EXPERIMENTAL STUDY OF PERFORMANCE AND EMISSION OF AN CI ENGINE FUELLED BY BLENDS OF LEMON OIL WITH BIODIESEL

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Abstract: A single cylinder four stroke variable compression multi fuel engine is used to study the performance and exhaust emission when fueled with 5%, 10% and 20% of lemon oil and methanol blended with diesel are investigated and compared with standard diesel. Experiments were carried out at different loading conditions. The effect of using different blend percentages on brake thermal efficiency, brake specific fuel consumption and exhaust emissions has been investigated and presented in this paper.

Keywords:- Brake thermal efficiency, emissions, spark angle, Lemon Peel oil, Brake specific fuel consumption.

I. Introduction

Exhaust emission produced by vehicles is the major concern for raise in pollution in most metropolitan cities. Due to rapid modernization and increasing population the number of vehicles has been increased causing rapid increasing the pollution. Bio fuels are looking as an important prospect to look in to thereby reducing the fuel consumption. Bio fuels sacrifice either performance for better emission or for better performance high emissions. Basavaraj M. Shirgiri et al. studied the performance, emission, and combustion characteristics of low heat rejection diesel engine using cotton seed and neem kernel oil methyl esters and compared both of them. They observed that there is a decrease in brake thermal efficiency by 5.91%, and 7.07% and brake specific fuel consumption is increased by 28.57% and 10.71%. They found that there is an increase in exhaust emission in which NOx has higher increase there is slight increase in carbon monoxide, smoke and hydrocarbon. K.Sivaramakrishnan investigated the performance and emission characteristics of a variable compression engine fueled with karanja and diesel blend. He conducted experiments with 20%, 25% and 30% blend s of the fuel at different compression ratios of 15:1, 16:1, 17:1 and 18:1. 25% karanja biodiesel-diesel blend produced the best results for a compression ratio of 18:1. He observed that there is an increase in brake thermal efficiency with increase in compression ratio, 30.46% is the maximum brake thermal efficiency. The minimum hydrocarbon emissions were obtained at 20% blend and Co emissions were minimum at 25% blend. Senthil Ramalingam et al. studied the performance, emission and combustion characteristics of diesel engine operated using Annona methyl ester by different injection timing and compression ratio. They found out that 20% blend can be used without any modifications to the engine. Optimum compression ratio and injection timing for better performance is 19.5 and 30^0 BTDC respectively. They observed that there is increase in brake thermal efficiency, reduction in specific fuel consumption and decrease in exhaust emissions with both increase in compression ratio and injection timing. S V Channapattana et al. investigated emission and performance using direct injection CI engine using honne oil methyl ester as bio diesel at different compression ratio 15:1, 16:1, 17:1 and 18:1. The engine operated at different fuel blends B20- B100 blend. B20 blend give better performance close to diesel for 18:1 compression ratio with 100% bio diesel there is 8.9% decrease in brake thermal efficiency and increase in specific fuel consumption. There is an increase in NOx emission at higher compression ratio and decrease in carbon monoxide and hydro carbon emission and increase in carbon dioxide emission. T. Balusamy et al. studied the effect of injection pressure and injection time on compression ignition engine fueled with methyl ester of thevetia peruviana seed oil and found out that optimum injection pressure and injection timing as 225 bar and 27^0 before TDC respectively. They observed that there is a significant increase in brake thermal efficiency and reduction in brake specific fuel consumption, carbon monoxide, hydro carbons and smoke emission by advancing the injection pressure. G.R.K. Sastry et al conducted experiments using fish oil bio diesel blends on diesel engine to analyze the vibration emission and performance. Fish oil in different percentages i.e. 20%, 30%, 40% is used to conduct the experiments they observed that there is increase in brake specific fuel consumption and reduction in brake thermal efficiency, carbon monoxide and smoke, increase in NOx emission.

G. Venkata subbaiah et al. investigated experimentally the performance and emission characteristics of a direct injection diesel engine fueled with rice bran bio diesel and ethanol blends. They conducted experiments using three different blend percentages and observed that 2.5% ethanol blended biodiesel produced optimum results.

There is 27.47% reduction smoke emission and reduction in carbon monoxide, unused oxygen, hydro carbons with 2.5% ethanol blend. Jayadhri N. Nair et al. analyzed the performance and exhaust emission on compression ignition engine using neem biodiesel as fuel. The experiments were carried out at 10%, 20% 30% bio diesel blends and the optimum performance and exhaust emissions were obtained at 10% blend percentage. They observed that 23% ,8.5% and 22% reduction in carbon monoxide, hydro carbons and NOx emission respectively and increase in brake thermal efficiency and reduction in brake specific fuel consumption when compared with diesel. S. Nagaraja et al. conducted experiments using preheated palm oil- diesel blends at different compression ratio to examine the performance and emission characteristics. The experiments were carried out at 5%, 10%, 15% and 20% blend percentages over five compression ratios i.e. 16:1 to 20:1. The optimum performance conditions were observed at 20% blend percentage at 20:1 compression ratio. They observed there is an increase in carbon dioxide and decrease in carbon monoxide and hydrocarbon emissions and there is 6% increase in brake power.

II EXPERIMENTAL SETUP

A single cylinder four stroke engine, multi fuel with variable compression ratio and injection angle was used to carry out the experiments. The engine was equipped with eddy current dynamometer for loading purpose. The setup consists of two fuel tanks for both diesel and gasoline. port fuel injection system was used as fuel injection system. Exhaust gases were analyzed by AVL gas analyzer. The pressure sensor was attached to the engine head to measure the combustion pressure in the engine cylinder. Several data acquisition systems are connected to the experimental setup to process the data obtained. Different parameters (i.e. volumetric efficiency, brake thermal efficiency, brake power etc.) can be studied using this setup.

