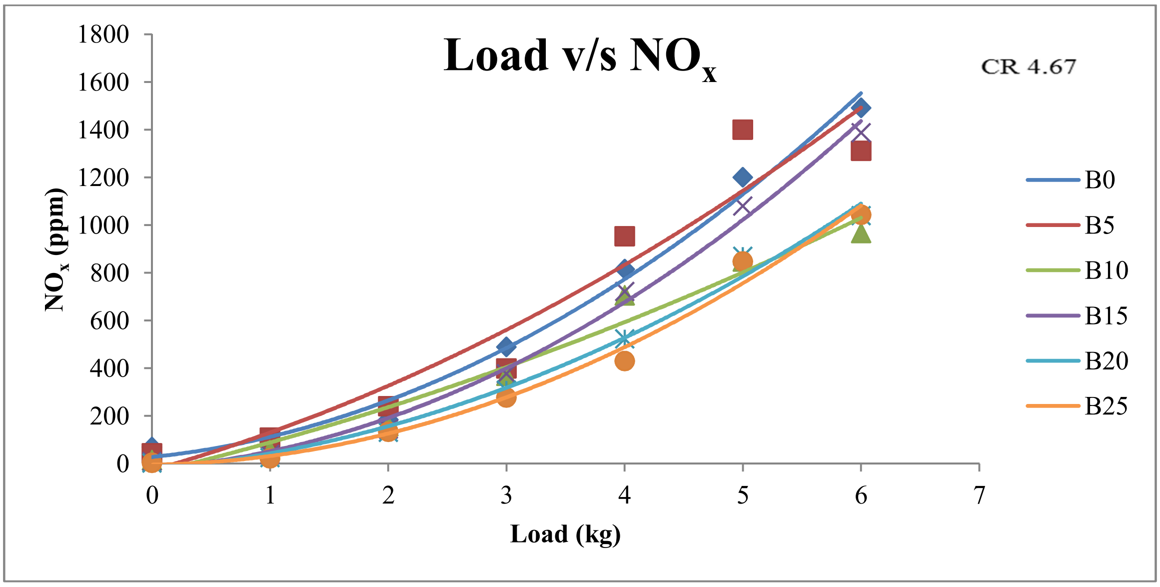

Figure 4:6 Comparison of NO_x emission for fuel blends at CR 4.67:1

From the analysis of the above trend-line graph, it was observed that, as the quantity of butanol is increased, the performance and emission characteristic are improved to a large extant. At original CR of 4.67:1, the engine running with the test fuel B20 gives better performance and emission characteristics from engine running with the other test fuels.

4.2 Performance and emission characteristics (CR 6:1)

4.2.1 Effect of n-butanol blends on BTE

Figure 4:7 shows the BTE of the engine running with all test fuels with increasing the loads at CR 6:1. At full load, the BTE of all test fuels were compared with those of gasoline and it was found that the BTE is increased by 4.29%, 3.46%, 4.59%, 2.18% and 15.07% for the test fuels of B5, B10, B15, B20 and B25 respectively. This is due to the fact that n-butanol has high latent heat of vaporization, therefore, n-butanol absorbs more heat from the cylinder wall during the vaporization in compression stroke, this will helps in decreasing the work done for compressing the air fuel mixture and finally thermal efficiency rises. The maximum BTE is obtained by the test fuel B25. There is an increment of 23.24% in BTE of B25 at CR 6:1 when compared it with that of neat gasoline at CR 4.67:1.

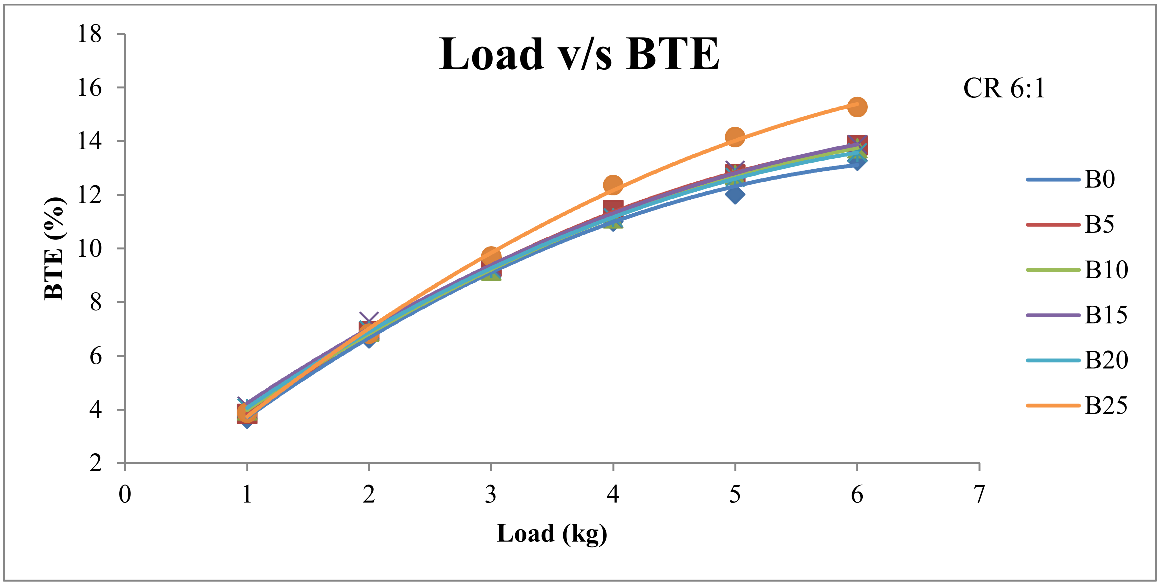

Figure 4:7 Comparison of BTE for fuel blends at CR 6:1

4.2.2 Effect of n-butanol blends on BSFC

The variation in the BSFC with increasing the loads for all test fuels at CR 6:1 is shown in the Figure 4:8. There is a very small variation in the BSFC for all test fuels when these are compared with that of gasoline. The maximum reduction of 3.27% in the BSFC was obtain with the fuel blend of B25 at CR of 6:1 when it compared with that of gasoline at same CR and it was 11.94% when compared with neat gasoline at CR of 4.67:1.

