# AN EXPERIMENTAL STUDY OF LEMON PEEL OIL/GASOLINE BLEND IN A PFI ENGINE

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# APPROVAL SHEET

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# ABSTRACT

Research on alternative fuels for fossil fuels become prominent due to the gradual depletion of fossil fuel and global warming. Lemon Peel Oil (LPO) is an alternative biofuel produced from lemon rinds. LPO has its properties lower heating value, octane number and air/fuel ratio are similar to that of gasoline. In this study, LPO is used in SI Engine as an alternative fuel.

In this study, the experimental investigation of LPO-gasoline blends for combustion, performance, and emission characteristics in an SI engine. For this work, gasoline and two different LPO-gasoline blends, 20% and 40% by volume concentration of LPO, has been prepared. The present work is investigated in the Port Fuel Injection (PFI), a four-stroke single cylinder engine. The engine is operated under various loading conditions at an equivalence ratio of one and constant speed (1500 RPM). The results of different LPO-blends are compared with the baseline gasoline under various loads for the analysis of combustion, performance and emission. For the statistical analysis, ANOVA with two-factor interaction is performed.

The results of shows that LPO-gasoline blends have similar brake specific fuel consumption and brake thermal efficiency to that of gasoline. The combustion characteristics heat release rate and in-cylinder pressure mean gas pressure, of LPO-gasoline blends, have similar trends that of gasoline. The decrease in emissions of HC and CO are observed with an increase of LPO content in blends. However, with the increase of LPO content in blends, an increase in NOx emissions is observed. The results indicate that LPO is a suitable alternative fuel for gasoline SI engine.

# NOMENCLATURE

| | |
|---|---|
| **IC** | Internal Combustion Engine |
| **SI** | Spark Ignition Engine |
| **PFI** | Port Fuel Injection |
| **VCR** | Variable Compression Ratio |
| **CR** | Compression Ratio |
| **ECU** | Electronic Control Unit |
| **RPM** | Revolution per minute |
| **TDC** | Top Dead Centre |
| **V** | Instantaneous in-cylinder volume |
| **MBT** | Maximum Brake Torque |
| **LPO** | Lemon Peel Oil |
| **LHV** | Lower Heating Value |
| **BDC** | Bottom Dead Centre |
| **GC-FID** | Gas Chromatography-Flame Ionization Detector |
| **GC-MS** | Gas Chromatography-Mass Spectrometer |
| **BMEP** | Brake Mean Effective Pressure |
| **BP** | Brake Power |
| **BSFC** | Brake Specific Fuel Consumption |
| **IMEP** | Indicated Mean Effective Pressure |
| **SFC** | Specific Fuel Consumption |
| **HRR** | Heat Release Rate |
| **CHRR** | Cumulative Heat Release Rate |
| **HC** | Hydrocarbon |

| | |
|---|---|
| **CO** | Carbon monoxide |
| **$NO_x$** | Nitrogen Oxides |
| **CAD** | Crank Angle Degrees |
| **COV** | Coefficient of variation |
| **$COV_{IMEP}$** | Coefficient of variation of indicated mean effective pressure |
| **RON** | Research Octane Number |
| $\frac{dQ_{ch}}{d\theta}$ | Net Heat Release Rate |
| $\frac{dP}{d\theta}$ | Rate of change of pressure with crank angle |
| $\frac{dV}{d\theta}$ | Rate of change of volume with crank angle |
| $\eta_{bth}$ | Brake Thermal Efficiency |
| $\Upsilon$ | Ratio of Specific Heats |
| **AFR** | Air Fuel ratio |
| $\Phi$ | Equivalence Ratio |
| $m_f$ | Mass Flow rate of Fuel |

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# Chapter 1

# Introduction

## 1.1 Background

Due to the fast pace of the contemporary economy, there is a gradual depletion of fossil fuels. Emissions from fossil fuels causes global warming and other environmental impacts. To decrease the dependence of fossil fuels development of renewable and economically viable alternative fuels such as biofuels, solar energy, wind power has begun. Biofuels have Properties of renewability, availability, high oxygen content & combustible properties similar to those of traditional fuels. Biofuels reduces global warming gas emissions, hydrocarbons and carbon monoxide. Fuels originated from the waste biomass are especially crucial because they do not affect the regular food supply to society [3].

In the world's energy consumption, Fossil fuel occupies 78.4%, and transportation occupies 26.6% according to EIA. According to EIA, in the U.S. for transportation sector energy 92% is based on petroleum products. In India, 23% of energy consumption is based on petroleum. Coal and petroleum products occupy two-third of total energy consumption in India. The fossil fuel reserves are depleting at rapid rate and emissions are released by vehicles day by day. Thus Biofuels are now finding their potential to replace conventional fuels. [5]

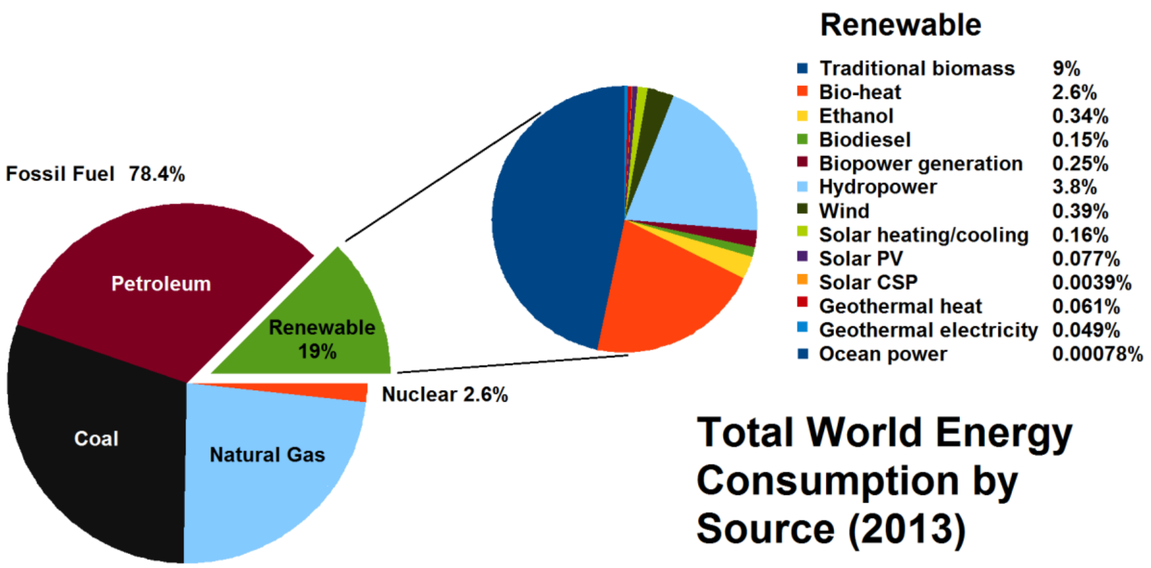



Figure1.1: Contribution of energy resources of the world [6]

Using bio-fuels, reduces the global warming gas emissions, hydrocarbons, and carbon monoxide. So biofuels are the focus of the world. Also, they have lower viscosity and similar heating value. Fuels from trees or plants such as lemon peel oil, orange oil, and pine oil are used as biofuels as they are eco-friendly. Lemon peel oil (LPO) has its properties octane number, stoichiometric air/fuel ratio and lower heating value similar to that of gasoline.

## 1.2 Motivation

The thermo-physical properties of the LPO are close to that of the gasoline; the present study aims to investigate the compatibility of this novel biofuel in SI engine applications. For that purpose, an experimental investigation is performed with blends of LPO and gasoline.

Analysis of combustion characteristics helps us understands the compatibility of LPO in a PFI SI Engine. Performance and emission analysis help us understands the efficiency of fuel and its usage as an eco-friendly biofuel.

## 1.3 Objective

The primary objective is to compare the effects of LPO-gasoline blends with baseline gasoline on performance and emission characteristics. In this, we analyse the LPO-gasoline blends performance and its effect on cycle to cycle variation.

The objective is to look into the following three crucial parameters of SI engine

1) Performance analysis
2) Combustion analysis
3) Engine Emissions

## 1.4 Scope of the Thesis

In this work, LPO-gasoline blends performance is compared with baseline gasoline by changing various parameters.

- Chapter 2 discusses literature and previous contribution on Bio-fuels in IC Engines.
- Chapter 3 discusses details of the preparation of lemon peel oil, engine setup, and experimental procedure.
- Chapter 4 discusses the performance and emission analysis results.
- Chapter 5 discusses the conclusion and future scope work.
- Chapter 6 includes references and citations of references.

# Chapter 2

# Literature Review:

## 2.1 Previous contribution:

In the transportation sector, IC Engines are now commonly used. Because of global warming and gradual depletion of fossil fuel contributes to an interest in alternative fuels like biofuels, which are eco-friendly. Recent research on biofuels has become prominent around the world, as biofuels from plant-based are renewable, biodegradable, eco-friendly.

In today's transportation system, Biofuels, which consists of bio-diesels and bio-alcohols, are used. Bio-diesels are obtained from the transesterification process of methyl esters derived from fatty acids (vegetable oils). Bio-diesels have their properties similar to diesel engine conditions. The researchers have studied their effect on engine performance and emissions. Bio-diesels are mainly obtained from oilseed plants such as jatropha, pine oil, palm, mahua, neem, cottonseed, soybean, and Karanja [3].

Alcohols are obtained from the fermentation of starchy biomass such as municipal solid waste, agricultural waste, algae and food waste. Alcohols have properties such as high octane number, faster flame speed, higher fuel volatility, which are similar to Spark ignition engine conditions. Biofuels have excellent combustion quality due to the presence of oxygen atoms. However, there are only a few types of alcohols, such as butanol, methanol, and ethanol, which are practically compatible with the SI engine. Alcohols like ethanol, butanol are blended with gasoline to reduce emissions. They also have become the focus of researchers because of their high octane number,. [4]

Because of its higher octane number, ethanol can manage a higher compression ratio. Due to the high heat of evaporation of ethanol, it affects engine performance and volumetric efficiency positively. Due to the presence of oxygen content in alcohol, there is an increase of specific fuel consumption for ethanol blends.

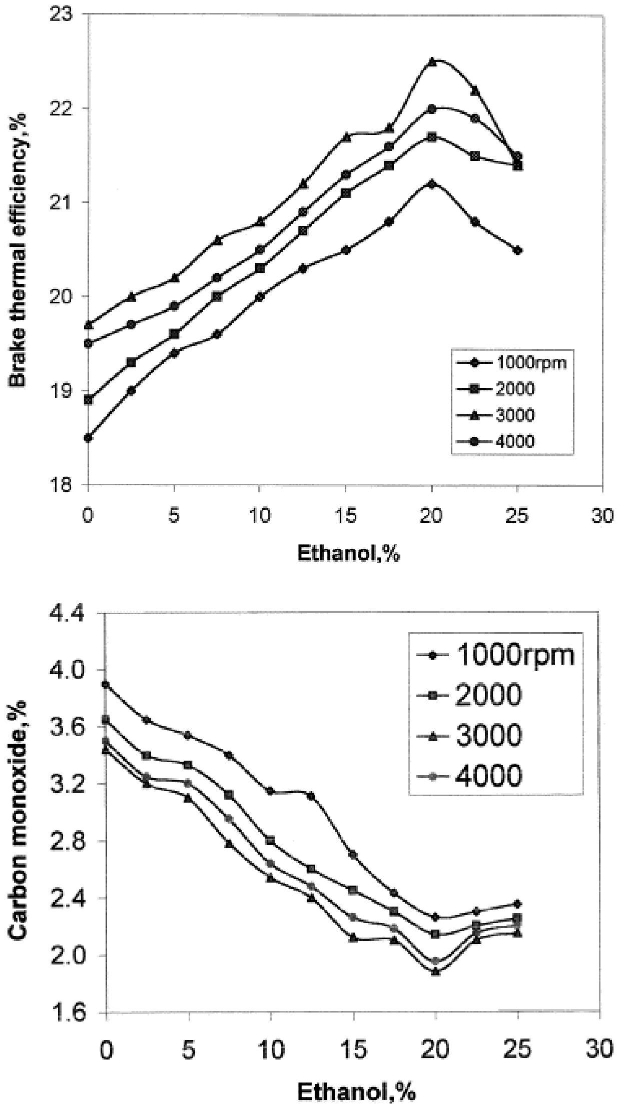
In Hydra SI engine, Yucesu et al. [9] experimented with gasoline-ethanol blends for various compression ratios. They reported that HC and CO emissions are lower for ethanol-gasoline blends, and ethanol can handle higher blends.

The gasoline-ethanol blends were researched by Yuksel et al. [11] to increase the percentage of ethanol in blends. In this study, HC, CO emissions decrease significantly, and $CO_2$ increases due to better combustion. They have reported that 60% by volume ethanol-gasoline blends can be blended for experiments.

Hsieh et al. [13] explored the effects on performance and emissions of gasoline-ethanol blends for a varying percentage of throttle opening. They recorded that CO, HC emissions decreases, and torque increases due to better combustion of oxygenated fuel, ethanol (leaning effect).

Thangavelu et al. [14] have conducted a review on different ethanol-gasoline blends, which showed that ethanol blends are helpful in reduction in HC, CO emissions. Also, there is a decrease in NOx emissions at a maximum of 58% literature.

The impact of unleaded ethanol-gasoline blends on efficiency and emissions at various engine speeds was studied by Al-Hasan [10]. It is reported that with the rise in ethanol percent shows an improvement in the BTE and decreases in the HC and CO emissions from Figure2.1. Also, for gasoline-ethanol blends, the combustion process is smooth, and there is no knocking effect. It is reported that 20 % of ethanol has an optimal blend for gasoline.