Table 1: Engine specifications

Engine Type	Single cylinder, 4-stroke CI engine
Cylinder bore	87 (mm)
Stroke length	110 (mm)
Connecting rod length	234 (mm)
Compression ratio	16:1
Swept volume	661 (cc)
Rated power	4.50 kw @1800 rpm
Throttle orifice diameter	20 (mm)
Orifice Coefficient of discharge	0.6
Dynamometer arm length	185 (mm)
Fuel Pipe Diameter	12 (mm)

III TEST FUEL

Orange oil and ethanol are blended with diesel to study the performance characteristics. Orange oil and ethanol oil are blended in 2:1 ratio (i.e. for 10% bio diesel blend it consist of 7.5% orange oil and 2.5% ethanol). Bio diesel blend of 10%, 20%, and 30% are used to conduct this experiment. Properties of both orange oil and ethanol are mentioned below in the table: 2

Table 2: Fuel properties

Density @ 30 ^{0}C (kg/m3)	0.8169
Kinematic viscosity @ 40^0 C (cSt)	3.52
Flash point (^{0}C)	74
Fire point (^{0}C)	82
Lower calorific value (kJ/kg)	34,650
Cetane number	47

IV RESULTS AND DISCUSSION

Carbon monoxide:

Variation of carbon monoxide with change in brake mean effective pressure at different blend percentages has been shown in figure 1. It has been observed that with increase in blend percentage there is a increase in carbon monoxide percentage at each brake mean effective pressure. But there is decrease in carbon monoxide percentage when each blend is compared with different brake mean effective pressure.

Break Mean Effective Pressure (bar)	Carbon monoxide (%)		
	LPO 0%	LPO 5%	LPO 10%
1.14	1.02	1.25	1.41
2.34	1.08	0.9625	0.892
3.75	0.38	0.3175	0.233

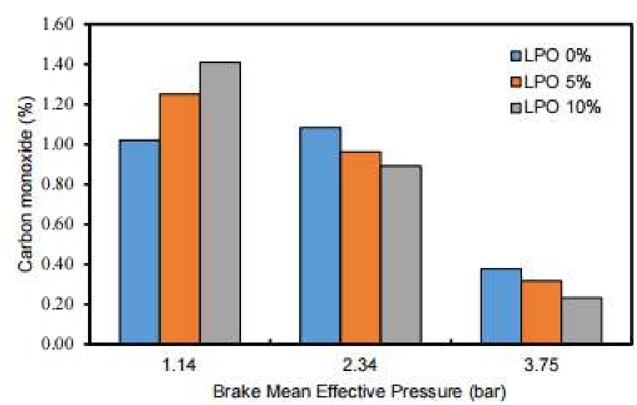


Figure 1: Variation of CO emission with different load conditions

Hydro carbons:

Variation of Hydro carbon with change in brake mean effective pressure at different blend percentages has been shown in figure 2. It has been observed that with increase in blend percentage there is increase in Hydro carbon percentage at each brake mean effective pressure. But there is decrease in Hydro carbon percentage when each blend is compared with different brake mean Smoke Emission:

Variation of carbon monoxide with change in brake mean effective pressure at different blend percentages have been shown in figure 4. It has been observed that bio diesel blends produce more smoke emission than diesel. There is a decrease in smoke emission with increase in brake mean effective pressure at each blend percentages but there is increase in smoke emission with increase in blend percentage at each brake mean effective pressure.

Break Mean Effective Pressure (bar)	Brake Specific Fuel Consumption (Kg/Kwh)		
	LPO 0%	LPO 5%	LPO 10%
1.14	0.433	0.48	0.529
2.34	0.335	0.341	0.402
3.75	0.272	0.29226	0.317

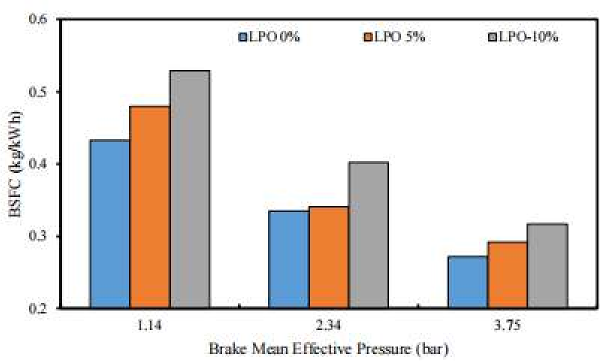


Figure 2: Variation of BSFC with Break mean effective pressure.

Break Mean Effective Pressure (bar)	Hydrocarbons (ppm)		
	LPO 0%	LPO 5%	LPO 10%
1.14	363.44	215.18	369.82
2.34	137.5	166.5	186.4
3.75	119.77	145.19	204.24

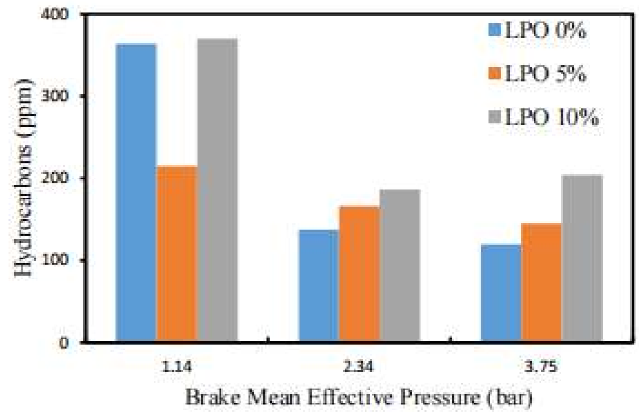


Figure 3: Variation of Hydrocarbons with brake mean effective pressure

NOx Emission:

Variation of carbon monoxide with change in brake mean effective pressure at different blend percentages have been shown in figure 3. It has been observed that with increase in blend percentage there is increase in NOx emission percentage at each brake mean effectivpressure. But there is decrease in NOX emission percentage when each blend is compared with different brake mean effective pressure.

Break Mean Effective Pressure (bar)	Brake Thermal Efficiency (%)		
	LPO 0%	LPO 5%	LPO 10%
1.14	18.87	17.11	15.5
2.34	24.93	24.06	20.45
3.75	30.02	28.088	25.88

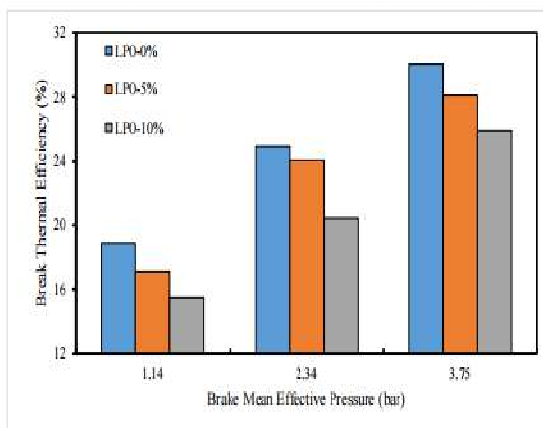
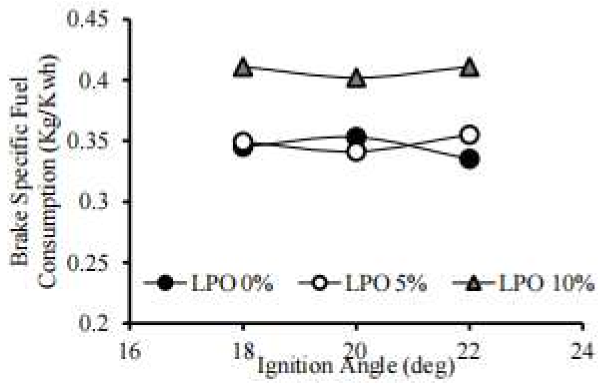


Figure 4:Variation of Brake Thermal Efficiency with Break mean effective pressure.