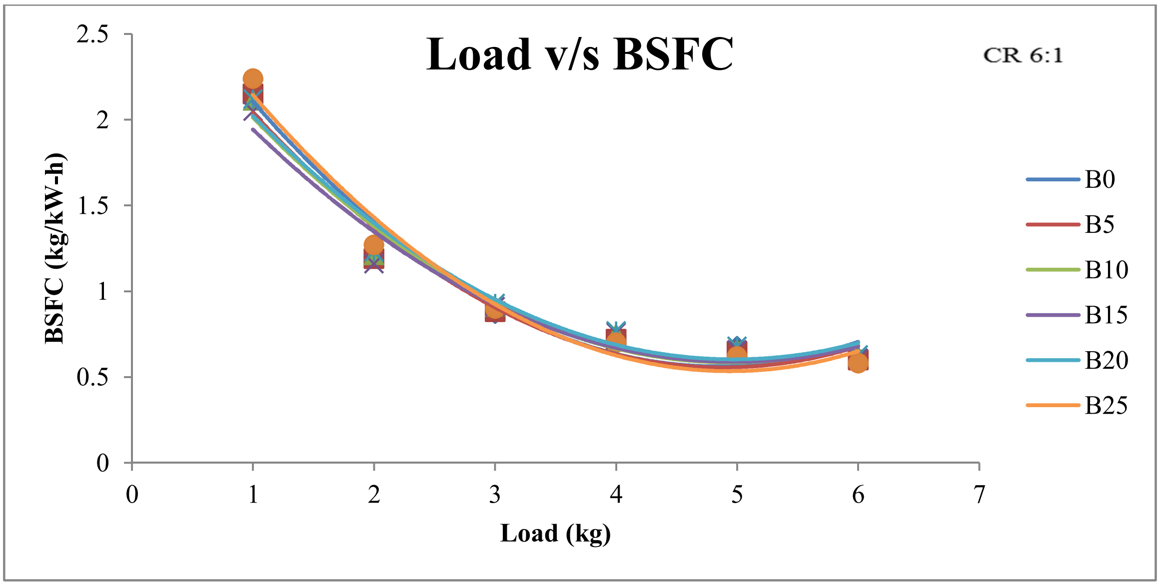

Figure 4:8 Comparison of BSFC for fuel blends at CR 6:1

4.2.3 Effect of n-butanol blends on CO

The variation in CO emissions with different loads for all the test fuels at CR of 6:1 is presented in the Figure 4:9. The CO emission is greatly depends upon the air fuel ratio. At higher CRs, the more homogeneous mixtures are formed and hence proper combustion of the fuel is made. CO emissions are reduced due to O2 enrichment of the test fuels. It was found from the figure that engine running with B25 fuel, engine emits very less CO emission as compared with that of gasoline. There were 8.22%, 1.21%, 19.91%, 43.89% and 90.30% decrement in CO emission at full load when compared with that of gasoline at CR of 6:1. The maximum decrement was obtained in the fuel of B25 and when it compares with that of neat gasoline at CR 4.67:1, it was found 92.18%.

4.2.4 Effect of n-butanol blends on CO_2

Figure 4:10 represents the variation in the CO_2 with increasing the loads for all the test fuels. CO and CO_2 have opposite correlation, i.e., as CO increases, CO_2 decreases. As the alcohols have lower C content and C/H content than gasoline, CO_2 emission is low. The variation in CO_2 emission for the test fuels of B5. B10, B15, B20 and B25 are 20.71%, 26.83%, 32.78%, 34.01% and 29.93% respectively when compared with that of gasoline at CR 6:1. The maximum decrement in CO_2 was obtained by the fuel blend of B20 and the decrement was 28.15% when it compared with that of neat gasoline at CR 4.67:1.

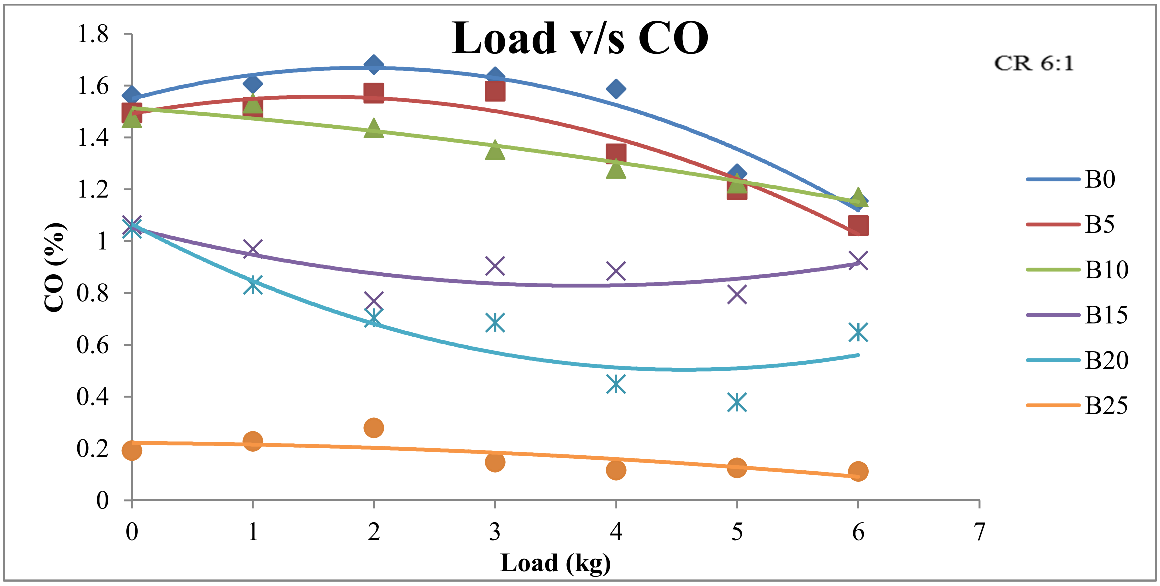

Figure 4:9 Comparison of CO emissions for fuel blends at CR 6:1

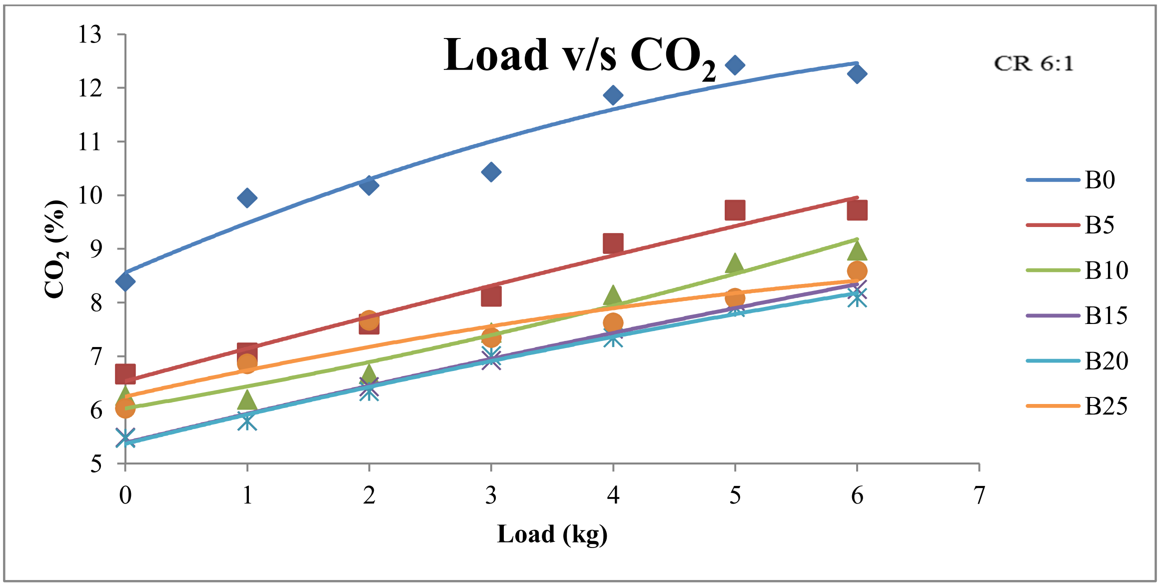

Figure 4:10 Comparison of CO_2 emissions for fuel blends at CR 6:1

4.2.5 Effect of n-butanol blends on HC

The variation in HC with increasing loads for all the test fuels at CR of 6:1 are depicted in the Figure 4:11. When the HC emissions are compared at full load, with that of gasoline at same CR, it is found that HC emissions are reduced by 32.85%, 45.0%, 46.90%, 46.90% and 54.04% for the test fuels of B5, B10, B15, B20 and B25 respectively. The maximum reduction in the HC emission is obtained by the test fuel of B25 and when it compared with that of gasoline at CR 4.67:1, it is found 38.14%. As the compression ratio increases, HC emissions are also increases. This is due to the fact that as CR increases, the surface/volume ratio increases resulting in the flame cools in the places near to surface and misfire occurs.