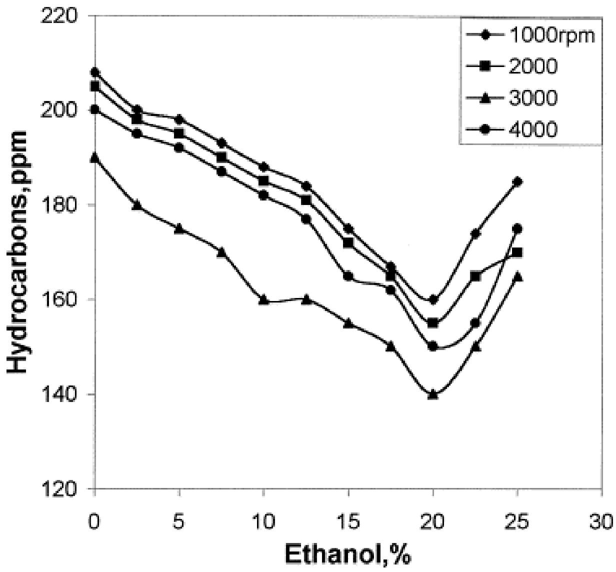



Figure 2.1: (a) BTE variation for ethanol blends at different engine speeds (b) CO emission variation for ethanol blends at different engine speeds (c) HC emission variation for ethanol blends at different engine speeds [10]

Costagliola et al. [15] has conducted the experiments for different ethanol-gasoline blends and butanol blends and studied their effect on the particulate matter in a PFI engine. They reported that a reduction in particulate number is observed for ethanol blends.

Celik [31] researched gasoline-ethanol blends performance and emission characteristics at various compression ratios from Figure2.2. With compression ratio, BTE increases and SFC decreases. It is recorded that for the rise of compression ratio from 6:1 to 10:1, emissions of CO, HC, and NOx were increased.

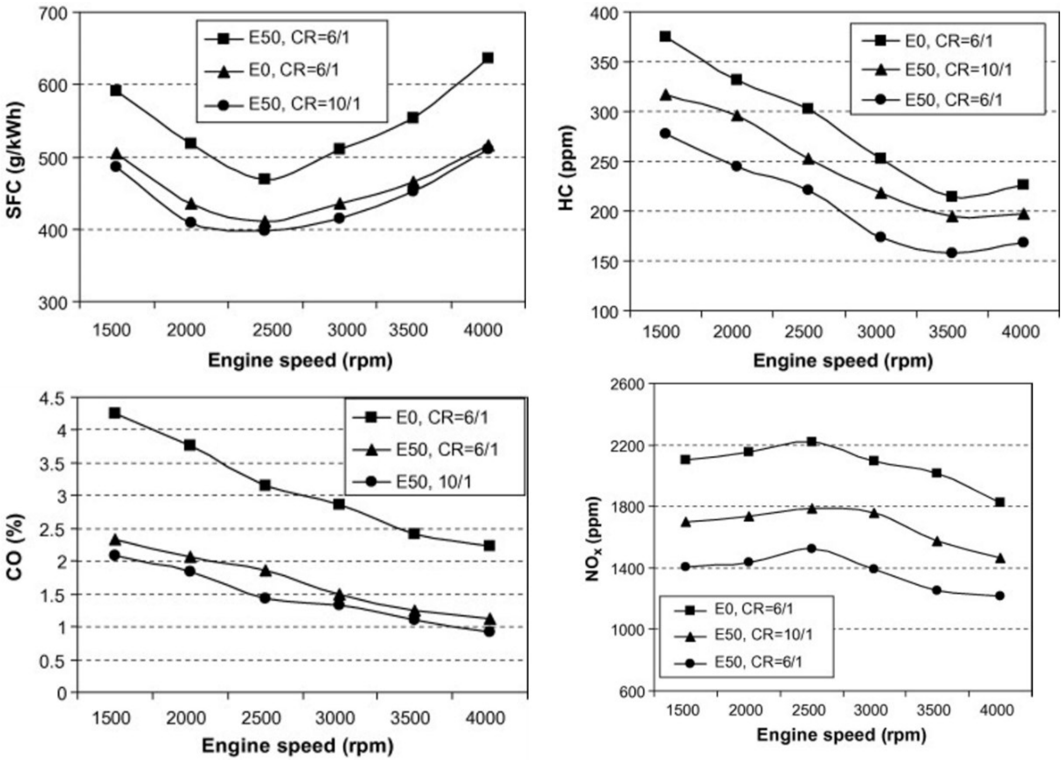



Figure2.2: Variation of SFC, HC, CO and NOx emissions for gasoline-ethanol blends at different compression ratio [31]

Methanol has lower LHV, high octane number, higher flame speed and higher latent heat of vaporization. Yanju et al. [17] have experimented in a 3-cylinder PFI engine for methanol gasoline blends (10%, 20%, and 85%). They reported that for ethanol-gasoline blends an increase in thermal efficiency, an increase in the unregulated $CH_3OH$ emissions and a decrease in the emissions of CO and NOx are observed.

Agarwal et al. [18] has experimented in a medium duty SI (4 cylinders) engine and investigated the effects of gasoline-methanol blends (10%and 20%) on performance and emissions. They have observed that methanol blending increases exhaust gas temperature, brake thermal efficiency. Methanol addition has lower NOx, CO, and particulate matter emissions are observed. Also, combustion characteristics of methanol blends are similar to that of gasoline. Abu-Zaid et al. [19] also have observed similar engine performance for methanol gasoline blends (3-15% volume), and they reported that optimal blending for beat engine performance is 15% ethanol and 85% gasoline.

Gu et al. [21] researched the impact of gasoline-butanol blends on emissions. Compared with the baseline gasoline, they reported reduced emissions of HC, CO, and NOx for gasoline-butanol blends. Also, adding butanol decreases particulate matter. They also observed that with Exhaust Gas Recirculation (EGR), HC and CO emissions increases. However, NO emissions and the particulate number decreases with EGR.

Dernotte et al. [22] explored the effects of emissions for gasoline-butanol blends in a PFI SI engine. They have reported that adding butanol improves the combustion stability, and decrease in HC and NOx emissions are observed.

Purushothaman et al. [23] have experimented in a diesel engine and explored the effects of orange oil with diethyl ether (DEE) and their blends on performance. They reported a decrease in emissions of HC, CO and smoke while an increase in NOx emissions is noted for orange oil blends. HRR and BTE are greater for DEE with orange oil.

Ashok et al. [24] conducted experiments in a Diesel engine and studied the performance and emission analysis of LPO-diesel blends. They noted higher BTE for LPO blends. The decrease in emissions of HC, CO, and smoke are recorded for LPO-Diesel blends compared to a diesel engine. There is, however, an increase in NOx emissions for LPO-Diesel blends.

### 2.2: IC Engines and various parameters:

Heat Engines are of two types, namely, the internal combustion engine (ICE) and the external combustion engine (ECE). The combustion process takes place inside the cylinder for the internal combustion engine.

IC Engine Classifications:

Based on the No of Strokes:

- Two Stroke engine: One complete combustion cycle requires one revolution of a crankshaft
- Four Stroke Engine: One complete combustion cycle requires two revolutions of the crankshaft

Based on the method of Ignition of Fuel:

- Spark Ignition Engines (SI Engine): Spark plug is used for fuel ignition.
- Compression Ignition Engines (CI Engines): Auto-ignition of fuel by compressed air.

Based on the cycle of combustion:

- Diesel Cycle: combustion process  at constant pressure heat addition cycle
- Otto Cycle: combustion process at constant volume heat addition cycle
- Dual Cycle. Combustion partly at constant volume and partly at constant pressure

Based on the method of Fuel Supply:

- Carburetted: Carburettor is used to mix air and fuel and then it is supplied to the engine cylinder.
- Port Fuel Injection (PFI): Fuel is sprayed into intake valves to mix with incoming air.
- Direct Injection: Fuel is sprayed directly into the cylinder where air/fuel mixing occurs.

For the current study, we use Port Fuel Injection four-stroke SI Engine. The cycle of operation of the four-stroke engine consists of four strokes namely:

a. Intake stroke　　b. Compression stroke

c. Power Stroke　　d. Exhaust stroke

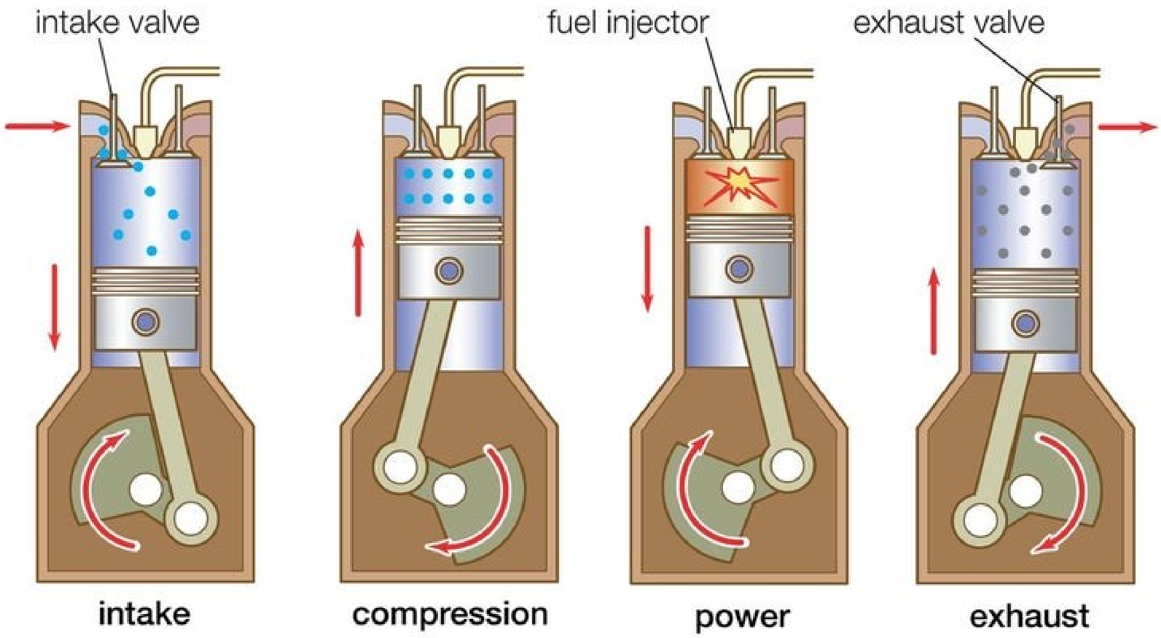



Figure2.3: Four strokes of IC Engine [27]

For Four stroke SI engine, the air standard cycle that works is known as the Otto cycle. The four processes of this cycle are [28]

- Isentropic compression: Compression of air.
- Constant heat addition: Spark plug ignites and combustion occurs
- Isentropic expansion: Expansion of air.
- Constant volume heat rejection: Heat is rejected to sink.

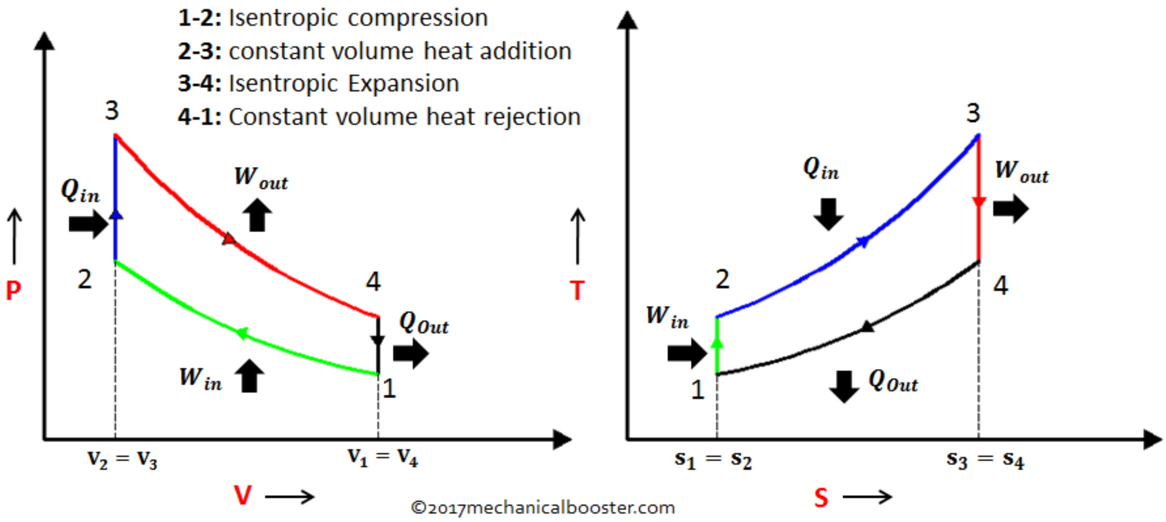



Figure2.4: P-V and T-S Diagram of Otto Cycle [28]

Engine parameters:

Performance, combustion, and emission characteristics of an IC engine are understood with the help of certain parameters. They are as follows:

Brake thermal efficiency (BTE): BTE is the ratio of brake power to the energy supplied in the form of fuel.

$$\eta_{bth} = \frac{\text{Brake } power}{\text{mass flow rate of fuel} * \text{calorific value}}$$

Brake specific fuel consumption (BSFC): It is the ratio of the mass of fuel rate consumption to the brake power.

$$BSFC = \frac{mass\ fuel\ rate\ consumption}{Brake\ power}$$

Heat release rate (HRR): HRR is the rate at which the combustion process releases the chemical energy of the fuel. HRR is estimated with respect to the crank angle from the engine cylinder pressure data. Cumulative heat release rate (CHRR): CHRR is the sum of heat release rate with respect to crank angle. CHRR is calculated by integrating the HRR with respect to crank angle degrees.

$$\text{HRR: } \frac{dQ_{net}}{d\theta} = \frac{\gamma}{\gamma-1} p \frac{dV}{d\theta} + \frac{1}{\gamma-1} V \frac{dp}{d\theta}$$

$$\text{CHRR: } Q_{CUM} = \int^{d} Q_{net} = \int \frac{\gamma}{\gamma-1} pdV + \int \frac{1}{\gamma-1} Vdp$$

Where $\gamma$ is the ratio of specific heat p is in-cylinder pressure, V is instantaneous cylinder volume and θ is the crank angle.

Combustion: Fuel and Oxidizer are reacted together to produce heat.

For the combustion process of fuel, a chemical reaction is given by

$$\mathbf{C_XH_YO_Z} + \frac{\left(\mathbf{x}+\frac{\mathbf{y}}{4}-\frac{\mathbf{z}}{2}\right)(\mathbf{O_2}+\mathbf{3.76N_2})}{\boldsymbol{\varphi}} \rightarrow \mathbf{aCO_2} + \mathbf{bCO} + \mathbf{cHC} + \mathbf{dO_2} + \mathbf{eN_2} + \mathbf{fH_2O}$$

Where φ is equivalence ratio

Emissions analysis is based on HC, CO, and NOx concentrations.