Brake Specific Fuel Consumption:

Brake specific fuel consumption is the ratio of brake power to the mass of fuel consumed. It is the vice versa of brake thermal efficiency. It is observed that with an increase in blend percentage there is an increase in fuel consumption due to its less calorific value. For LPO 0% brake specific fuel consumption is minimum at 22^0 BTDC ignition angle. But for LPO 5% and LPO 10% the minimum brake specific fuel consumption was obtained at 20^0 BTDC ignition angle.



V CONCLUSION

Orange oil and ethanol are used as bio diesel and its additive the emission characteristics at different brake mean effective pressures has been studied in this experiment. It has been observed that B30 blend produced low emission characteristics. Except NOx all the emissions decreased with increase in brake mean effective pressure but increased with increase in blend percentage at each brake mean effective pressure. NOx emission increased with increase in blend percentage and brake mean effective pressure.

Acknowledgement

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IMPLEMENTATION OF BIO-FUEL AND ITS ADDITIVES ON DIESEL ENGINE TO REDUCE EXHAUST EMISSIONS

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Abstract: A single cylinder four stroke variable compression multi fuel engine is used to study the performance and exhaust emission when fueled with 0%, 5% and 10% of orange oil and ethanol blended with diesel are investigated and compared with standard diesel. Experiments were carried out at different loading conditions. The effect of using different blend percentages on brake thermal efficiency, brake specific fuel consumption and exhaust emissions has been investigated and presented in this paper.

Keywords:- Brake thermal efficiency, emissions, spark angle, Lemon Peel oil, Brake specific fuel consumption**.**

I.Introduction

Exhaust emission produced by vehicles is the major concern for raise in pollution in most metropolitan cities. Due to rapid modernization and increasing population the number of vehicles has been increased causing rapid increasing the pollution. Bio fuels are looking as an important prospect to look in to thereby reducing the fuel consumption. Bio fuels sacrifice either performance for better emission or for better performance high emissions. Basavaraj M. Shirgiri et al. studied the performance, emission, and combustion characteristics of low heat rejection diesel engine using cotton seed and neem kernel oil methyl esters and compared both of them. They observed that there is a decrease in brake thermal efficiency by 5.91%, and 7.07% and brake specific fuel consumption is increased by 28.57% and 10.71%. They found that there is an increase in exhaust emission in which NOx has higher increase there is slight increase in carbon monoxide, smoke and hydrocarbon. K.Sivaramakrishnan investigated the performance and emission characteristics of a variable compression engine fueled with karanja and diesel blend. He conducted experiments with 20%, 25% and 30% blend s of the fuel at different compression ratios of 15:1, 16:1, 17:1 and 18:1. 25% karanja biodiesel-diesel blend produced the best results for a compression ratio of 18:1. He observed that there is an increase in brake thermal efficiency with increase in compression ratio, 30.46% is the maximum brake thermal efficiency. The minimum hydrocarbon emissions were obtained at 20% blend and Co emissions were minimum at 25% blend. Senthil Ramalingam et al. studied the performance, emission and combustion characteristics of diesel engine operated using Annona methyl ester by different injection timing and compression ratio. They found out that 20% blend can be used without any modifications to the engine. Optimum compression ratio and injection timing for better performance is 19.5 and 30^0 BTDC respectively. They observed that there is increase in brake thermal efficiency, reduction in specific fuel consumption and decrease in exhaust emissions with both increase in compression ratio and injection timing. S V Channapattana et al. investigated emission and performance using direct injection CI engine using honne oil methyl ester as bio diesel at different compression ratio 15:1, 16:1, 17:1 and 18:1. The engine operated at different fuel blends B20- B100 blend. B20 blend give better performance close to diesel for 18:1 compression ratio with 100% bio diesel there is 8.9% decrease in brake thermal efficiency and increase in specific fuel consumption. There is an increase in NOx emission at higher compression ratio and decrease in carbon monoxide and hydro carbon emission and increase in carbon dioxide emission. T. Balusamy et al. studied the effect of injection pressure and injection time on compression ignition engine fueled with methyl ester of thevetia peruviana seed oil and found out that optimum injection pressure and injection timing as 225 bar and 27^0 before TDC respectively. They observed that there is a significant increase in brake thermal efficiency and reduction in brake specific fuel consumption, carbon monoxide, hydro carbons and smoke emission by advancing the injection pressure. G.R.K. Sastry et al conducted experiments using fish oil bio diesel blends on diesel engine to analyze the vibration emission and performance. Fish oil in different percentages i.e. 20%, 30%, 40% is used to conduct the experiments they observed that there is increase in brake specific fuel consumption and reduction in brake thermal efficiency, carbon monoxide and smoke, increase in NOx emission.

G. Venkata subbaiah et al. investigated experimentally the performance and emission characteristics of a direct injection diesel engine fueled with rice bran bio diesel and ethanol blends. They conducted experiments using three different blend percentages and observed that 2.5% ethanol blended biodiesel produced optimum results. There is 27.47% reduction smoke emission and reduction in carbon monoxide, unused oxygen, hydro carbons with 2.5% ethanol blend. Jayadhri N. Nair et al. analyzed the performance and exhaust emission on compression ignition engine using neem biodiesel as fuel. The experiments were carried out at 10%, 20% 30% bio diesel blends and the optimum performance and exhaust emissions were obtained at 10% blend percentage. They observed that 23% ,8.5% and 22% reduction in carbon monoxide, hydro carbons and NOx emission respectively and increase in brake thermal efficiency and reduction in brake specific fuel consumption when compared with diesel. S. Nagaraja et al. conducted experiments using preheated palm oil- diesel blends at different compression ratio to examine the performance and emission characteristics. The experiments were carried out at 5%, 10%, 15% and 20% blend percentages over five compression ratios i.e. 16:1 to 20:1. The optimum performance conditions were observed at 20% blend percentage at 20:1 compression ratio. They observed there is an increase in carbon dioxide and decrease in carbon monoxide and hydrocarbon emissions and there is 6% increase in brake power.