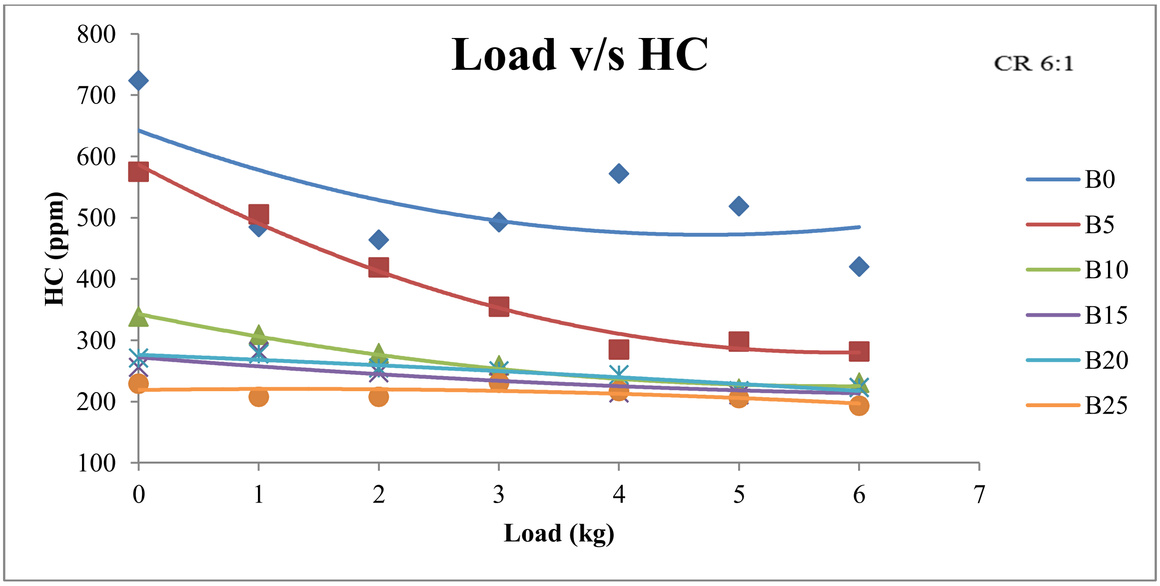

Figure 4:11 Comparison of HC emissions for fuel blends at CR 6:1

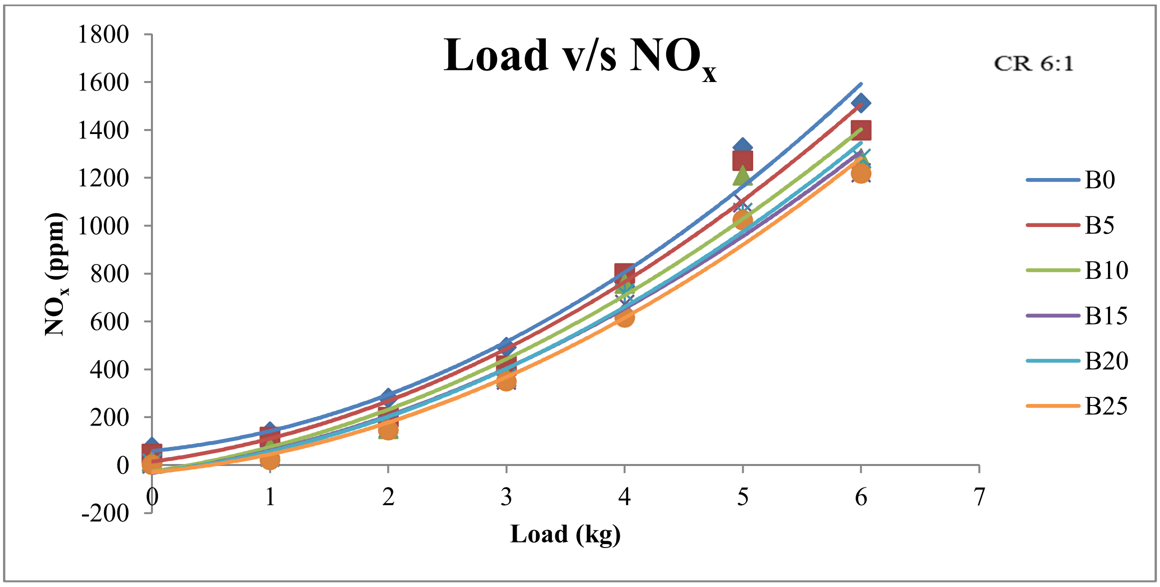

Figure 4:12 Comparison of NO$_x$ emission for fuel blends at CR 6:1

4.2.6 Effect of n-butanol blends on NO$_x$

The variation in the NO$_x$ emissions with increasing the loads for all the test fuels at CR 6:1 is presented in the Figure 4:12. As the temperature of the combustion chamber is reduced by the butanol, the formation of NO$_x$ is reduced for the butanol test blends. When the NO$_x$ emissions of these test fuels are compared with that of gasoline at same CR, it is found that the NO$_x$ emissions are decreased by 7.53%, 15.26%, 19.29%, 15.33% and

19.43% for the test fuels of B5, B10, B15, B20 and B25 respectively. The maximum variation is found in the test fuel of B15 and when it compares with that of gasoline at CR of 4.67:1, it is 18.16%.

From the analysis of the above trend-line graphs, it is observed the engine running with the test fuel B25 gives better performance and emission characteristics from engine running with the other test fuels at CR 6:1.

4.3 Performance and emission characteristics (CR 8:1)

4.3.1 Effect of n-butanol blends on BTE

Figure 4:13 shows the BTE of the engine running with all the test fuels with increasing the loads at CR 8:1. At full load, the BTE of all test fuels were compared with those of gasoline and it was found that the BTE was increased by 2.4%, 3.15%, 2.74%, 2.46% and 4.66% for the test fuels of B5, B10, B15, B20 and B25 respectively. The maximum BTE was obtain by the test fuel B25. There was an increment of 23.16% in BTE of B25 at CR 8:1 when compared it with those of neat gasoline at CR 4.67:1.