## 2.3 Taguchi method:

Taguchi method is developed by Genichi Taguchi. It is a statistical method for improving the quality of manufactured goods and applied to engineering, marketing, and biotechnology. As there are various influencing factors (fuel blends, loading conditions) so instead of testing all the possible combination of various parameters, we select optimal combination using orthogonal arrays to save both time and expenses. We use the Taguchi method to optimize factors in the Lemon peel oil experiments. Signal to noise ratio is used to understand characteristics. There are three ways of optimizing factors using Taguchi method. They are larger the better, smaller the better ratio, and nominal the best. [26]

For the larger-the-better signal to noise ratio, we can calculate by the

$$\frac{\mathrm{s}}{\mathrm{n}} = -10log_{10}[\text{mean of sum squares of reciprocal of measured data}]$$

For the smaller-the-better signal to noise ratio, we can calculate by the

$$\frac{\mathrm{s}}{\mathrm{n}} = -10log_{10}[\text{ mean of the sum of squares of measured data }]$$

For the nominal-the-best signal to noise ratio, we can calculate by the

$$\frac{\mathrm{s}}{\mathrm{n}} = -10log_{10}\frac{square\ of\ mean}{variance}$$

| **Factors** | **1** | **2** | **3** |
|---|---|---|---|
| **Fuel blends** | 0 | 20 | 40 |
| **Load** | 40 | 60 | 80 |

| Case No : | 1 | 2 |
|---|---|---|
| 1 | 1 | 1 |
| 2 | 1 | 2 |
| 3 | 1 | 3 |
| 4 | 2 | 1 |
| 5 | 2 | 2 |
| 6 | 2 | 3 |
| 7 | 3 | 1 |
| 8 | 3 | 2 |
| 9 | 3 | 3 |

From above Array, we get results of response variables (BTE, CO, HC, and NOx) for each trail case three times. We calculate the S/N ratio for each case, and we get the contribution of each factor from below formulae.

$$\frac{\overline{S}}{N} = \frac{1}{9}\sum_{i=1}^{9}(\frac{S}{N})_i$$

$$SS = \sum_{i=1}^{9}[\left(\frac{S}{N}\right)_i - \frac{\overline{S}}{N}]^2$$

$$SS_i = \sum_{i=1}^{3}[\left(\frac{S}{N}\right)_i - \frac{\overline{S}}{N}]^2$$

$$contribution\ \% = \frac{SS_i}{SS} * 100\%$$

Where S/N is signal to voice ratio for each trial.

# Chapter 3

# Experimental Setup

In the present work, the performance and emission analysis of two LPO blends (LPO20, LPO40) are performed and compared with the baseline fuel, gasoline. The experiments are carried out for three different engine loading conditions (40%, 60%, and 80%) for each blend. The details about the preparation of fuel (lemon peel oil), Engine setup and experimental procedure are discussed in the following section.

## 3.1 Preparation of Fuel:

In the present work study, the Steam distillation method is used to prepare Lemon Peel Oil from waste lemon grinds. In this work, LPO is procured from Synthite Industries Ltd. Figure3.1 shows the schematic diagram of the steam distillation process, which explains the steam separation chamber and distillation chamber separately. In the steam separation chamber, water is contained in its lower section, and heat is supplied to it, which converts it to steam. The lemon peels are in distillation chamber which is heated by heated steam to produce fumes of LPO. The steam and fumes of LPO are passed through a cooling tank in which cold water supply at a constant rate to make vapour to condense into a mixture of liquid LPO and water. The mixture of LPO and water is collected in a separation chamber and separated them based on their variation in their density. [8]

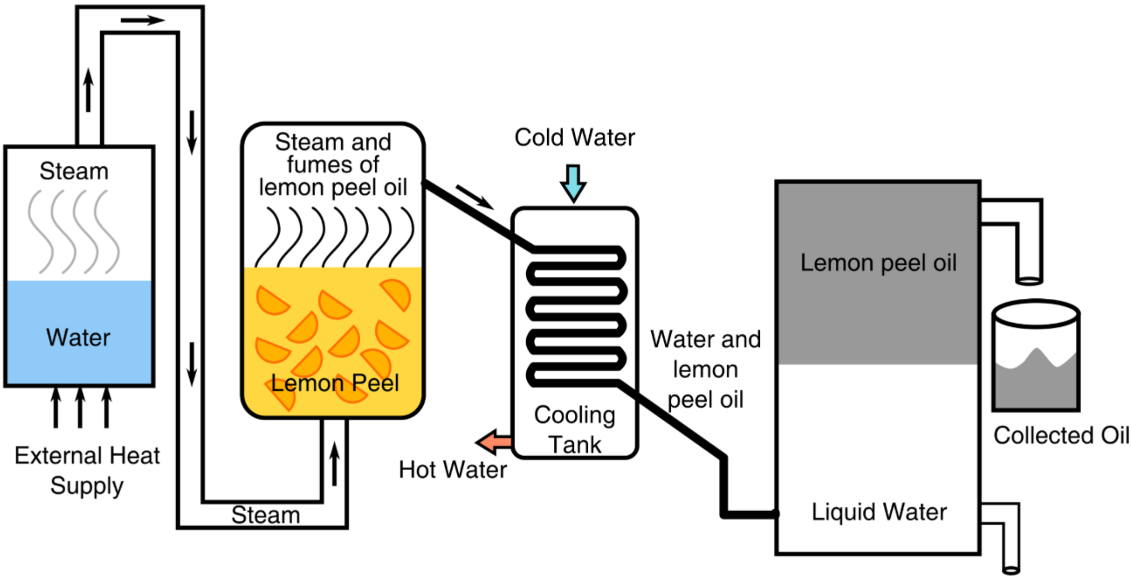



Figure3.1: Schematic diagram of the steam distillation process for the preparation of LPO

The extracted lemon peel oil is blended with gasoline by 20% and 40% by volume basis and named as LPO20 and LPO40 respectively. Figure3.2 shows the photographic view of LPO and its blends. The samples are kept steady for 24 hrs to observe no phase separation in those blends. While starting the experiments, the blend samples are stirred properly to ensure fuel homogeneity.

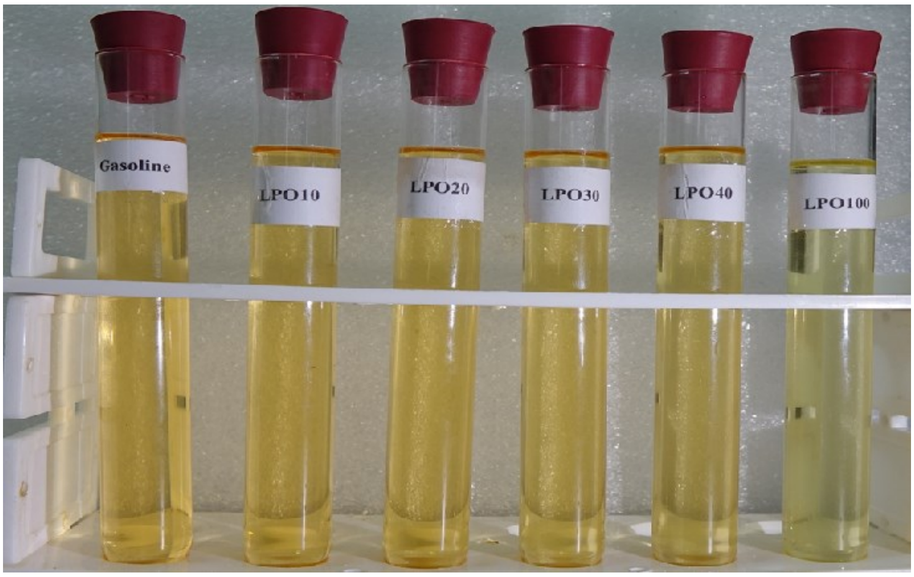



Figure3.2: Photographic view of gasoline and LPO blends (Gasoline, LPO20, LPO40, and LPO100)

Thermo-physical properties of lemon peel oil are close to that of gasoline; this research seeks to explore the compatibility of this novel bio-fuel in SI engine application.

Table 1. Fuel properties

| Properties | LPO | Petrol | Ethanol |
|---|---|---|---|
| Chemical formula | $C_{10}H_{16}O_{0.082}$ | $C_5 – C_{12}$ | $C_2H_5OH$ |
| Stoichiometric Air/Fuel ratio | 14.1 | 14.7 | 9 |
| Density 15$^0$ C (kg/m3) | 830 | 725 | 790 |
| Kinematic Viscosity @ 40$^0$ C (cSt) | 1.06 | 0.6 | 1.08 |
| Flash point ($^0$C) | 54 | -43 | 16.6 |
| Fire point ($^0$C) | 64 | -23 | |
| Final boiling point (K) | 449 | 498 | 351 |
| Lower calorific value (kJ/kg) | 45000 | 44000 | 27000 |
| Latent heat of vaporization (kJ/kg) | 290 | 380-400 | 938 |
| Octane number | 80 | 90 | 109 |

Lemon Peel Oil chemical composition is known by Gas Chromatography-Mass Spectrometer (GC-MS), and Gas Chromatography-Flame Ionization Detector (GC-FID) provides its weight percentage. GC-MS conducted on GC-MS-QP2010 Ultra and GC-FID conducted on GC-2014 (SHIMADZU). In this GC-MS and FID process, DBWAX fused-silica capillary column (30m*0.25mm*0.25µm) is used for identification of components in LPO. For the GC-MS oven temperature is programmed from $60^0$C (with 5 min hold) at $10^0$ C /min increased up to $240^0$C. The injector temperature was kept at $250^0$C and volume injected was 0.2 µL (with split ratio 1:30). Detector temperature is maintained at $240^0$ C. similar procedure is used for flame ionization detector (GC-FID) with ion source temperature $200^0$C and DBWAX column is used. The chemical composition of LPO is given in Table 2.

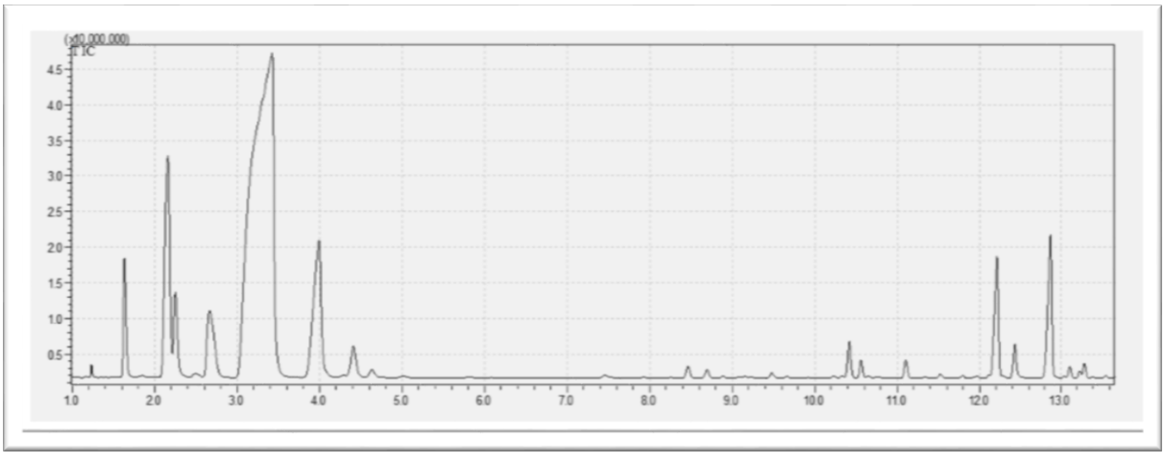


Figure3.3: Gas Chromatography-Mass Spectrometer of lemon peel oil

Table2. Chemical composition of Lemon Peel Oil

| Chemical component | IUPAC Name | Weight percentage (%) | Chemical formula |
|---|---|---|---|
| Alpha-Pinene | (1R,5R)-2,6,6-Trimethylbicyclo[3.1.1]hept-2-ene | 1.85 | $C_{10}H_{16}$ |
| 1-beta-Pinene | 6,6-Dimethyl-2-methylenebicyclo[3.1.1]heptane | 9.75 | $C_{10}H_{16}$ |
| Beta-Myrcene | 7-Methyl-3-methylene-1,6-octadiene | 1.67 | $C_{10}H_{16}$ |
| D-Limonene | (4*R*)-1-methyl-4-prop-1-en-2-ylcyclohexene | 76.07 | $C_{10}H_{16}$ |
| Gamma Terpinene | 1-methyl-4-propan-2-ylcyclohexa-1,4-diene | 6.29 | $C_{10}H_{16}$ |
| p-Cymene | 1-methyl-4-propan-2-ylbenzene | 0.92 | $C_{10}H_{14}$ |

| | | | |
|---|---|---|---|
| L-Linalool | (3*R*)-3,7-dimethylocta-1,6-dien-3-ol | 0.31 | $C_{10}H_{18}O$ |
| Z-Citral | (2Z)-3,7-dimethylocta-2,6-dienal | 1.36 | $C_{10}H_{16}O$ |
| Alpha Terpineol | 2-(4-Methylcyclohex-3-en-1-yl)propan-2-ol | 0.32 | $C_{10}H_{18}O$ |
| Citral | (2*E*)-3,7-dimethylocta-2,6-dienal | 1.43 | $C_{10}H_{16}O$ |

### 3.2 Engine Setup:

Testing Equipment comprises of a four-stroke, single cylinder, water cooled, variable compression ratio and PFI equipped spark ignition engine. Eddy current type dynamometer is connected to loading the engine. Table3 mentions the specifications of the research engine. At each operating point, the ignition angle, fuel injection angle, fuel injection time is programmed with open Electronic control unit (ECU) based on engine speed and throttle position, which helps in optimizing engine performance across its working range. Throttle position, coolant temperature, air temperature, and trigger sensor are connected to Open ECU to regulate fuel pump, fuel injector, ignition coil, and idle air.

Rotameters are provided to control and flow rate measurement of cooling water. The calorimeter is used to measure the temperature of coolant water. Instruments are provided to engine equipment to measure fuel flow, airflow, load and temperatures measurements. The setup has a standalone panel box consisting of petrol and diesel tanks, air box, manometer, air flow measurement, fuel flow measurement, load controller, process indicator and hardware interface.