II EXPERIMENTAL SETUP

A single cylinder four stroke engine, multi fuel with variable compression ratio and injection angle was used to carry out the experiments. The engine was equipped with eddy current dynamometer for loading purpose. The setup consists of two fuel tanks for both diesel and gasoline. port fuel injection system was used as fuel injection system. Exhaust gases were analyzed by AVL gas analyzer. The pressure sensor was attached to the engine head to measure the combustion pressure in the engine cylinder. Several data acquisition systems are connected to the experimental setup to process the data obtained. Different parameters (i.e. volumetric efficiency, brake thermal efficiency, brake power etc.) can be studied using this setup.

Engine Type	Single cylinder, 4-stroke CI engine
Cylinder bore	87 (mm)
Stroke length	110 (mm)
Connecting rod length	234 (mm)
Compression ratio	16:1
Swept volume	661 (cc)
Rated power	4.50 kw @1800 rpm
Throttle orifice diameter	20 (mm)
Orifice Coefficient of discharge	0.6
length	
Fuel Pipe Diameter	12 (mm)

Table 1: Engine specifications

III.TEST FUEL

Orange oil and ethanol are blended with diesel to study the performance characteristics. Orange oil and ethanol oil are blended in 2:1 ratio (i.e. for 10% bio diesel blend it consist of 7.5% orange oil and 2.5% ethanol). Bio diesel blend of 10%, 20%, and 30% are used to conduct this experiment. Properties of both orange oil and ethanol are mentioned below in the table: 2

Density @ 30 ^{0}C (kg/m3)	0.8169
Kinematic viscosity @ 40^{0} C (cSt)	3.52
Flash point (^{0}C)	74
Fire point (^{0}C)	82
Lower calorific value (kJ/kg)	34,650
Cetane number	47

Table 2: Fuel properties

The distillation curve of the lemon peel oil has been plotted and it is found out that initial boiling point is 159.70 c and the final boiling point is 212.10 c and the residual content in the lemon peel oil is 0.8%.

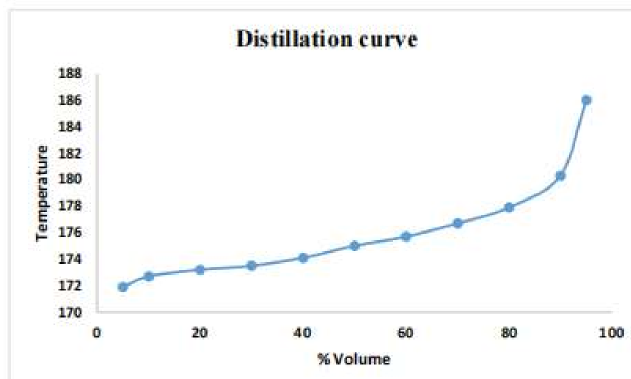

Figure 2.1 :Distillation curve of Pure Lemon Peel oil

IV. RESULTS AND DISCUSSION

Combustion characteristics:

The combustion characteristics consist of engine parameters like in-cylinder pressure, maximum in-cylinder pressure, heat release rate etc.

In-cylinder Pressure

The growth of in-cylinder pressure after complete combustion and release of pressure in a proper way (depending on piston position with respect to TDC) as per the engine requirement has the vital role on engine power development.

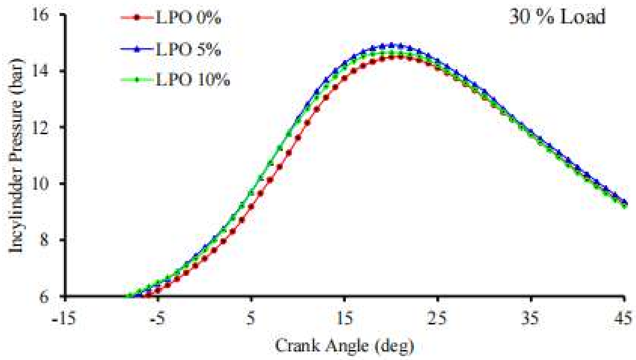

Figure: 4.1 Variation of In-cylinder Pressure with Crank angle (deg) at 30% Load

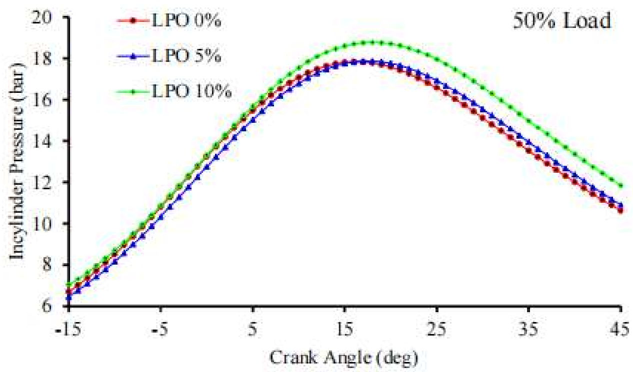

Figure: 4.2 Variation of In-cylinder Pressure with Crank angle (deg) at 50% Load

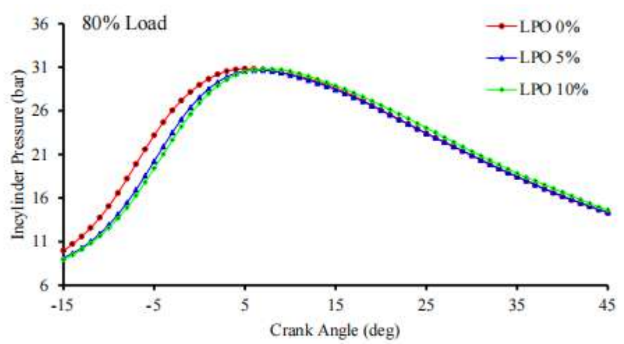

Figure: 4.3 Variation of In-cylinder Pressure with Crank angle (deg) at 80% Load

Carbon monoxide:

Variation of carbon monoxide with change in brake mean effective pressure at different blend percentages has been shown in figure 1. It has been observed that with increase in blend percentage there is a increase in carbon monoxide percentage at each brake mean effective pressure. But there is decrease in carbon monoxide percentage when each blend is compared with different brake mean effective pressure.