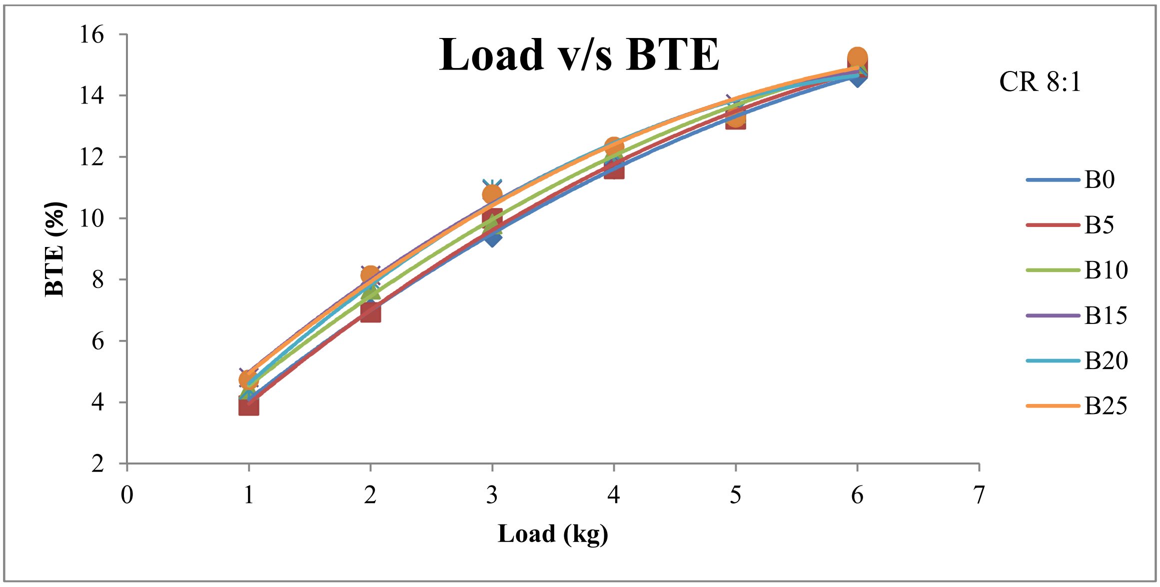

Figure 4:13 Comparison of BTE for fuel blends at CR 8:1

4.3.2 Effect of n-butanol blends on BSFC

The variation in the BSFC with increasing the loads for all the test fuels at CR of 8:1 is shown in the Figure 4:14. It is concluded from the figure that for the test fuels, the variation in the BSFC is very small when compared with that of gasoline at same CR. The reason is that the calorific value of the n-butanol is lesser than gasoline. For higher energy, more fuel is burn.

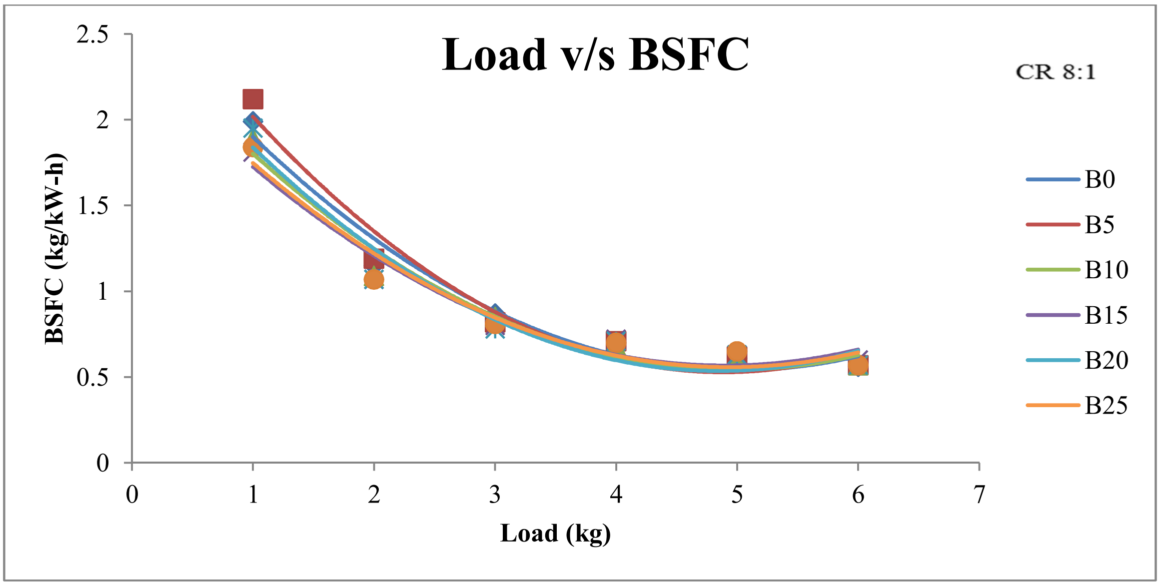

Figure 4:14 Comparison of BSFC for fuel blends at CR 8:1

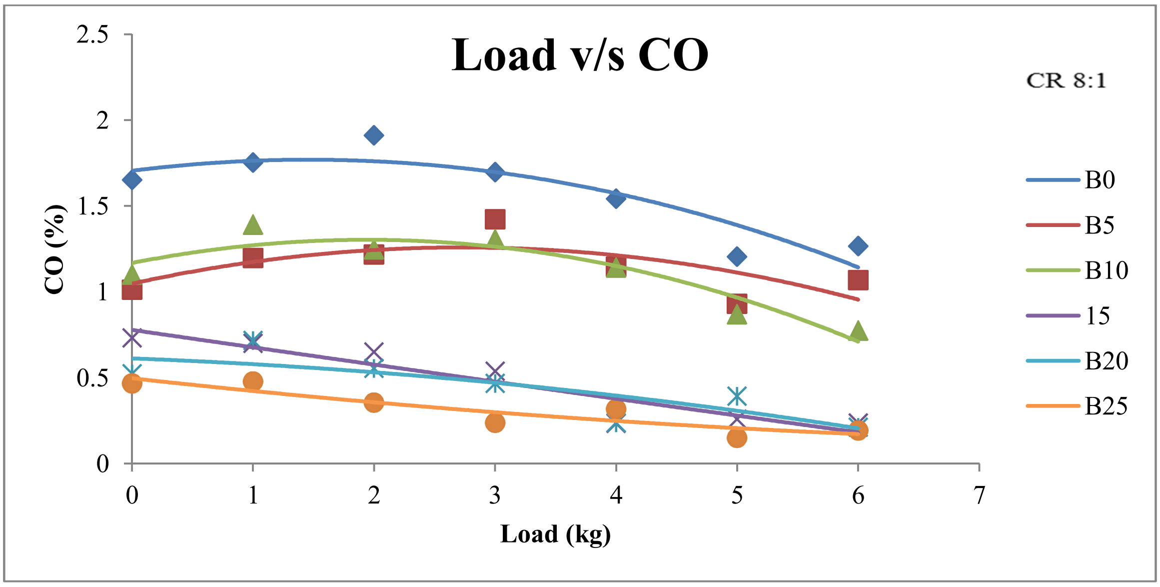

Figure 4:15 Comparison of CO emission for fuel blends at CR 8:1

4.3.3 Effect of n-butanol blends on CO

The variation in CO emissions with different loads for all the test fuels at CR of 8:1 is presented in the Figure 4:15. It was found from the figure that engine running with B25 fuel, engine emits very less CO emission as compared with that of gasoline. There were 15.54%, 38.91%, 81.37%, 83.34% and 84.76% decrement in CO emission at full load when compared with that of gasoline at CR of 8:1. The maximum decrement was obtained in the fuel of B25 and when it compares with that of neat gasoline at CR 4.67:1, it was found 86.53%.