A piezoelectric dynamic pressure transducer (BERU PSG) has been mounted on a test engine to find the in-cylinder pressure data. With the help of a crankshaft encoder, the cylinder pressure at each crank angle was recorded. The cylinder pressure data for each crank angle from -360$^0$ CA to +360$^0$ CA was obtained by using National Instruments (NI) data acquisition system. The temperature of exhaust gas is measured by thermocouple type K.


Figure3.4: IC engine Setup, Apex Innovation 240PE

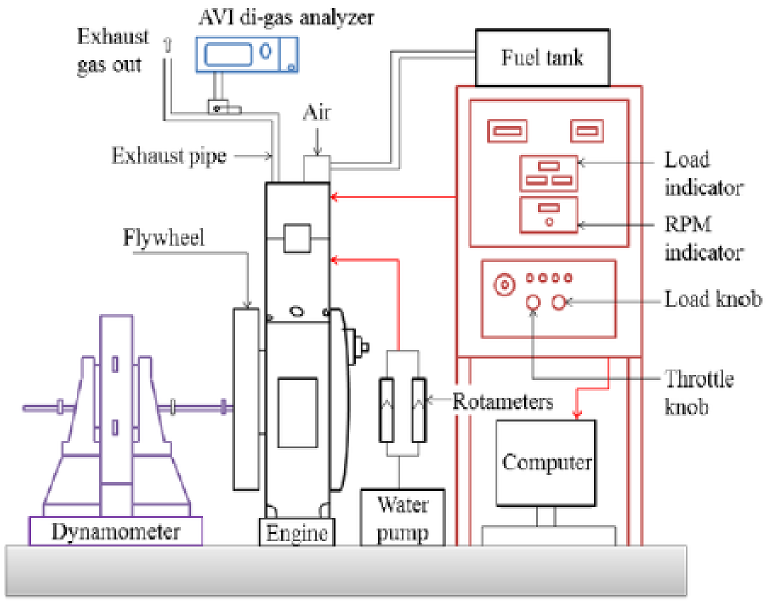



Figure3.5: Schematic representation of the single cylinder PFI engine

Table3. Specifications of the test engine

| | |
|---|---|
| Engine type | Single cylinder PFI engine |
| Model and make | TV1, Kirloskar Oil Engines |
| Ignition | Spark ignition |
| Injection pressure | 3 bar |
| Injection timing | 359 $^0$BTDC |

| | |
|---|---|
| Compression ratio | 10:1 |
| Cubic capacity | 662 $cm^3$ |
| Connecting rod | 234 mm |
| Bore*stroke | 87.5 mm* 110 mm |
| Cooling type | Water Cooled |

AVL Gas Analyzer:

Exhaust gas emissions are measured by using the five gas analyzer Model AVL DiGas 444. It measures the exhaust gases $CO_2$ , $O_2$, HC , CO and NOx emissions.

Figure3.6: AVL Digas 444 Gas analyzer

Bomb Calorimeter:

For measuring the Lower heating values of gasoline, LPO and LPO-gasoline blends, bomb calorimeter (IKA C200-ASTM D4809) is used. In this 0.5 ml sample is taken and water coolant is maintained around $20^0$C. The pressure inside the calorimeter is maintained at 30 bar. We have taken three values, and average values are reported. We have obtained the lower heating values as 44000 kJ/Kg, 45000 kJ/Kg for gasoline and LPO respectively.

Table4. Density and Lower heating values of LPO and Gasoline

| **Fuel** | **Density (kg/lit)** | **Lower heating value(J/kg)** |
|---|---|---|
| Gasoline | 0.725 | 44000 |
| LPO20 | 0.746 | 44186 |
| LPO40 | 0.768 | 44363 |
| LPO100 | 0.833 | 45000 |


Figure3.7: Bomb Calorimeter Setup

### 3.3 Experimental Procedure:

In this study, the engine speed with MBT spark timing is maintained at 1500 ± 20 rpm, and the equivalence ratio is maintained at 1 ±0.02 for each operating conditions. For each working condition, the pressure data is averaged over 50 cycles. Each reading is taken three times for statistical analysis, and average values are recorded.

The following tests are conducted in SI engine using gasoline, LPO20 and LPO40 as fuel.

### Procedure for load test:

1. Pour the fuel (gasoline, LPO20, LPO-40) tested into the engine fuel tank before start of the engine.
2. Water pump supply is started for cooling purpose.
3. Set the rotameters at the required water levels for the proper mass flow rate of water
4. Switch on the load and speed indicators
5. Fuel flow is opened using PFI controller.
6. Connect the laptop installed with Labview software (Enginesoft) to the engine for reading the data.
7. The engine was started with no load condition and wait for 5 minutes to reach steady state.
8. The throttle needs to be rotated very slowly to increase the air supply rate.
9. The load is changed by controlling the load knob very slowly and carefully.
10. Try to adjust both throttle position and load knob to get required constant speed.
11. Air consumption is measured in the attached software.

12. Fuel consumption rate is measured from stand-alone box fuel controller using stop watch for 12 cc of fuel consumption.
13. The required equivalence ratio is adjusted by using throttle and fuel map from the software.
14. The engine is let to run for 10 min to achieve the equilibrium for each test condition before taking the final results
15. Save the obtained data in the desired folder.
16. Similarly, obtain data for different loading conditions.
17. Then stop the engine using the software and then keep the throttle and load knob to zero levels. Then close the fuel supply.
18. Repeat a similar test for different LPO-gasoline blends.

**Procedure for emission test:**

1. Switch on the AVL Digas 444 gas analyzer and allow it to settle down to display zero readings of emissions.
2. Perform the leak check test, zero check test and HC residue test to get accurate readings.
3. Start the engine and run for required operating conditions.
4. Hold the gas analyzer probe at the exhaust gas outlet. Take the readings shown in the display after they have reached a maximum value in 3-5 minutes.
5. After noting the obtained data remove the gas analyzer probe from the exhaust gas outlet and wait for 5 min to settle display at zero readings.
6. Repeat a similar test for different loads of gasoline and LPO-gasoline blends.

# Chapter 4

# Results and Discussion

In present work, we experiment with an SI engine with a constant engine speed 1500 ±20 rpm and varying loading conditions 40%, 60%, and 80% for Gasoline and LPO-Gasoline blends. The equivalence ratio is kept constant, and spark timing is set for Maximum Brake Toque (MBT) for each operating case. Combustion, performance, and emission analysis of LPO-Gasoline blends compared with baseline gasoline for each operating conditions.

### 4.1 Performance analysis:

Brake specific fuel consumption:

From the Figure4.1, we can observe that as BMEP increases, BSFC decreases. It can be observed that for the gasoline and LPO-gasoline blends, BSFC has no significant change due to the similar calorific value of both fuels. We can observe that BSFC is decreased slightly with the fuel blends, which is due to the slight increase in the LPO's calorific value compared to gasoline. Additionally, LPO blend burns more effectively because of the faster flame speed of LPO compared to gasoline. BSFC is observed lowest for LPO40 and higher loading condition (12 kg; BMEP = 4.7 bar).

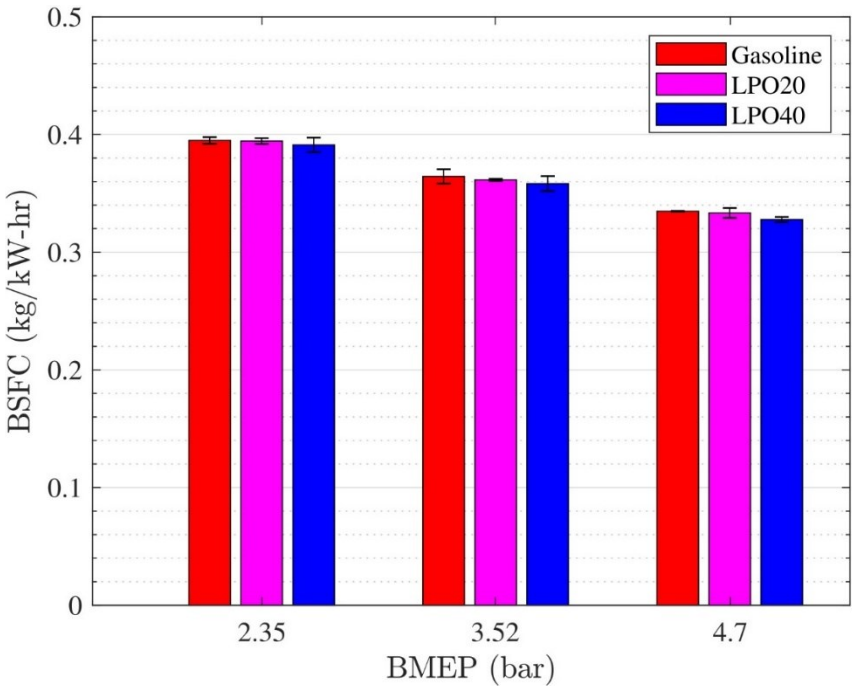



Figure4.1: BSFC variation for LPO-gasoline blends at various loading conditions.

Brake thermal efficiency (BTE):

BTE variation for LPO-gasoline blends with BMEP is shown in Figure4.2. The results show that BTE improves with increase in load. Also, BTE shows a slight increment for LPO20 and LPO 40 compared to baseline gasoline. Due to slight increase in the calorific value of LPO compared to gasoline and higher flame speed of LPO. We can also observe that BTE is inversely proportional to BSFC.

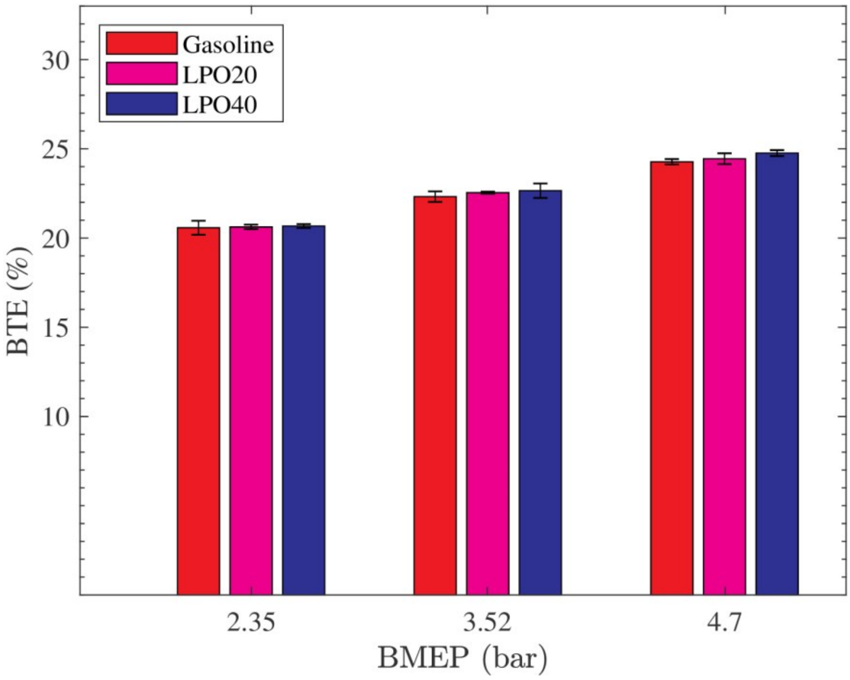



Figure4.2. BTE variation for LPO-gasoline blends at various loading conditions.

Exhaust gas temperature (EGT):

In the Figure4.3, EGT variation for LPO-gasoline blends with BMEP is shown. It can be observed that with an increase in BMEP, EGT increases due to higher energy input. For LPO-gasoline blends, it is observed that their EGT is higher compared to gasoline, which is due to the lower latent heat of vaporization for blends, the charge cooling effect is lower in the intake manifold, so it increases the EGT. Thus as LPO% increases charge cooling effect decreases so higher EGT is observed.

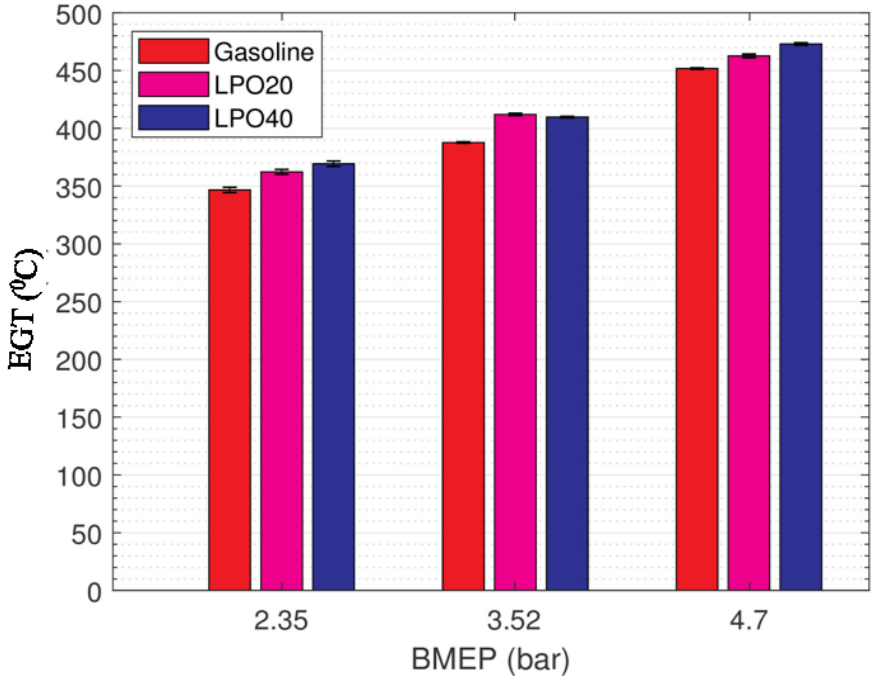



Figure4.3 EGR variation for LPO-gasoline blends at various loading conditions.

## 4.2 Combustion analysis:

In this study, Combustion parameters such as in-cylinder mean gas pressure, heat release rate, and cumulative heat release rate are analysed for the suitability of LPO blends in SI engine operation conditions.

### Instantaneous P-θ curve:

From instantaneous P-Theta curve for 50 cycles and the mean cylinder pressure curves at 9 kg load are presented in the Figure4.4. From these curves, we can know the range of pressure peak and pressure changes in an operating condition and for the LPO blends and gasoline, we observe similar peak pressure values and similar curves trends are observed. By this we can conclude combustion characteristics of LPO blends are similar to the gasoline.