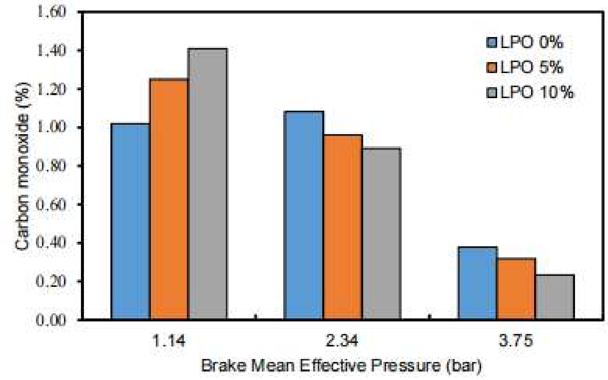

Figure: 4.4 Variation of CO emission with different load conditions

Hydro carbons:

Variation of Hydro carbon with change in brake mean effective pressure at different blend percentages has been shown in figure 2. It has been observed that with increase in blend percentage there is increase in Hydro carbon percentage at each brake mean effective pressure. But there is decrease in Hydro carbon percentage when each blend is compared with different brake mean effective pressure.

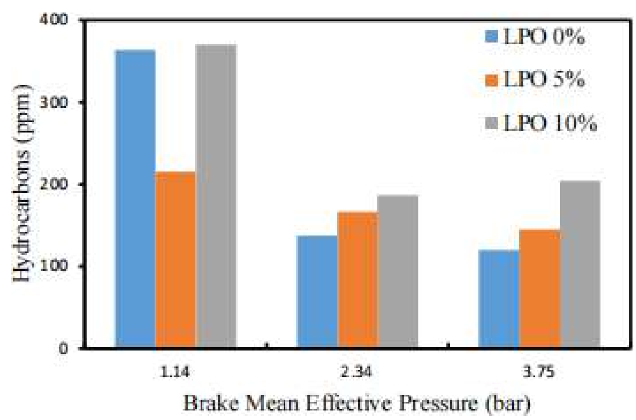

Figure 4.4: Variation of HC emission with different load conditions

Brake Specific Fuel Consumption:

Brake specific fuel consumption is the ratio of brake power to the mass of fuel consumed. It is the vice versa of brake thermal efficiency. It is observed that with an increase in blend percentage there is an increase in fuel consumption due to its less calorific value. For LPO 0% brake specific fuel consumption is minimum at 220 BTDC ignition angle. But for LPO 5% and LPO 10% the minimum brake specific fuel consumption was obtained at 200 BTDC ignition angle.

Spark Angle (deg)	Brake Specific Fuel Consumption (Kg/Kwh)		
	LPO 0%	LPO 5%	LPO 10%
18	0.345	0.349	0.411
20	0.353	0.341	0.402
22	0.335	0.355	0.411

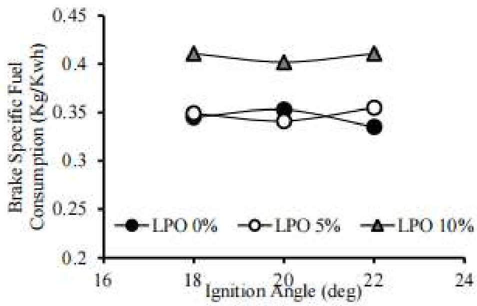

Figure: 4.5 Variation of BSFC with ignition angle for different blends

Brake Thermal Efficiency:

Brake thermal efficiency is the ratio of brake power and product of the mass of fuel consumed and its calorific value it has been observed that with an increase in blend percentage there is a decrease in the efficiency and with an increase in spark angle the efficiency increased and then decreased by LPO 5% and LPO 10% blend percentages. Maximum efficiency is obtained at 200 BTDC spark angle for LPO 5% and LPO 10% blends. This is due to change in ignition angle there is a delay in ignition due to the low calorific value of the fuel the ignition angle needs to be retarded thereby increasing the efficiency but further retardation leads to incomplete combustion leading to decrease in efficiency.

Spark Angle (deg)	Brake Thermal Efficiency (%)		
	LPO 0%	LPO 5%	LPO 10%
18	23.67	23.51	19.99
20	23.15	24.06	20.45
22	24.93	23.11	19.99

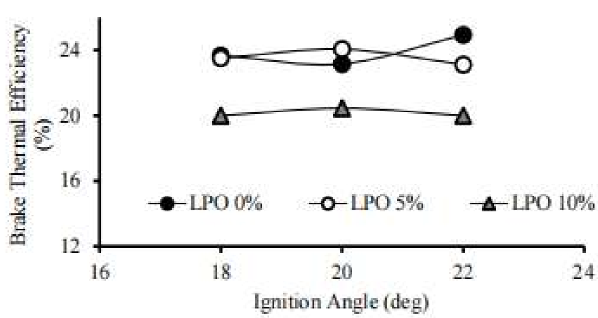

Figure: 4.6 Variation of Break thermal efficiency with ignition angle for different blends

CONCLUSION

Orange oil and ethanol are used as bio diesel and its additive the emission characteristics at different brake mean effective pressures has been studied in this experiment. It has been observed that B30 blend produced low emission characteristics. Except NOx all the emissions decreased with increase in brake mean effective pressure but increased with increase in blend percentage at each brake mean effective pressure. NOx emission increased with increase in blend percentage and brake mean effective pressure.

Acknowledgement:

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EXECUTIVE SUMMARY

The excessive use of fossil fuel, led to the depletion of energy sources at a very fast rate. This has forced researchers to find an alternative renewable source of energy to fossil fuel. In order to find alternative fuel, researchers are concentrating on diesel blends. Lemon oil methyl ester (LOME) is an alternative renewable fuel derived from fresh lemon rinds. The main advantages of using this alternative fuel are its renewability and biodegradability. In this work, an experimental investigation has been done on the performance, combustion characteristics and exhaust emission characteristics of an SI engine. The experiment has been carried out in different stages. In the first stage, the base reading was obtained using gasoline. In the other two phases, the engine performance was studied by blending of Lemon oil methyl ester (LOME) with diesel in different percentage. The engine is fueled with a mixture of LOME and diesel in different proportion by volume. The data obtained from the engine with the blend as the fuel is compared with the data obtained from sole diesel as the fuel. To validate the results, the trails are repeated two times. The engine works at different load and throttle opening but at a fixed speed. For the comparison of the data like performance, combustion and emission characteristics, the engine has been operated under different operating conditions under various load. The results of this study showed that the brake thermal efficiency of the engine decreased with an increase in the percentage of a blend of the Lemon oil methyl ester (LOME) in diesel fuel at different brake mean effective pressures. Fuel consumption increased as it is vice versa to the brake thermal efficiency. With the increase in ignition angle the increase in BTE is very less. Carbon monoxide emission increased with increase in blend percentage at lower BMEP but at higher BMEP it decreased with increase in blend percentage.