4.3.4 Effect of n-butanol blends on CO_2

Figure 4:16 represents the variation in the CO_2 with increasing the loads for all the test fuels. The variation in CO_2 emission for the test fuels of B5. B10, B15, B20 and B25 are 13.01%, 23.38%, 25.2%, 26.02% and 25.29 respectively when compared with that of gasoline at CR 8:1. The maximum decrement in CO_2 was obtained by the fuel blend of B25.

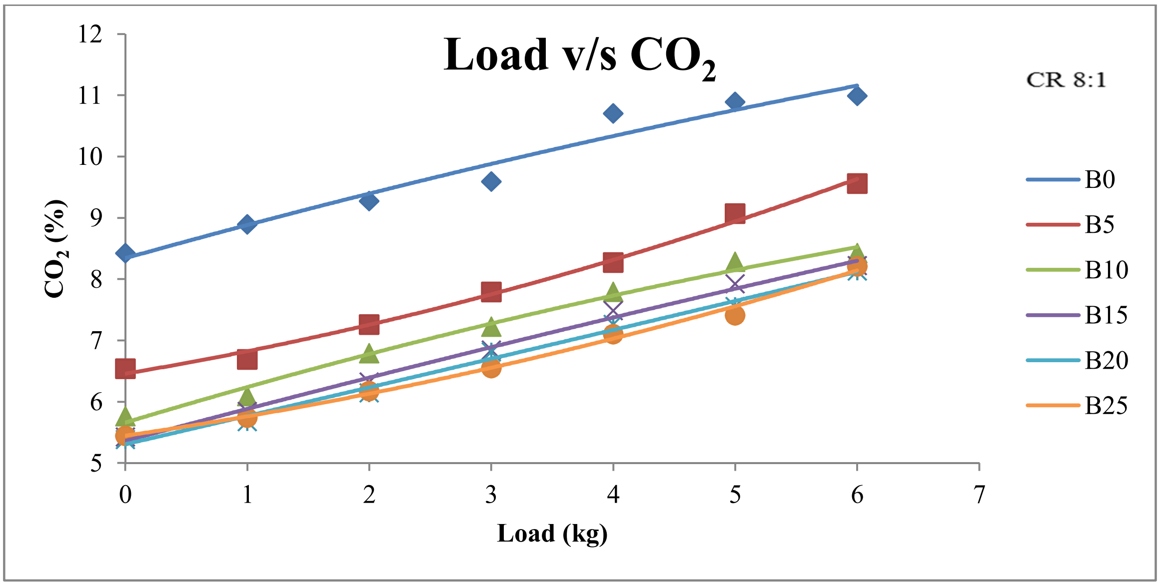

Figure 4:16 Comparison of CO_2 emission for fuel blends at CR 8:1

4.3.5 Effect of n-butanol blends on HC

The variation in HC with increasing loads for all the test fuels at CR of 8:1 are depicted in the Figure 4:17. When the HC emissions are compared at full load, with that of gasoline at same CR, it is found that HC emissions are reduced by 24.41%, 41.76%, 17.05%, 35.29% and 38.23% for the test fuels of B5, B10, B15, B20 and B25 respectively. The maximum reduction in the HC emission is obtained by the test fuel of B25.

4.3.6 Effect of n-butanol blends on NO_x

The variation in the NO_x emissions with increasing the loads for all the test fuels at CR 8:1 is presented in the Figure 4:18. When the NO_x emissions of these test fuels are compared with that of gasoline at same CR, it is found that the NO_x emissions are decreased by 16.39%, 18.49%, 24.07%, 28.73% and 17.62% for the test fuels of B5, B10, B15, B20 and B25 respectively. The maximum variation is found in the test fuel of B20 and when it compares with that of gasoline at CR of 4.67:1, it is 6.76%.