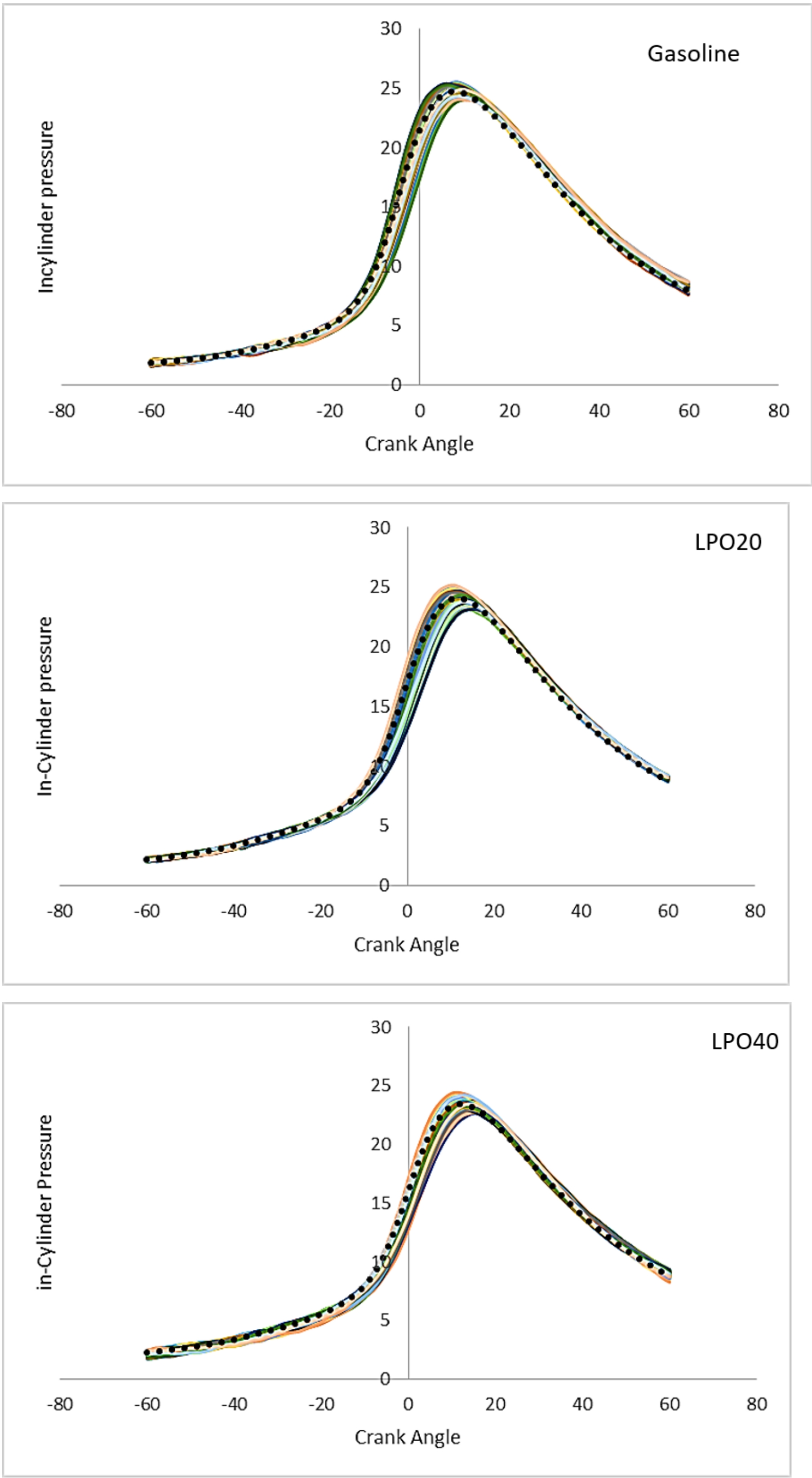
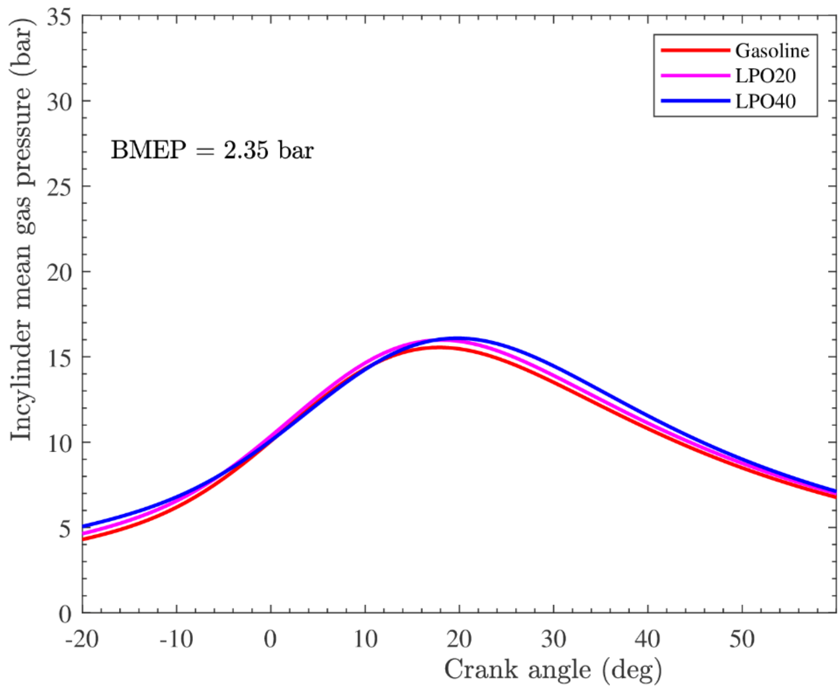



Figure4.4: (a) Instantaneous pressure curve for 50 cycles of 9 kg load for gasoline (b) Instantaneous pressure curve for 50 cycles of 9 kg load for LPO20 (c) Instantaneous pressure curve for 50 cycles of 9 kg load for LPO40

In-cylinder mean gas pressure:

The in-cylinder mean gas pressure vs. crank angle for gasoline, LPO20, and LPO40 for different BMEP conditions is shown in Figure4.5. Cylinder pressure is increased with an increase in BMEP due to an increase in the amount of air/fuel mass into a cylinder. As BMEP increases, the position of peak pressure shifting towards TDC for each fuel, which is due to improved evaporation of air/fuel mixture at higher load leading to the higher mass burning velocity. For gasoline and LPO-gasoline blends, we observe that p-θ almost overlaps each other for each loading condition. As properties like LHV, air-fuel ratio, and octane rating are very similar for LPO and gasoline, so similar combustion phasing is observed. The maximum Pmax and θPmax are for each fuel blends are similar to baseline gasoline for each loading condition. For the LPO20, LPO40 there is a slight increase in Pmax and θPmax is shifted towards TDC because of the faster flame speed of LPO compared to gasoline, which is due to the presence of cyclohexane.



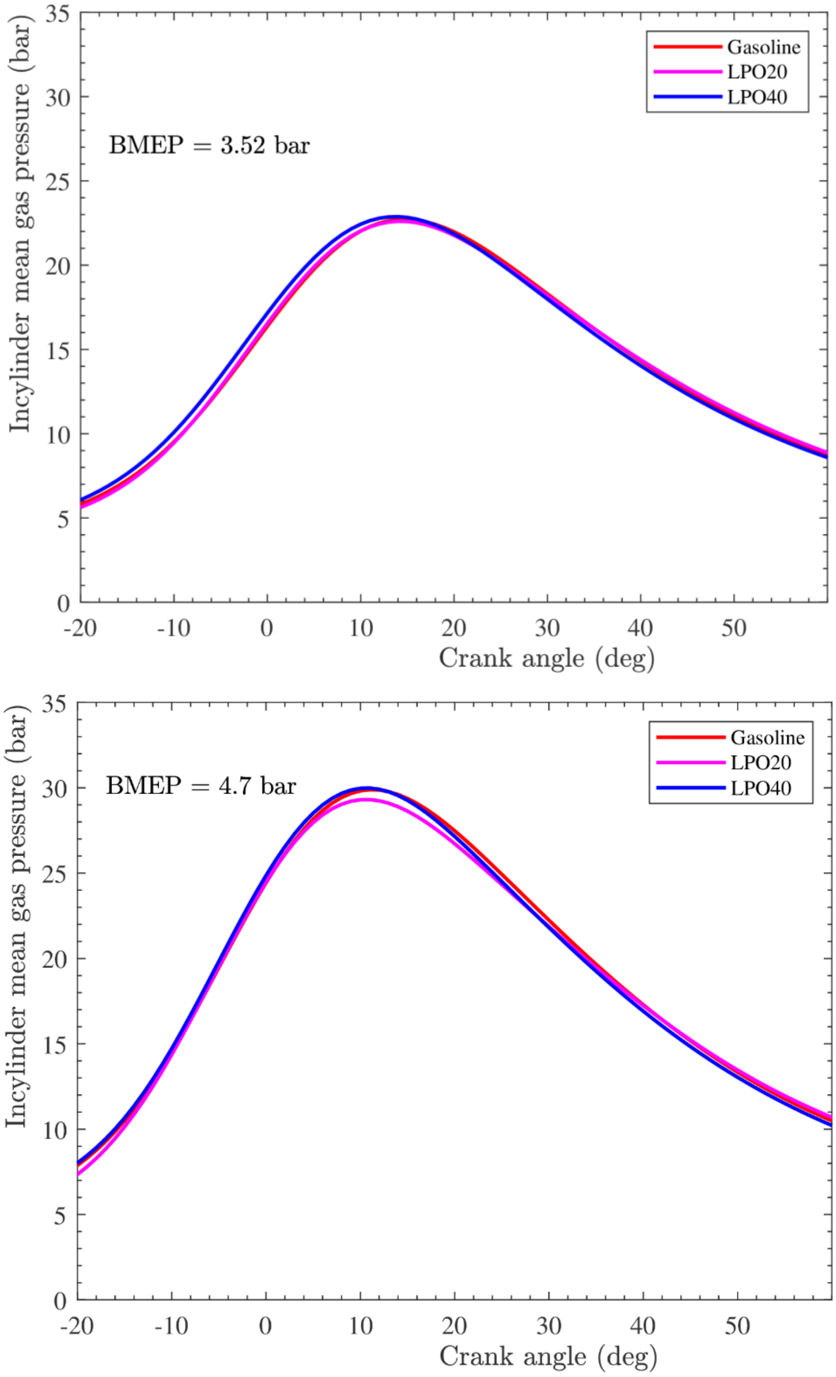
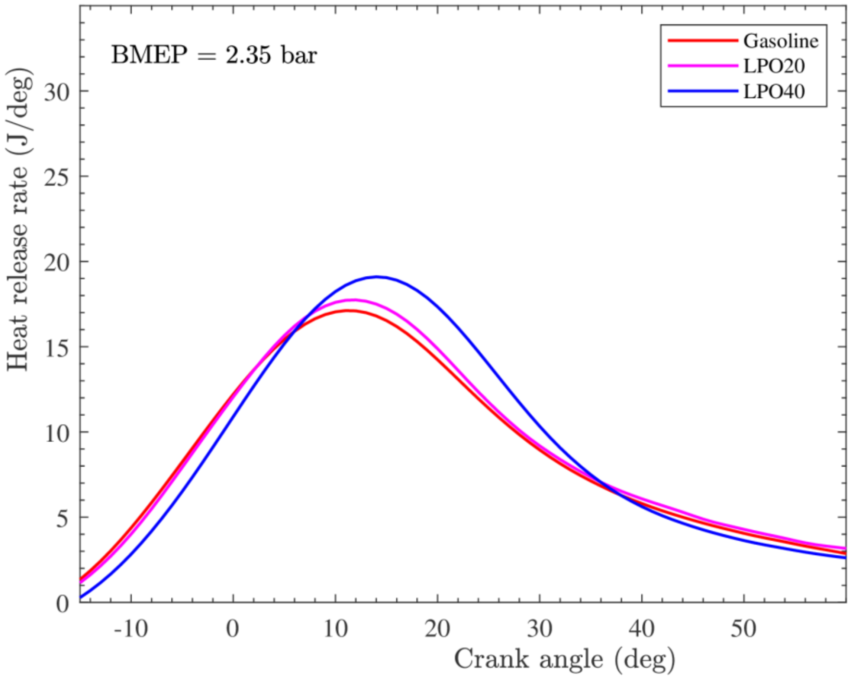
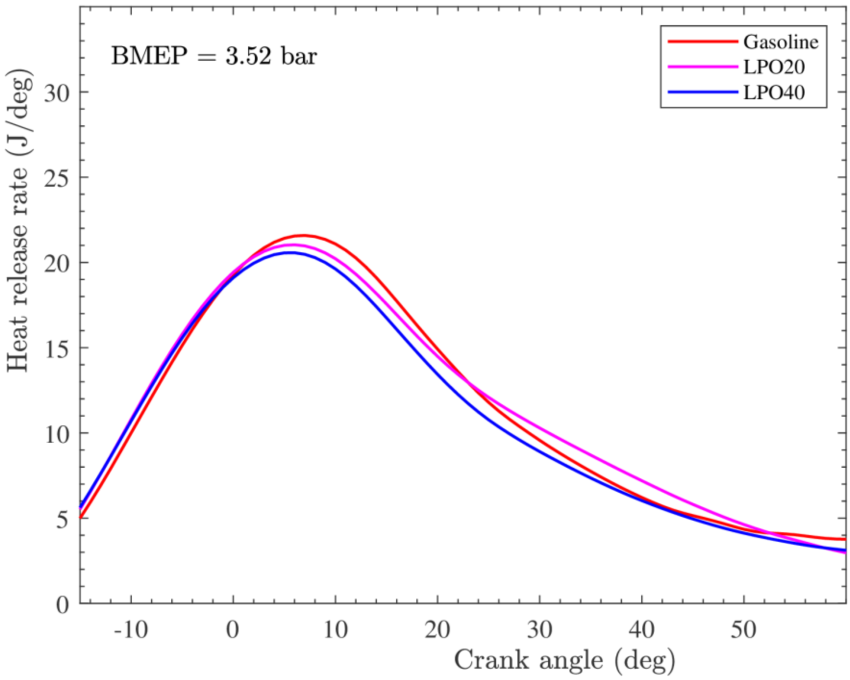



Figure4.5. (a) Cylinder pressure variation for LPO-gasoline blends at BMEP = 2.35. (b)Cylinder pressure variation for LPO-gasoline blends at BMEP = 3.52. (c) Cylinder pressure variation for LPO-gasoline blends at BMEP = 4.7

Heat release rate:

Figure4.6 shows the HRR variation of different fuel blends for various loading conditions (BMEP). The heat release rate increases with the increase of BMEP. As load increases, more fuel was drawn into the cylinder chamber; the higher energy was released from the combustion process. The peak position of HRR is shifted towards closer to TDC due to the increase in flame speed. For LPO20 and LPO40, the HRR-θ curve is almost similar to baseline gasoline. HRR max and θHRR max are almost similar. HRR max is slightly higher and θHRR max is shifted towards TDC for LPO blends because of the faster flame speed of LPO blends.