Technical report submitted to UGC Minor Research Project

Implementation of bio-Fuels and its additives on diesel Engine to reduce exhaust emissions

UGC Minor Research project sanction **F. No. MRP-6986/16 (UGC-SERO)**

Link NO: 6986

(Technical report No. AITAM/ME/UGC/Minor Res proj/ Laxmana Rao Kunchi/2019/August/03)

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Mr. Laxaman Rao Kunchi

Principal Investigator

CERTIFICATE

This is to certify that the present work titled **Implementation of bio-Fuels and its additives on diesel engine to reduce exhaust emissions** is carried out by me and was not submitted for full/ partial financial assistance to any other funding agency.

Laxmana Rao Kunchi

ABSTRACT

The excessive use of fossil fuel, led to the depletion of energy sources at a very fast rate. This has forced researchers to find an alternative renewable source of energy to fossil fuel. In order to find alternative fuel, researchers are concentrating on diesel blends. Lemon oil methyl ester (LOME) is an alternative renewable fuel derived from fresh lemon rinds. The main advantages of using this alternative fuel are its renewability and biodegradability. In this work, an experimental investigation has been done on the performance, combustion characteristics and exhaust emission characteristics of an SI engine. The experiment has been carried out in different stages. In the first stage, the base reading was obtained using gasoline. In the other two phases, the engine performance was studied by blending of Lemon oil methyl ester (LOME) with diesel in different percentage. The engine is fueled with a mixture of LOME and diesel in different proportion by volume. The data obtained from the engine with the blend as the fuel is compared with the data obtained from sole diesel as the fuel. To validate the results, the trails are repeated two times. The engine works at different load and throttle opening but at a fixed speed. For the comparison of the data like performance, combustion and emission characteristics, the engine has been operated under different operating conditions under various load.

The results of this study showed that the brake thermal efficiency of the engine decreased with an increase in the percentage of a blend of the Lemon oil methyl ester (LOME) in diesel fuel at different brake mean effective pressures. Fuel consumption increased as it is vice versa to the brake thermal efficiency. With the increase in ignition angle the increase in BTE is very less. Carbon monoxide emission increased with increase in blend percentage at lower BMEP but at higher BMEP it decreased with increase in blend percentage

Nomenclature

BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
BMEP	Brake mean effective pressure
IMEP	Indicated mean effective pressure
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Hydrocarbon
LOME	Lemon oil Methyl Ester
MBT	Maximum brake torque timing
SI	Spark ignition
LHV	Lower heating value
TDC	Top dead center
BDC	Bottom dead center
PFI	Port fuel injection
T	Temperature
P	Pressure
V	Volume

CHAPTER 1 INTRODUCTION

1.1 Background

The increase in population, urbanization, and industrialization, led to rapid consumption of fossil fuels. Therefore, the world is looking for a new direction to develop long sustainable renewable energy resources. They maybe solar energy, wind energy, nuclear energy etc. But it is very difficult to incorporate these resources into vehicles. So it is imperative to develop fuels that would run with the existing engines. Synthetic fuels and biofuels are developed to this extent. Biofuels are developed from a feedstock of vegetables, agricultural waste, and animal waste. Biodiesel can be produced from regular oils by producing their esters by using different processes.

Due to rapid modernization, the number of vehicles used and sold or rapidly increasing. The world was mostly depending on fossil fuels for petroleum-based fuels but they are depleting quickly. Developing countries like India depends on other countries for their fuel supply. India is the third largest crude oil importer in the world. India mostly depends on Syria, Sudan, Nigeria for its crude oil imports but due to the rapid declination of political stabilities in these countries, India has to look for alternative sources of procurement of crude oil from other countries or to develop onshore gas and crude oil fields. Thereby decreasing the import and dependency on other countries.

Crude oil is refined into petrol, diesel and natural gases. Most of the petroleum products obtained from the crude oil are used as fuel for automobiles, generators, or for any other type of locomotives in a manner. Recently there are quite a few developments in automobiles i.e., electric vehicles, hybrid vehicles etc. But there are a lot of complications in adapting these technologies to our automobiles. It will take a lot of time in getting these resources available for daily use i.e. when electric vehicles used it would be difficult to charge it within a short period of time. What we need is an alternative that was available now and can incorporate into the existing automobiles. Biofuels are one such alternative that can implement in the existing vehicles with only fewer or no modifications to the engine or automobiles.

According to the report submitted by the Petroleum planning and analysis cell (PPAC) to the Ministry of petroleum and natural gas, it states that 70% of the diesel and 99.6% of the petrol consumed throughout India is mainly for the purpose of transportation. It shows that there is a need to concentrate mainly on the transportation sector so that even a little change that can bring to this sector can drastically affect the petroleum consumption. But the existing designs can't be modified because there are a number of vehicles are running on the roads. The best way to face this existing challenge is to provide alternative fuels that can run the existing and upcoming vehicles without any modifications and at the same time it cannot affect the performance of the engine.

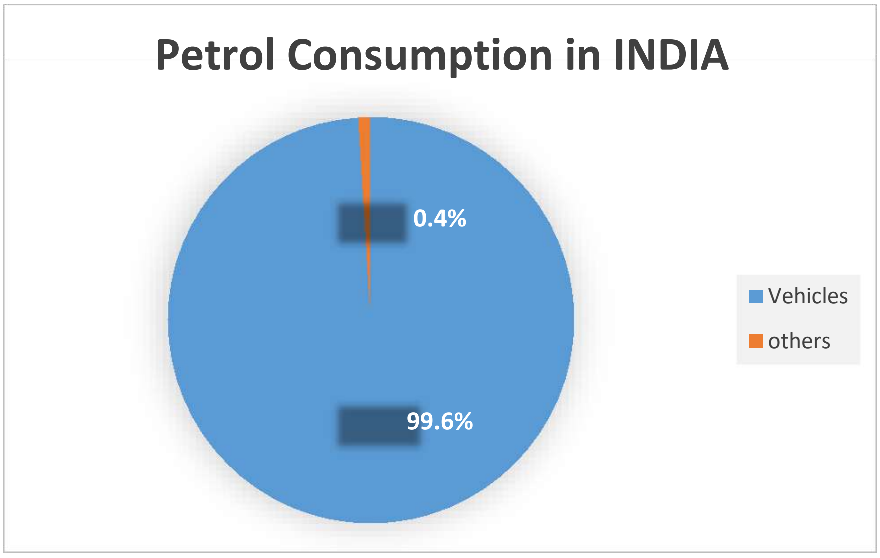


Figure: 1.1 Comparison of Petrol Consumption in India [22]

In this direction there is a lot of research has been done to provide better biofuels particularly for diesel engines. A number of oil marketing companies are looking into ethanol and iso-butanol as the alternatives to the conventional fuels. By blending these alternative fuels with the conventional ones it will be possible to reduce the consumption of petroleum-based fuels.