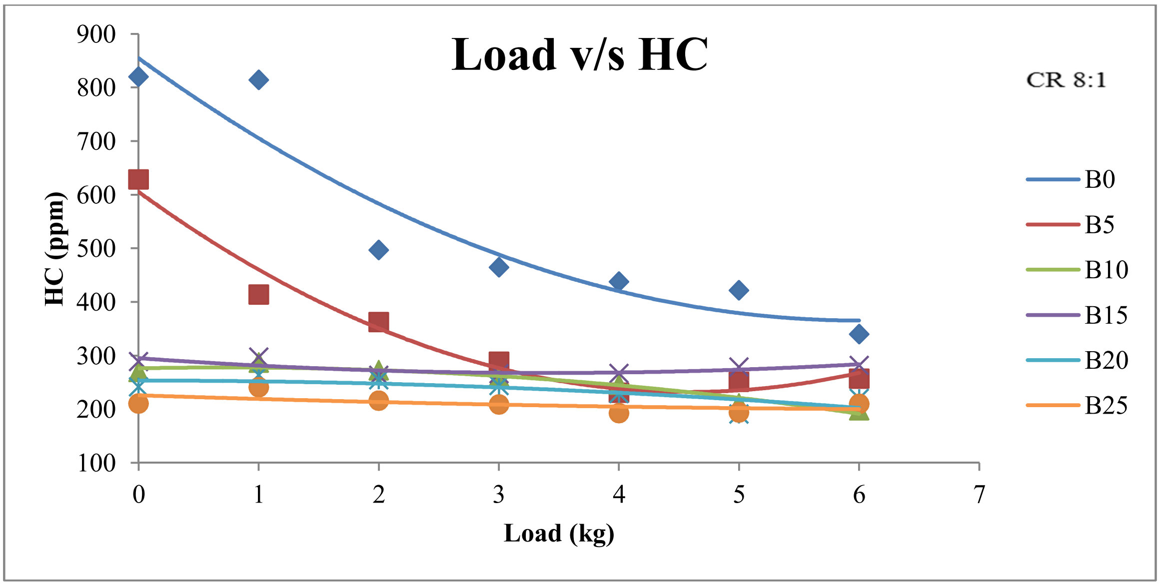

Figure 4:17 Comparison of HC emission for fuel blends at CR 8:1

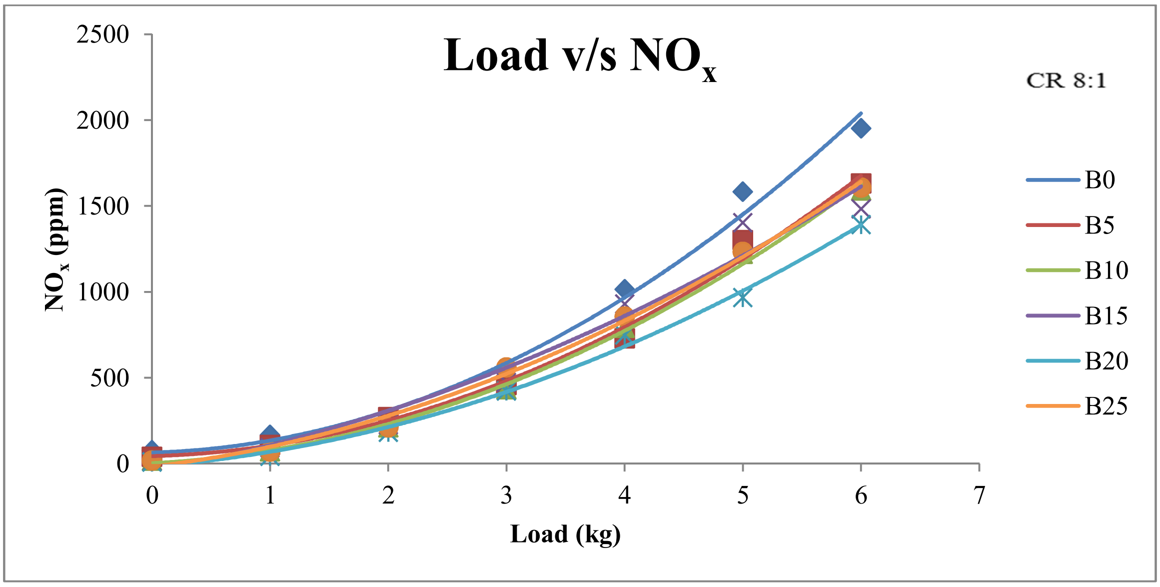

Figure 4:18 Comparison of NO_x emission for fuel blends at CR 8:1

From the analysis of the above trend-line graph, it is observed the engine running with the test fuel B25 gives better performance and emission characteristics from engine running with the other test fuels at CR 8:1.

4.4 Optimum compression ratio with best fuel blends

From the above analysis, it is observed that the test fuel B20 gives the better performance and emission characteristics on CR 4.67:1 and B25 gives on CR 6:1 and 8:1. For finding the test fuel, which gives better performance and emission characteristics, it is desired to compare these test fuels at particular CR. The following graphs are presented the comparison between them.

4.4.1 Comparison of BTE

Figure 4:19 present the comparison of BTE with increasing the loads. From the trend-line of the graph, the fuel B25 at CR 8 perform better overall, but at full load, test fuel B25 at CR 8 gives maximum efficiency. When these data are compared with that of gasoline at original CR, the BTE is increased by 13.96%, 23.24% and 23.16% for the test fuel of B20 at CR 4.67, B25 at CR 6:1 and B25 at CR 8:1.

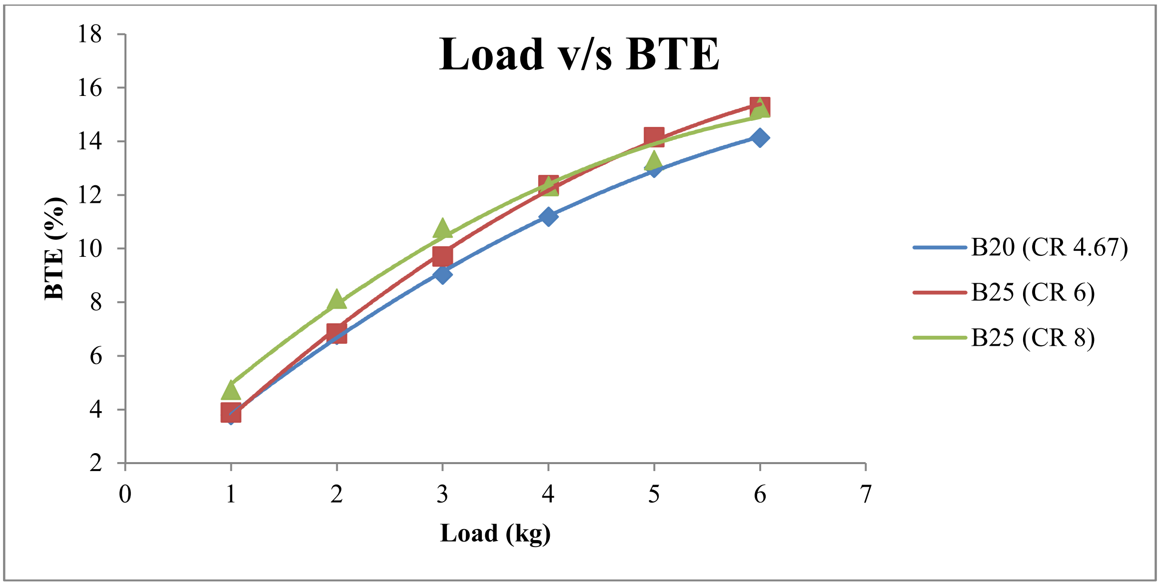

Figure 4:19 Comparison of BTE for different test fuels at particular CR

4.4.2 Comparison of BSFC

The comparison of BSFC with load is shown in Figure 4:20 for find out the best pair for better performance. The test fuel B25 at CR 8:1 gives better BSFC throughout the load as shown by the trend-line of the graph. The BSFC is reduced by 8.95%, 13.43% and 14.92% for the test fuel of B20 at CR 4.67:1, B25 at CR 6:1 and B25 at CR 8:1, when these data are compared with that of gasoline at original CR of the engine.

4.4.3 Comparison of CO emission

The variation in the CO emission with the loads is shown in Figure 4:21. From the trend-line of the graph, the emission of CO is very low at all test loads for the fuel of B25 at CR 6:1. When the BSFC of these test fuels at full load are compared with that of gasoline at original CR, it is reported that BSFC is reduced by 83.53%, 92.18% and 86.53% for the test fuels of B20 at CR 4.67:1, B25 at CR 6:1 and B25 at CR 8:1.