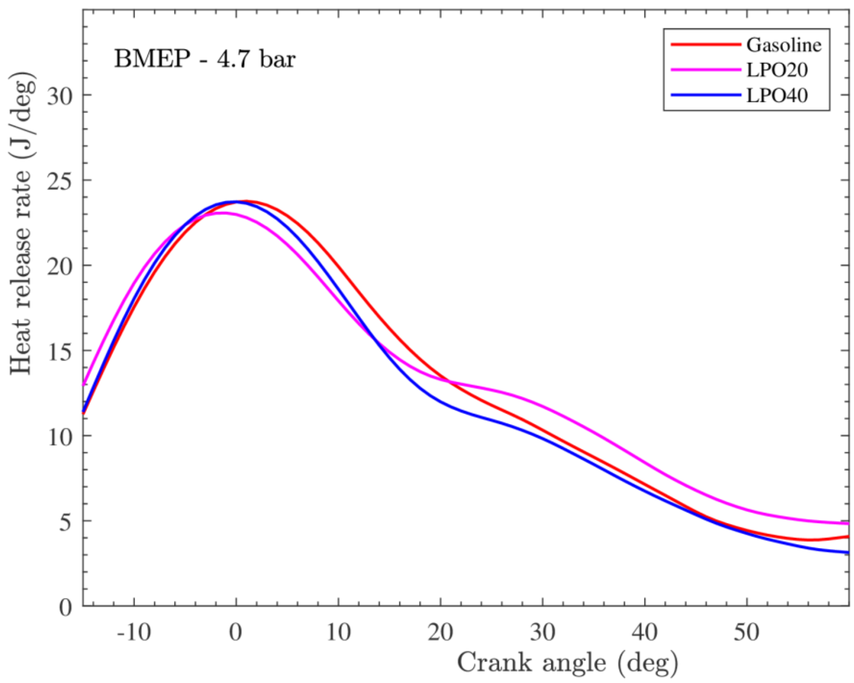
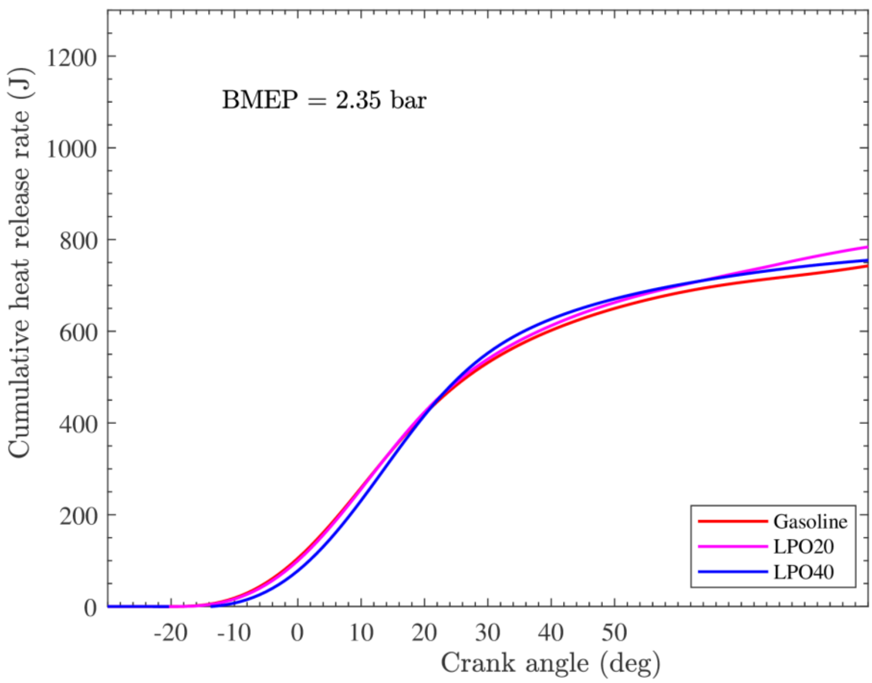



Figure4.6: (a) HRR variation for LPO-gasoline blends at BMEP = 2.35. (b) HRR variation for LPO-gasoline blends at BMEP = 3.52. (c) HRR variation for LPO-gasoline blends at BMEP = 4.7.

Cumulative Heat release rate:

Figure4.7 shows CHRR for LPO blends at different BMEP; we observe that CHRR is similar for the fuel blends at each loading condition. HRR and CHRR are similar from the combustion process point of view.



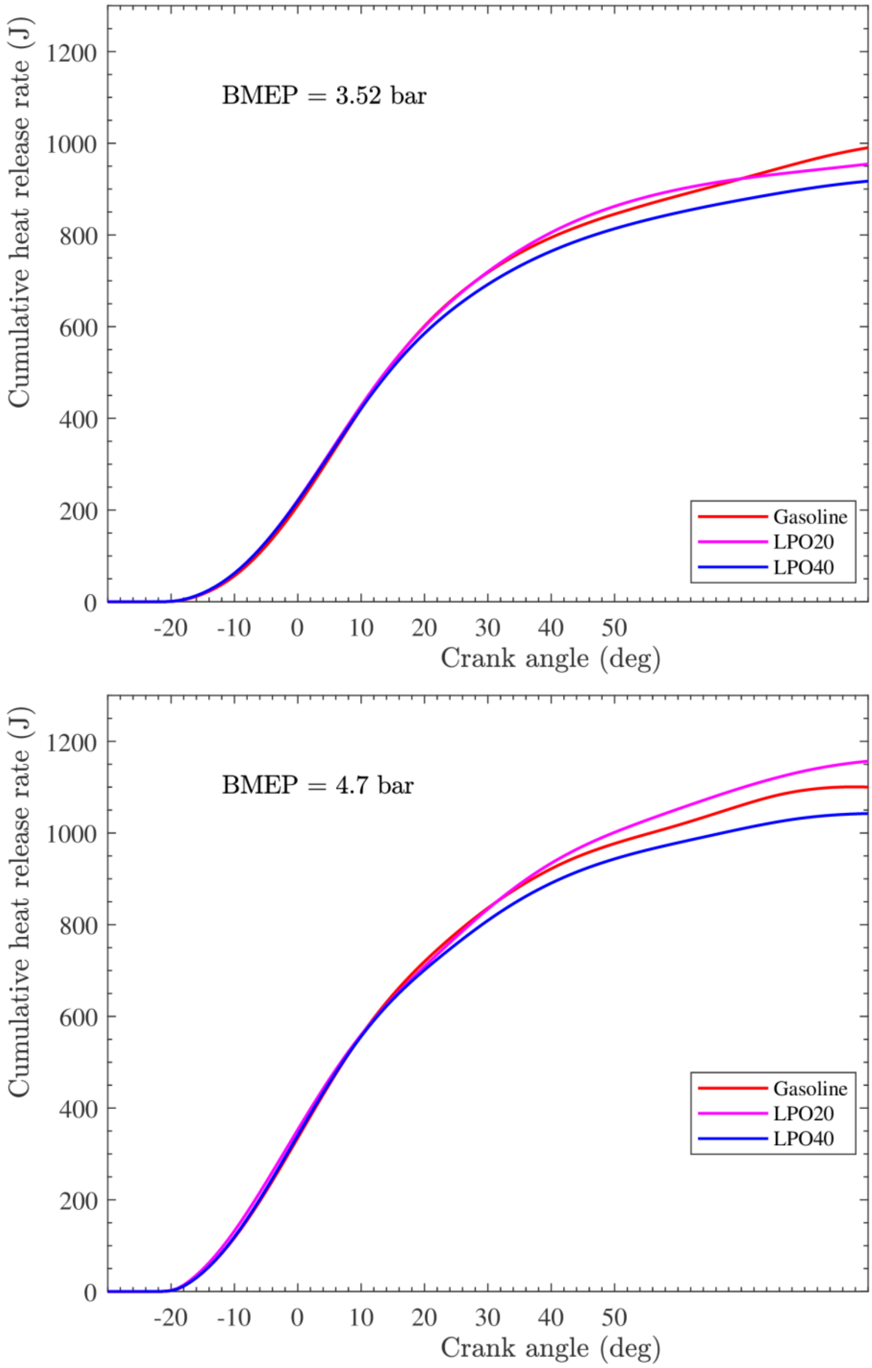



Figure4.7: (a) CHRR variation for LPO-gasoline blends at BMEP = 2.35. (b) CHRR variation for LPO-gasoline blends at BMEP = 3.52. (c) CHRR variation for LPO-gasoline blends at BMEP = 4.7.

Cyclic variability:

Cyclic variability occurs due to various factors such as variation in mixture preparation, in-cylinder motion, and initial flame kernel development. For a general SI engine, a cycle-to-cycle variation less than 5% is desirable. Cycle-to-cycle variation ($COV_{imep}$) is the ratio of the standard deviation of indicated mean effective pressure (IMEP) to the mean of IMEP, expressed in percentage.

The variation of COV in IMEP for gasoline and LPO blends is shown in Figure4.8. COV is with desirable value for all operating conditions. With an increase in load, the combustion is more stable, and COV decreases. Also, at high throttling condition, the initial pressure fluctuations are lower. For LPO-gasoline blends, $COV_{imep}$ is in desirable percentage, as combustion is stable and there is no drivability problem with the addition of LPO to gasoline.

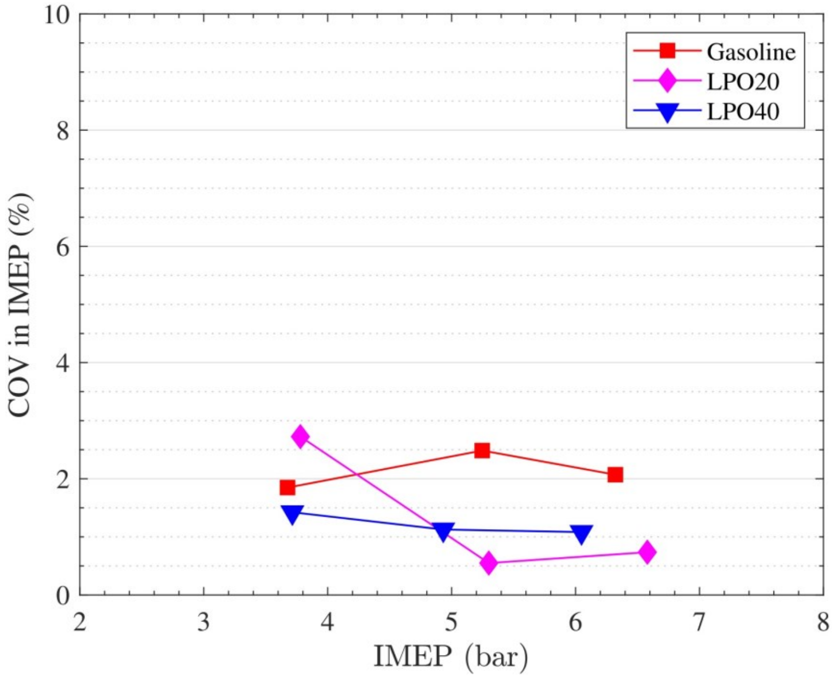



Figure4.8: Variation of COV of IMEP for gasoline and LPO-gasoline blends.

### 4.3 Emission analysis:

In this study, the emission analysis of gasoline LPO blends is investigated for three different loading conditions. AVL Digas analyzer is used to measure the emission concentrations of HC, CO, and NOx.

Carbon monoxide (CO) Emissions:

CO emission depends on A/F ratio and engine operating condition. In this Figure4.9, we observe the variation of CO emissions for gasoline, LPO20, and LPO40 for different engine loading conditions. It is observed that with an increase of load, CO emissions are reduced. With an increase in load, CO emission goes down mainly because of high throttling condition and increase in engine head temperature, which improves evaporation of fuel. It is also observed that with LPO-gasoline blends CO emission are decreasing. This is because LPO's faster flame speed, which promotes the process of combustion, decreases the CO emissions.

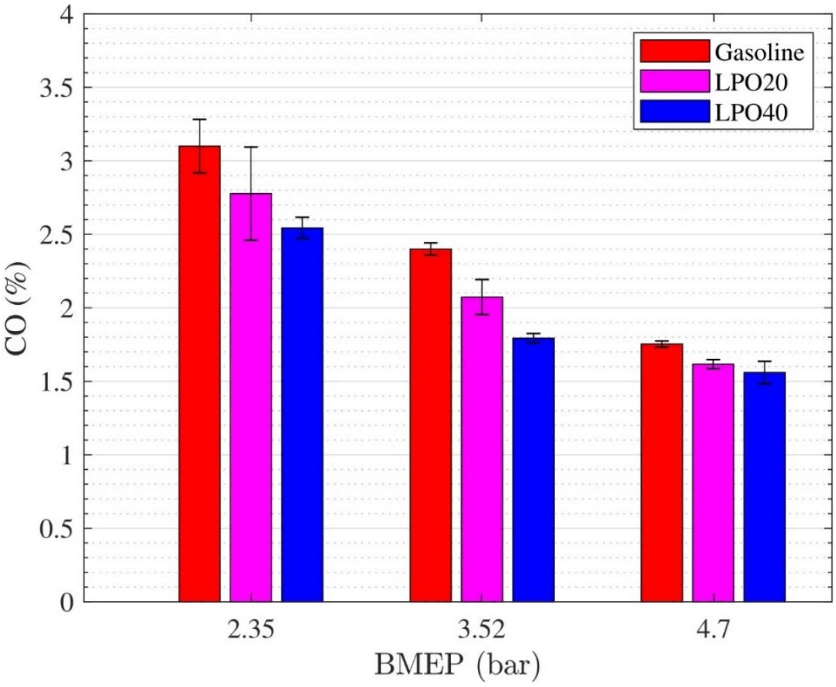



Figure4.9: CO emission variation for LPO-gasoline blends at various loading conditions.