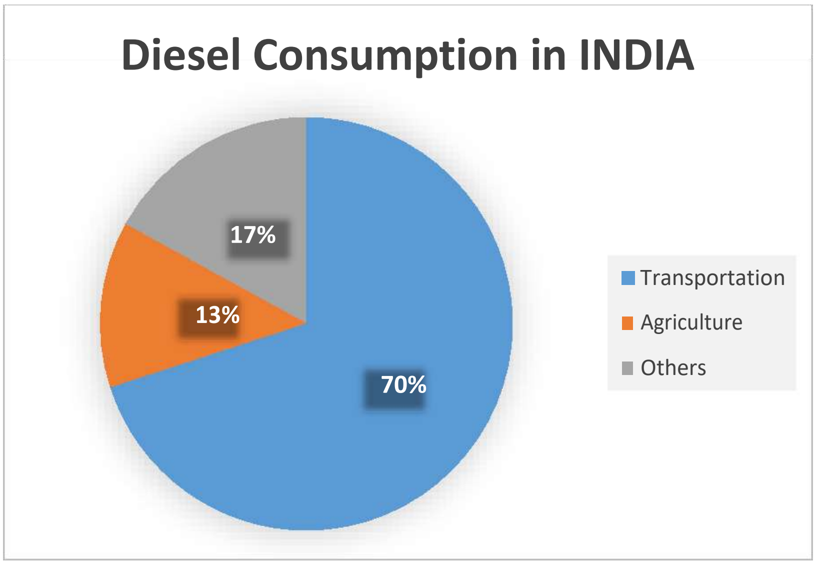


Figure: 1.2 Comparison of Diesel comparison in India

Pollution emitted by the vehicle is mainly dependent on the condition of the vehicle and fuel used that's why fuel used in the vehicle has to be selected carefully. The fuels are categorized based on the sulfur content. The government has taken measures so that how much sulfur has to contain in the fuel. Over the years for gasoline the sulfur content was reduced from 500 PPM in 2005 to 10 PPM by 2020 and for diesel, sulfur content was reduced from 10000 PPM in 1995 to 10 PPM by 2020.

The Fuel was Categorized during the years as given below

Table: 1.1 Categorization of fuels based on sulfur content

Date	**Diesel**	**Gasoline**
1995	10,000 ppm (nationwide)	–
1996	5,000 ppm (Delhi + selected cities)	–
1998	2,500 ppm (Delhi)	–
1999	500 ppm (BS II, Delhi, limited supply)	–
2000	2,500 ppm (nationwide)	–
2001	500 ppm (BS II, selected cities)	–
2005	500 ppm (BS II, nationwide) 350 ppm (BS III, selected cities)	500 ppm (BS II, nationwide) 150 ppm (BS III, selected cities)
2010	350 ppm (BS III; nationwide) 50 ppm (BS IV; selected cities)	150 ppm (BS III, nationwide) 50 ppm (BS IV, selected cities)
2017	50 ppm (BS IV; nationwide)	50 ppm (BS IV; nationwide)
2020*	10ppm (BS VI; nationwide)	10 ppm (BS VI; nationwide)

The pollution emitted by the vehicles also has to be below certain standards. The vehicles are categorized by using these standards. Different countries follow different emission standards i.e. European union follows Euro emission standards, Indian government uses Bharat stage emission standards which are based on euro emission standards which are categorized from Euro1 to Euro6 likewise Indian government has BS II to BS VI

The emission standards have been regulated by categorizing the gasoline vehicles as

Table: 1.2 Emission standards for different vehicle categories

Year	Reference	Standard	CO	HC	HC+Nox	PM
1991			14.3	2.0-2.9		
			27.1			
1996			8.68			
			12.4		3.00-4.36	
1998			4.34			
			6.20		1.50-2.18	
2000	Euro I	India 2000	2.72			
			6.90		0.97-1.70	
2005	Euro II	BS II	2.2-5.0		0.5-0.7	
			2.3	0.2		0.5
2010	Euro III	BS III	4.17	0.25		0.18
			5.22	0.29		0.21
			1	0.1		0.08
2010	Euro IV	BS IV	1.81	0.13		0.1
			2.27	0.16		0.11

1.2 Various Bio Fuels used in CI Engine

Ethanol

Most of the ethanol produced is used as engine fuel or as a fuel additive. Brazil as the world's leading producer of the ethanol mostly depends on ethanol as an engine fuel. Gasoline sold in Brazil contains at least 25% anhydrous ethanol. Hydrous ethanol (about 95% ethanol and 5% water) can be used as fuel in more than 90% of new gasoline-fueled cars sold in the country. Due to its high carbon sequestration sugar cane is used for producing Brazilian ethanol. The US and many other countries primarily use E10 and E85 ethanol/gasoline mixtures

Ethanol combustion in an IC engine produces many of products of incomplete combustion produced by gasoline and a very high amount of formaldehyde and acetaldehyde. It will lead to higher photochemical reactivity and ground-level ozone. It has been shown that ethanol emissions produce 2.14 times ozone than gasoline exhaust by The Clean Fuels Report Comparison of fuel emissions. When this taking into account with localized pollution index

(LPI) of The Clean Fuels Report Local pollution of gasoline is 1.0 whereas ethanol is 1.7 as the higher the rating signifies higher the pollution.

Methanol

Methanol is often used as a fuel for IC engines. It produces carbon dioxide and water when it burns. The main problem with methanol is at higher concentrations alcohols corrode metals, particularly aluminum. For ground transportation methanol has been proposed. Methanol can be adopted for gasoline internal combustion with less or no modifications to the engines infrastructure and its fuel delivery system and it is one of its main advantages. But the fuel consumption of methanol is twice as that of gasoline due to the energy density of methanol is half that of gasoline.