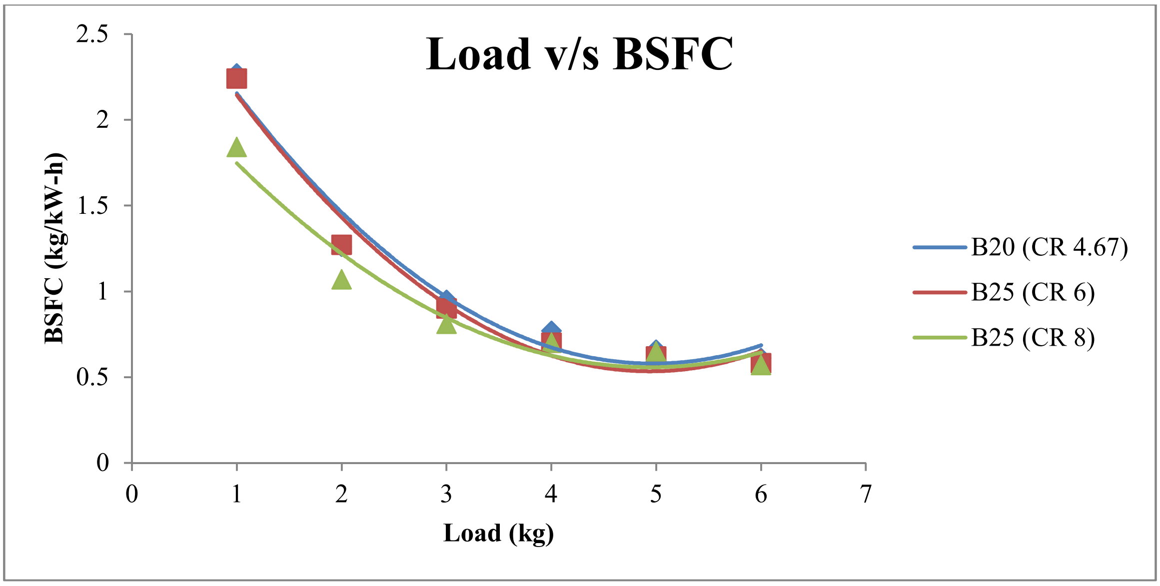

Figure 4:20 Comparison of BSFC for different test fuels at particular CR

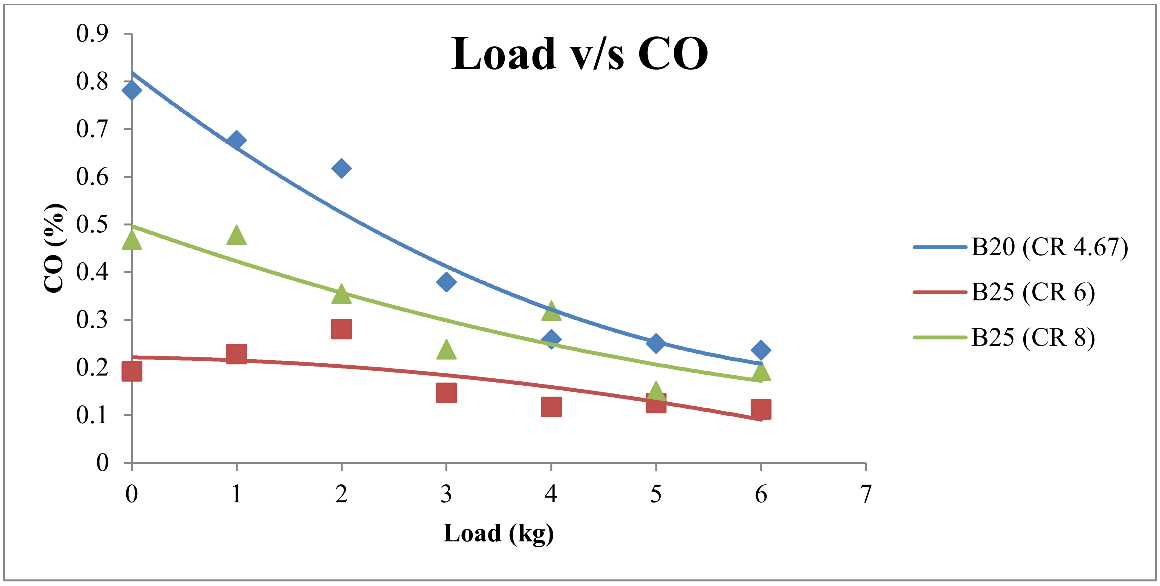

Figure 4:21 Comparison of CO emission for different test fuels at particular CR

4.4.4 Comparison of CO_2

Figure 4:22 shows the comparison of CO_2 emission with the loads. From the trend-line of the graph, the emission of CO_2 is very low for the B25 at CR 8:1 and very high for the fuel of B25 at CR 6:1. The emission of CO_2 is not in the category of pollutants because nature recycles it into O_2. At full load, the CO2 is reduced by 25.93%, 23.71% and 27.08% for the test fuel of B20 at CR 4.67:1, B25 at CR 6:1 and B25 at CR 8:1, when the CO2 emissions are compared with that of gasoline at original CR.

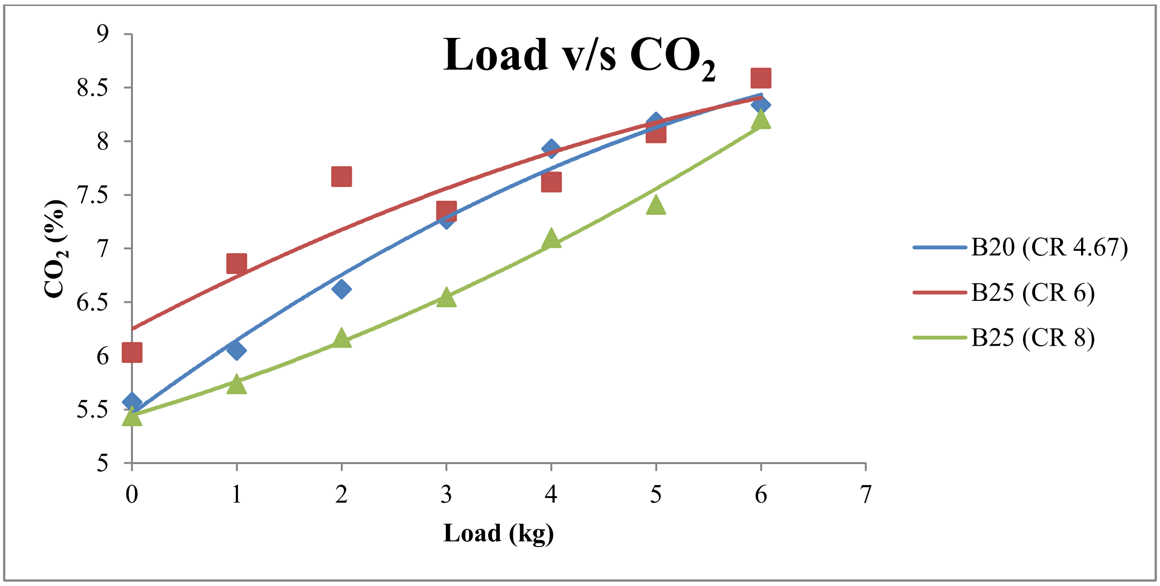

Figure 4:22 Comparison of CO_2 emission for different test fuels at particular CR

4.4.5 Comparison of HC

The variation in the HC emission with the loads is depicted in Figure 4:23. From the trend-line of the graph, the HC emissions are reducing continuously for test fuel of B20 at CR 4.67:1 and for the B25 at CR 6:1 and 8:1, the variation is very small with increasing the test loads. At full load, the HC emission is reduced by 51.28%, 38.14% and 32.69% for the test fuel of B20 at CR 4.67:1, B25 at CR 6:1 and B25 at CR 8:1, when the HC emissions are compared with that of gasoline at original CR.

4.4.6 Comparison of NO_x

Figure 4:24 depicted the variation in the emission of NO_x with the loads. From the trend-line of the graph, the NO_x emissions of B25 at CR 8:1 are very high and for the B20 at CR 4.67:1 and B25 at CR 6:1, these are nearly same. When the NO_x emissions are compared with that of gasoline at original CR and at full load, the NO_x emissions are reduced by 30.36%, 18.29% and 7.77% for the test fuel of B20 at CR 4.67, B25 at CR 6:1 and B25 at CR 8:1.