## Hydrocarbon (HC) Emissions:

Figure4.10 shows the HC emission variation for LPO-gasoline blends for various loading conditions. As BMEP increases, HC emissions are decreasing due to the rise in cylinder temperature. As combustion of fuel and oxygen is easier with an increase in cylinder temperature. LPO-gasoline blends result in lower HC emissions compared to that of gasoline. Due to the presence of cyclohexane in LPO chemical composition, which increases the flame speed of LPO, promotes the combustion process, which reduces in HC emissions.

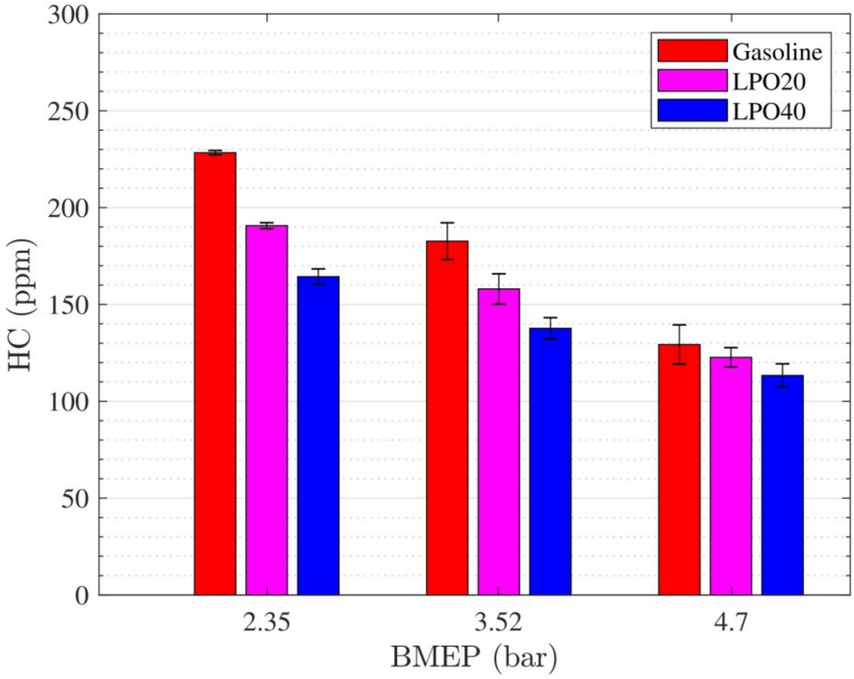


Figure4.10: HC emission variation for LPO-gasoline blends at various loading conditions.

Nitrogen Oxides (NOx) Emissions:

NOx emission mainly depends on maximum combustion temperature, equivalence ratio, and excess oxygen available. NOx emission variation for LPO-gasoline blends for various loading conditions is shown in Figure4.11. As BMEP increases, Nox concentration increases because of the higher temperature of combustion. NOx concentration increases for LPO-gasoline blends compared to gasoline. As latent Heat of vaporization of LPO blends is lower than gasoline, charge cooling effect LPO blends lower, which increases combustion temperature in the cylinder.

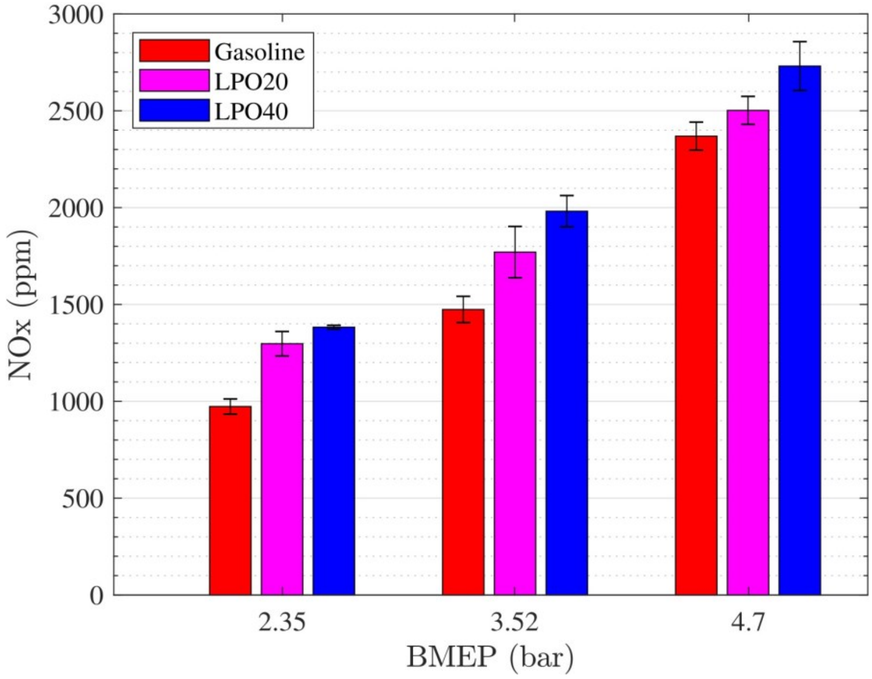



Figure4.11: NOx emission variation for LPO-gasoline blends at various loading conditions.

### 4.4 Statistical analysis:

Analysis of variance is a statistical method used to analyse the difference among group means in a sample. ANOVA is used for the study of the effects of multiple factors. In this study, ANOVA with 2-factor interaction was performed on independent variables (Engine BMEP and Fuel Blends) and Dependent variables (BTE, CO, HC, and NOx) with a 95% confidence level and 5% significance level. The normal probability of residuals is observed for BTE, HC, CO, and NOx. It is statically observed that all the results obtained are normally distributed and there are no possible outliners. The results of two way ANOVA for BTE, CO, HC, and NOx are shown in the table. P-value is observed to be less than 0.05, suggests that model terms are statistically significant. Adeq. Precision value exceeding four is favorable. The $R^2$ value for each independent variable series is 95 to 100 %. The predicted $R^2$ value is also within a reasonable range of adjusted $R^2$ value with a difference of less than 0.2. From the percentage of influence, we can note that LPO Blends shows an influence of 0.60% on BTE, 12.18% on CO, 22.96 % on HC and 9.29% on NOx. Also load as an influence of 97.41% on BTE, 81.38% on CO, 69.62% on HC and 88.84% on NOx. Normality plot residuals for BTE, CO, HC and NOx are shown in Figure4.12.

| Source | Sum of squares | Df | Mean of the sum of squares | % influence | F-value | P-value |
|---|---|---|---|---|---|---|
| BTE | | | | | | |
| Model | 67.922 | 8 | 8.490 | | 122.959 | 0.0001 |
| LPO Blends | .416 | 2 | 0.208 | 0.6014 | 3.015 | 0.074 |
| Engine load | 67.374 | 2 | 33.687 | 97.410 | 487.865 | 0.0001 |
| Blend X load | .132 | 4 | 0.033 | 0.196 | .477 | |
| Pure error | 1.243 | 18 | 0.069 | 1.797 | | |
| Total | 69.145 | 26 | | | | |
| Std. Dev | 0.2732 | | Mean | 22.54 | | |
| $R^2$ | .982 | | Adj. $R^2$ | 0.974 | | |
| Adeq. precision | 42.4855 | | Pred. $R^2$ | 0.9672 | | |

| Source | Sum of squares | Df | Mean of the sum of squares | % influence | F-value | P-value |
|---|---|---|---|---|---|---|
| CO | | | | | | |
| Model | 7.282 | 8 | 0.91 | | 48.883 | .0001 |
| LPO Blends | 0.928 | 2 | 0.464 | 12.18 | 24.919 | .0001 |
| Engine load | 6.201 | 2 | 3.101 | 81.39 | 166.5 | .0001 |
| Blend X load | 0.153 | 4 | 0.38 | 2.01 | 2.057 | |
| Pure error | 0.335 | 18 | .019 | 4.66 | | |
| Total | 7.618 | 26 | | | | |
| Std. Dev | .149 | | Mean | 2.18 | | |
| $R^2$ | 0.956 | | Adj. $R^2$ | 0.936 | | |
| Adeq. precision | 25.1968 | | Pred. $R^2$ | 0.9034 | | |

| Source | Sum of squares | Df | Mean of the sum of squares | % influence | F-value | P-value |
|---|---|---|---|---|---|---|
| HC | | | | | | |
| Model | 33415.33 | 8 | 4176.917 | | 102.805 | 0.0001 |
| LPO Blends | 7840.667 | 2 | 3920.333 | 22.96 | 96.49 | 0.0001 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Engine load | 23772.667 | 2 | 11886.33 | 69.619 | 292.553 | 0.0001 |
| Blend X load | 1802.00 | 4 | 450.5 | 5.2772 | 11.088 | |
| Pure error | 731.333 | 18 | 40.63 | 2.142 | | |
| Total | 34146.667 | 26 | | | | |
| Std. Dev | 6.37 | | Mean | 158.56 | | |
| $R^2$ | 0.979 | | Adj. $R^2$ | 0.969 | | |
| Adeq. precision | 31.2491 | | Pred. $R^2$ | 0.9518 | | |

| Source | Sum of squares | Df | Mean of the sum of squares | % influence | F-value | P-value |
|---|---|---|---|---|---|---|
| NOx | | | | | | |
| Model | 8.774e+06 | 8 | 1.096e+06 | | 162.698 | 0.0001 |
| LPO Blends | 8.262e+05 | 2 | 4.131e+05 | 9.287 | 61.28 | 0.0001 |
| Engine load | 7.9035e+06 | 2 | 3.9517e+06 | 88.84 | 586.203 | 0.0001 |
| Blend X load | 44953.481 | 4 | 11148.37 | 0.501 | 1.654 | |
| Pure error | 121343.333 | 18 | 6741.296 | 1.364 | | |
| Total | 8.896e+06 | 26 | | | | |
| Std. Dev | 86.85 | | Mean | 1831.15 | | |
| $R^2$ | 0.986 | | Adj. $R^2$ | 0.98 | | |
| Adeq. Precision | 46.6225 | | Pred. $R^2$ | 0.9714 | | |

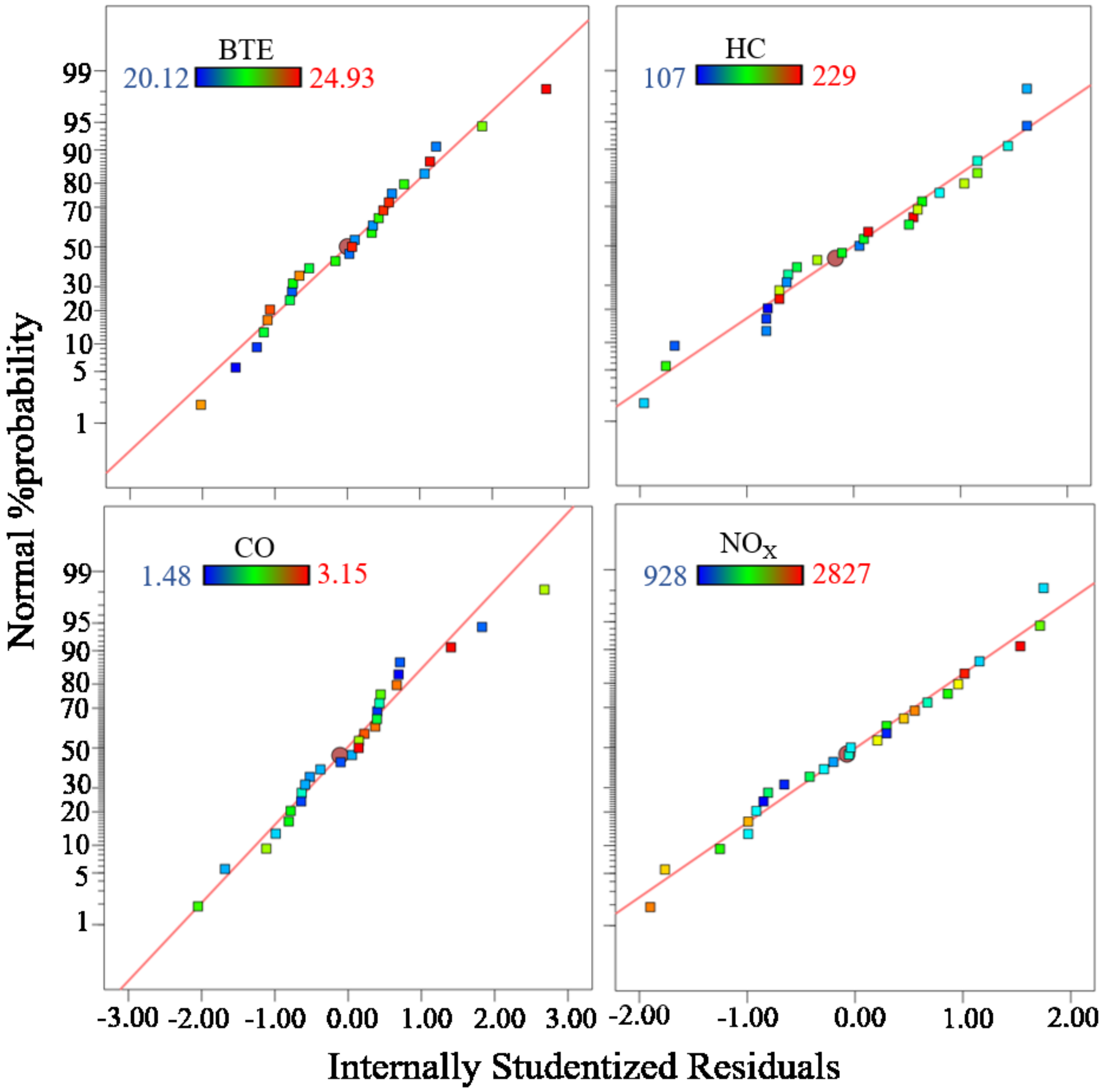



Figure4.12: Normality plot residuals for BTE, CO, HC and NOx

**Taguchi Method:**

From the Taguchi method, we can know that BTE is optimal for LPO20 and load 12 Kg, CO is optimal at LPO20 and load 6 Kg, HC is optimal at LPO40 and load 12 kg, Nox is optimal at LPO20 and load 9 kg from Figure 4.13 and Figure 4.14 which shows the S/N ratio response curves for fuel and load factors