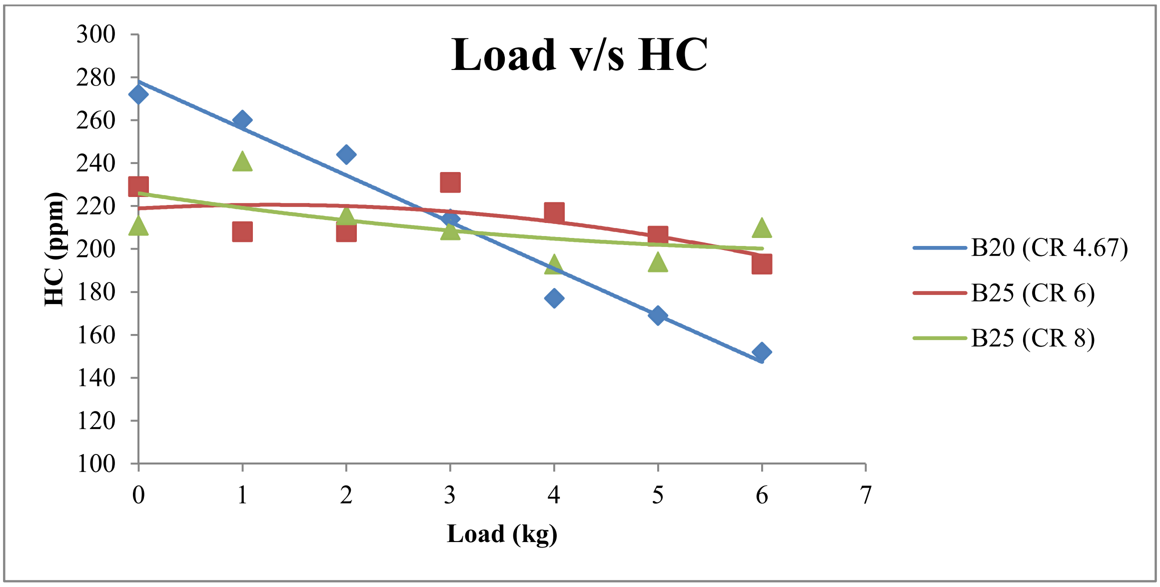

Figure 4:23 Comparison of HC emission for different test fuels at particular CR

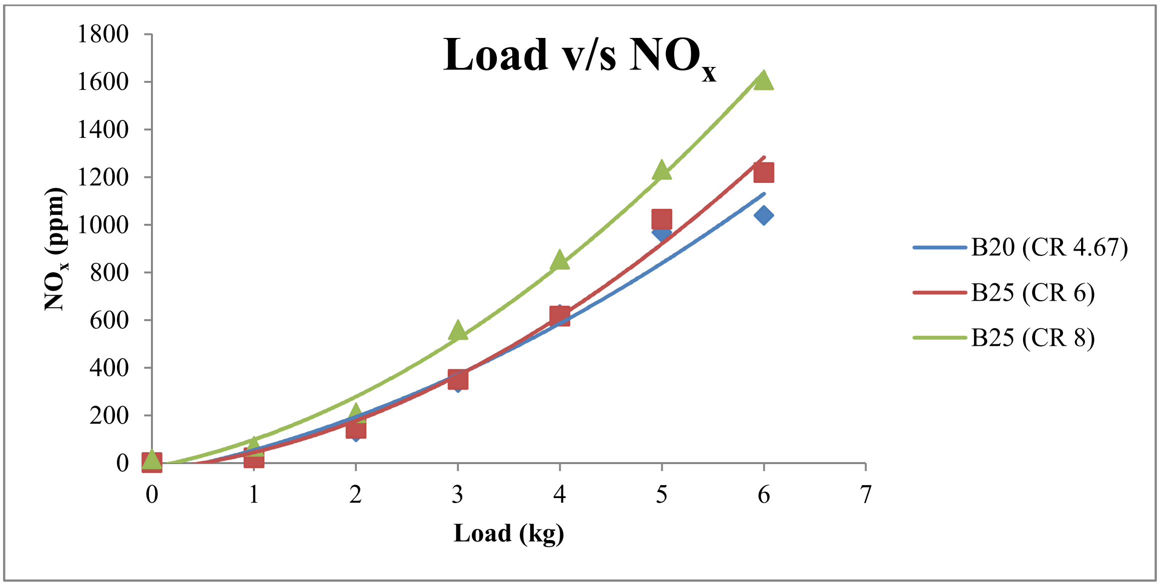

Figure 4:24 Comparison of NO_x emission for different test fuels at particular CR

Chapter 5

Conclusion & Future Work

5.1 Conclusion

In this study, a single cylinder four stroke spark ignition engine was operated with the different test fuels of B0, B5, B10, B15, B20 and B25 and the compression ratios were 4.67:1, 6:1 and 8:1. The performance and emission characteristics of the engine were compared and analyzed. The following conclusions are drawn from the basis of the experimental results.

1. The best performance and emission characteristics are observed by the engine running with test fuel of B25 at CR 6:1.

2. As the compression ratio increases, the BTE of gasoline engine rises by 18.63% with gasoline at full load and by adding 25% of n-butanol in the gasoline, the BTE is increases by 23.24% at CR 6:1. This is due to the fact that as compression ratio increases, BTE also increases due to proper combustion and high temperature of engine cylinder. Due to oxygen molecules present in the n-butanol, fuel burns proper resulting in the increase in the BTE for the blends of butanol.

3. The BSFC is just reverse of the BTE. Due to higher density and oxygenated n-butanol, the BSFC of B25 is reduced by 13.43% at CR of 6:1 from BSFC of gasoline at original CR.

4. The CO emission in case of gasoline is higher than the blends of n-butanol. As the load increases, CO emissions are also reduces. The emissions of CO are reduced as increasing the load and compression ratio of the cylinder. The n-butanol has very low the carbon content and high oxygen molecules. At original CR, test fuel of B25 gives 89.11% reduced emissions from gasoline fuel. 92.18% reduced emissions of CO are obtained by the test fuel of B25 at CR 6:1 from that of gasoline at original CR.

5. Carbon dioxide is having a great effect on green-house gases due to form of blanket effect on the atmosphere as it aids global warming. But CO_2 is not in the

category of pollutants as nature recycles it again. The emissions of CO_2 are very high from the engine running with gasoline at all test compression ratios. By adding 25% of n-butanol in the gasoline at CR 6:1, CO_2 emissions are reduced by 23% at CR 6:1.

6. By quenching the flame propagation from the cool cylinder surfaces, a layer of HC will be formed. These layers are increased as the continuous running of the engine. As the load and compression ratio increases, the temperature of the cylinder also increases results the lower formation of HC particles. The emissions of HC of B25 are reduced by 38.14% at CR of 6:1 from that of gasoline at original CR.

7. The NO_x emissions from the engine running with gasoline at original CR exhausted 1492 ppm. With increasing the CR, the NO_x emissions are also increased by 30.83% from the original CR. By adding the 25% n-butanol in the gasoline, the NO_x emissions exhausted by the engine running at CR 6:1 is 1219 ppm. It is -18.29% from the NO_x emitted by gasoline at original CR. As the load and compression ratio increases, the temperature of the cylinder also increases. As the temperature increases, the nitrogen presented in the air combines with the oxygen and formed oxides of nitrogen. Due to higher latent heat of vaporization of n-butanol, the NO_x formation is very low for the fuels blends of n-butanol.

5.2 Future work

In the present work, performance and emission parameters of n-butanol fuel blends viz B5, B10, B15, B20 and B25 have been investigated at different compression ratio of 4.67:1, 6:1 and 8:1. For increasing the performance characteristics, more blends are to be taken. For exhaust emission, Exhaust Gas Recirculation (EGR) can be used for reducing the pollution.

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