| | | | | | | BTE | CO | HC | Nox |
|---|---|---|---|---|---|---|---|---|---|
| | | BTE | CO | HC | Nox | Ssij | | | |
| gasoline | 1 | -34.41 | -31.97 | -45.92 | -27.95 | -38.75 | -30.963 | -31.244 | -28.3302 |
| | 2 | -37.58 | -22.41 | -25.67 | -26.75 | | | | |
| | 3 | -44.25 | -38.51 | -22.13 | -30.3 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LPO20 | 4 | -38.47 | -18.83 | -41.93 | -26.26 | -42.91 | -26.0356 | -31.928 | -26.5191 |
| | 5 | -52.13 | -24.8 | -26.12 | -22.52 | | | | |
| | 6 | -38.12 | -34.47 | -27.74 | -30.78 | | | | |
| LPO40 | 7 | -45.54 | -30.92 | -32.18 | -43.07 | -41.33 | -30.7183 | -28.542 | -32.517 |
| | 8 | -34.96 | -34.93 | -27.96 | -27.77 | | | | |
| | 9 | -43.49 | -26.3 | -25.48 | -26.71 | | | | |
| | | | | | | | | | |
| | | | | | | BTE | CO | HC | Nox |
| load | | BTE | CO | HC | Nox | Ssij | | | |
| 40 | 1 | -34.41 | -31.97 | -45.92 | -27.95 | -39.47 | -27.2429 | -40.01 | -32.4254 |
| | 2 | -38.47 | -18.83 | -41.93 | -26.26 | | | | |
| | 3 | -45.54 | -30.92 | -32.18 | -43.07 | | | | |
| 60 | 4 | -37.58 | -22.41 | -25.67 | -26.75 | -41.56 | -27.379 | -26.584 | -25.6769 |
| | 5 | -52.13 | -24.8 | -26.12 | -22.52 | | | | |
| | 6 | -34.96 | -34.93 | -27.96 | -27.77 | | | | |
| 80 | 7 | -44.25 | -38.51 | -22.13 | -30.3 | -41.95 | -33.095 | -25.119 | -29.264 |
| | 8 | -38.12 | -34.47 | -27.74 | -30.78 | | | | |
| | 9 | -43.49 | -26.3 | -25.48 | -26.71 | | | | |

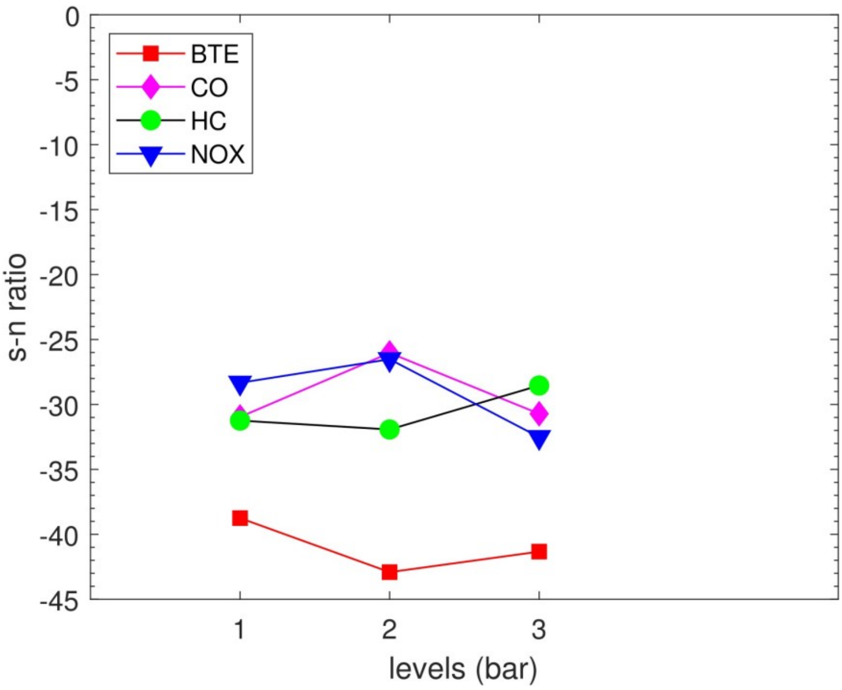



Figure4.13: S/N response curves for Fuel factor

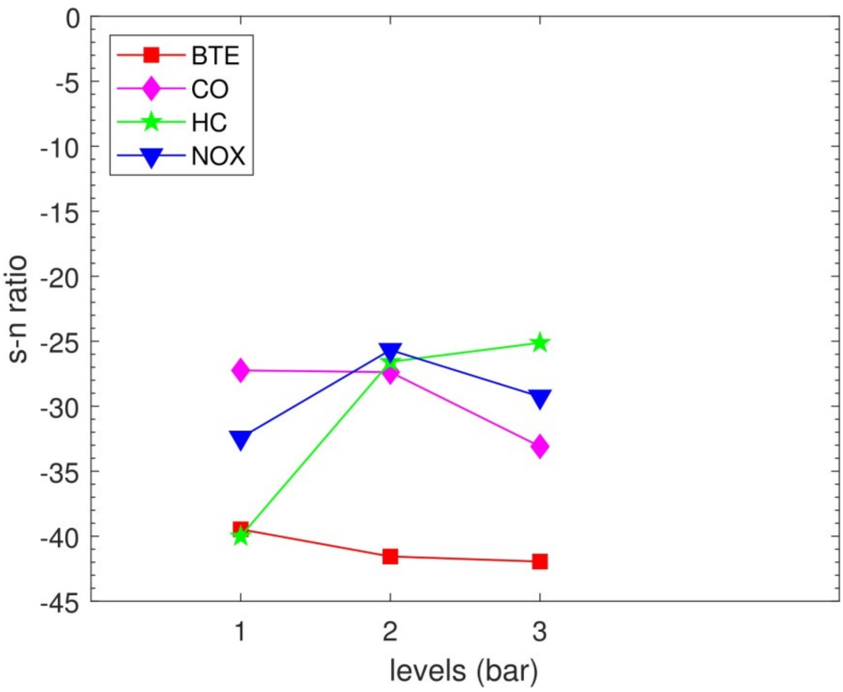



Figure4.14: S/N response curves for load factor

| FACTOR | Optimal fuel blend | Optimal load |
|---|---|---|
| BTE | LPO20 | 12 |
| CO | LPO20 | 6 |
| HC | LPO40 | 12 |
| NOx | LPO20 | 9 |

# Chapter 5

# Conclusion and Future work

## 5.1 Conclusion:

In the present study, the effect of lemon peel oil-gasoline blends on engine performance, combustion and emission characteristics in a single cylinder PFI engine have been investigated experimentally. Important findings are:

- LPO-Gasoline blends have similar BTE and BSFC compared gasoline. LPO20 and LPO40 have slightly higher BTE as compared to gasoline because of higher LHV and higher laminar mass burning rates of LPO.
- With the addition of LPO to gasoline, EGT increases because of lower latent heat of vaporization in LPO blends.
- HRR and CHRR of LPO blends have no significant change compared to that of gasoline.
- Combustion is stable with LPO-gasoline blends as $COV_{IMEP}$ is less than 5% for all operating conditions.
- Because of better combustion with the addition of LPO to gasoline, HC and CO emissions of LPO blends are lower compared to that of gasoline.
- NOx emissions are higher for LPO20 and LPO40 compared to gasoline. The high temperature of exhaust gas and better combustion results in higher emissions of NOx.
- For best performance and best thermal efficiency, 20% LPO and 80% gasoline is the optimum blend preparation.

## 5.2 Future scope:

- Effect of Exhaust Gas Recirculation (EGR) for LPO-gasoline blends to reduce emissions of NOx.
- Performance, combustion, and emission analysis with GDI engine
- Water emulsification of LPO-gasoline blends for reduction of NOx emissions.
- With a change in equivalence ratio, we can observe the performance, emissions of LPO blends
- In emission characteristics, smoke emissions and particulate number can be studied.

# REFERENCES


1. Turns, Stephen R. An Introduction to combustion. New York McGraw-hill 1996
2. Heywood, John B. Internal combustion engine fundamentals. NewYork McGraw hill 1988.
3. Agarwal, A. K., Gupta, T., Shukla, P. C., & Dhar, A. (2015). Particulate emissions from biodiesel fuelled CI engines. Energy Conversion and Management, 94, 311-330
4. Chansauria, P., & Mandloi, R. K. (2018). Effects of ethanol blends on performance of spark ignition engine-a review. Materials Today: Proceedings, 5(2), 4066-4077
5. https://www.eia.gov/energyexplained/index.php?page=us_energy_transportation
6. Energy Mix Wikipedia https://en.wikipedia.org/wiki/Energy_mix
7. Biswal, A., Kale, R., Balusamy, S., Banerjee, R., & Kolhe, P. (2019). Lemon peel oil as an alternative fuel for GDI engines: A spray characterization perspective. Renewable Energy, 142, 249-263.
8. Biswal, Abinash and Balusamy, Saravanan and Kolhe, Pankaj et. al (2018) Experimental Investigation of Lemon Peel Oil-Gasoline Blends as a Fuel in Spark Ignition Engine. In: Proceedings of the 7th International and 45th National Conference on Fluid Mechanics and Fluid Power (FMFP), 10-12 December 2018, IIT Bombay, Mumbai, India.
9. Topgül, T., Yücesu, H. S., Cinar, C., & Koca, A. (2006). The effects of ethanol–unleaded gasoline blends and ignition timing on engine performance and exhaust emissions. Renewable energy, 31(15), 2534-2542.
10. Al-Hasan, M. (2003). Effect of ethanol–unleaded gasoline blends on engine performance and exhaust emission. Energy conversion and management, 44(9), 1547-1561.
11. Yüksel, F., & Yüksel, B. (2004). The use of ethanol–gasoline blend as a fuel in an SI engine. Renewable energy, 29(7), 1181-1191.
12. Koç, M., Sekmen, Y., Topgül, T., & Yücesu, H. S. (2009). The effects of ethanol–unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine. Renewable energy, 34(10), 2101-2106.
13. Hsieh, W. D., Chen, R. H., Wu, T. L., & Lin, T. H. (2002). Engine performance and pollutant emission of an SI engine using ethanol–gasoline blended fuels. Atmospheric Environment, 36(3), 403-410
14. Thangavelu, S. K., Ahmed, A. S., & Ani, F. N. (2016). Review on bioethanol as alternative fuel for spark ignition engines. Renewable and Sustainable Energy Reviews, 56, 820-835.
15. Costagliola, M. A., De Simio, L., Iannaccone, S., & Prati, M. V. (2013). Combustion efficiency and engine out emissions of a SI engine fueled with alcohol/gasoline blends. Applied energy, 111, 1162-1171.
16. Liu, S., Clemente, E. R. C., Hu, T., & Wei, Y. (2007). Study of spark ignition engine fueled with methanol/gasoline fuel blends. Applied Thermal Engineering, 27(11-12), 1904-1910.

17. Yanju, W., Shenghua, L., Hongsong, L., Rui, Y., Jie, L., & Ying, W. (2008). Effects of methanol/gasoline blends on a spark ignition engine performance and emissions. Energy & Fuels, 22(2), 1254-1259.
18. Agarwal, A. K., Karare, H., & Dhar, A. (2014). Combustion, performance, emissions and particulate characterization of a methanol–gasoline blend (gasohol) fuelled medium duty spark ignition transportation engine. Fuel processing technology, 121, 16-24.
19. Abu-Zaid, M., Badran, O., & Yamin, J. (2004). Effect of methanol addition on the performance of spark ignition engines. Energy & Fuels, 18(2), 312-315.
20. Elfasakhany, A. (2015). Investigations on the effects of ethanol–methanol–gasoline blends in a spark-ignition engine: performance and emissions analysis. Engineering Science and Technology, an International Journal, 18(4), 713-719.
21. Gu, Xiaolei, Zuohua Huang, Jian Cai, Jing Gong, Xuesong Wu, and Chia-fon Lee. "Emission characteristics of a spark-ignition engine fuelled with gasoline-n-butanol blends in combination with EGR." Fuel 93 (2012): 611-617.
22. Dernotte, J., Mounaim-Rousselle, C., Halter, F., & Seers, P. (2010). Evaluation of butanol–gasoline blends in a port fuel-injection, spark-ignition engine. Oil & Gas Science and Technology–Revue de l'Institut Français du Pétrole, 65(2), 345-351.
23. Purushothaman, K., & Nagarajan, G. (2009). Experimental investigation on a CI engine using orange oil and orange oil with DEE. Fuel, 88(9), 1732-1740.
24. Ashok, B., Raj, R. T. K., Nanthagopal, K., Krishnan, R., & Subbarao, R. (2017). Lemon peel oil–A novel renewable alternative energy source for diesel engine. Energy conversion and management, 139, 110-121.
25. Ashok, B., Nanthagopal, K., Anand, V., Aravind, K. M., Jeevanantham, A. K., & Balusamy, S. (2019). Effects of n-octanol as a fuel blend with biodiesel on diesel engine characteristics. Fuel, 235, 363-373.
26. Xiao, S., Sun, W., Du, J., & Li, G. (2014). Application of CFD, Taguchi method, and ANOVA technique to optimize combustion and emissions in a light duty diesel engine. Mathematical Problems in Engineering, 2014.
27. https://www.reference.com/vehicles/four-stroke-engine-work-2ec8d5f1dff0c977
28. Mechanical Booster (https://www.mechanicalbooster.com/2017/10/otto-cycle.html)
29. https://trak.in/tags/business/2013/03/19/indias-energy-consumption-4th-largest-in-the-world

30. Ashok, B., Nanthagopal, K., Saravanan, B., Somasundaram, P., Jegadheesan, C., Chaturvedi, Bhaskar Chaturvedi, Shivam Sharma, & Patni, G. (2018). A novel study on the effect lemon peel oil as a fuel in CRDI engine at various injection strategies. Energy conversion and management, 172, 517-528.
31. Celik, M. B. (2008). Experimental determination of suitable ethanol–gasoline blend rate at high compression ratio for gasoline engine. Applied Thermal Engineering, 28(5-6), 396-404.
32. Galloni, E., Fontana, G., Staccone, S., & Scala, F. (2016). Performance analyses of a spark-ignition engine firing with gasoline–butanol blends at partial load operation. Energy Conversion and Management, 110, 319-326