Butanol

Butanol is considered to have higher potential as biofuel (Butanol fuel). Due to its high blending percentage i.e. Butanol at 85 percent can be used in vehicles without any changes to the engine infrastructure and the energy density of Butanol is higher than the ethanol and almost as much as gasoline, therefore, fuel consumption of the butanol is almost same as gasoline. To reduce soot emission Butanol can be added to diesel fuel.

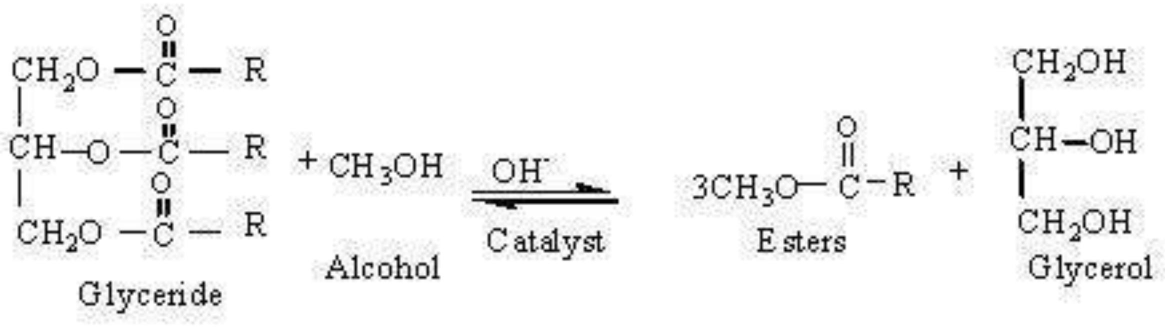
1.3 Bio-Diesel Production Methods

Transesterification Process

Transesterification of natural glycerides with methanol to methyl esters is a technically important reaction that has been used extensively in the soap and detergent manufacturing industry worldwide for many years. Almost all biodiesel is produced in a similar chemical process using base-catalyzed transesterification as it is the most economical process, requiring only low temperatures and pressures while producing a 98% conversion yield. The transesterification process is the reaction of a triglyceride (fat/oil) with an alcohol to form esters and glycerol. A triglyceride has a glycerin molecule as its base with three long-chain fatty acids attached. The characteristics of the fat are determined by the nature of the fatty acids attached to the glycerin. The nature of the fatty acids can, in turn, affect the characteristics of the biodiesel.

During the esterification process, the triglyceride is reacted with an alcohol in the presence of a catalyst, usually a strong alkaline like sodium hydroxide. The alcohol reacts with the fatty acids to form the mono-alkyl ester, or biodiesel, and crude glycerol. In most production, methanol or ethanol is the alcohol used (methanol produces methyl esters, ethanol produces ethyl esters) and is base-catalyzed by either potassium or sodium hydroxide. Potassium hydroxide has been found more suitable for the ethyl ester biodiesel production, but either base can be used for methyl ester production.

The figure below shows the chemical process for methyl ester biodiesel. The reaction between the fat or oil and the alcohol is a reversible reaction, so the alcohol must be added in excess to drive the reaction towards the right and ensure complete conversion.



The products of the reaction are the biodiesel itself and glycerol.

A successful transesterification reaction is signified by the separation of the methyl ester (biodiesel) and glycerol layers after the reaction time. The heavier co-product, glycerol, settles out and may be sold as is or purified for use in other industries, e.g. pharmaceutical, cosmetics, and detergents.

Esterification Process

The chemical reaction of producing biodiesel is a biodiesel esterification. Animal and plant fats and oils are typically made of triglycerides which are esters of free fatty acids with the trihydric alcohol, glycerol. In the transesterification process, the alcohol is deprotonated with a base to make it a stronger nucleophile. Commonly, ethanol or methanol are used.

Normally, this reaction will proceed either exceedingly slowly or not at all. Heat, as well as an acid or base, are used to help the reaction proceed more quickly. It is important to note that the acid or base are not consumed by the transesterification reaction, thus they are not reactants but catalysts.

Almost all biodiesel is produced from virgin vegetable oils using the base-catalyzed technique as it is the most economical process for treating virgin vegetable oils, requiring only low temperatures and pressures and producing over 98% conversion yield (provided the starting oil is low in moisture and free fatty acids). However, biodiesel produced from other sources or by other methods may require acid catalysis which is much slower.

After the transesterification reaction and the separation of the crude heavy glycerin phase, the producer is left with a crude light biodiesel phase. This crude biodiesel requires some purification prior to use.

Supercritical process

An alternative, catalyst-free method for transesterification uses supercritical methanol at high temperatures and pressures in a continuous process. In the supercritical state, the oil and methanol are in a single phase, and the reaction occurs spontaneously and rapidly. The process can tolerate water in the feedstock, free fatty acids are converted to methyl esters instead of soap, so a wide variety of feedstock's can be used. Also, the catalyst removal step is eliminated. High temperatures and pressures are required, but energy costs of production are similar or less than catalytic production routes.

Ultra- and high-shear in-line and batch reactors

Ultra- and High Shear in-line or batch reactors allow production of biodiesel continuously, semi-continuously, and in batch-mode. This drastically reduces production time and increases production volume.

The reaction takes place in the high-energetic shear zone of the Ultra- and High Shear mixer by reducing the droplet size of the immiscible liquids such as oil or fats and methanol. Therefore, the smaller the droplet size the larger the surface area the faster the catalyst can react.

Ultrasonic reactor method

In the ultrasonic reactor method, the ultrasonic waves cause the reaction mixture to produce and collapse bubbles constantly. This cavitation simultaneously provides the mixing and heating required to carry out the transesterification process. Thus, using an ultrasonic reactor for biodiesel production drastically reduces the reaction time, reaction temperatures, and energy input. Hence the process of transesterification can run inline rather than using the time-consuming batch processing. Industrial scale ultrasonic devices allow for the industrial scale processing of several thousand barrels per day.

Lipase-catalyzed method

Large amounts of research have focused recently on the use of enzymes as a catalyst for the transesterification. Researchers have found that very good yields could be obtained from crude and used oils using lipases. The use of lipases makes the reaction less sensitive to high free-fatty-acid content, which is a problem with the standard biodiesel process. One problem with the lipase reaction is that methanol cannot be used because it inactivates the lipase catalyst after one batch. However, if methyl acetate is used instead of methanol, the lipase is not inactivated and can be used for several batches, making the lipase system much more cost effective.

Volatile fatty acids from anaerobic digestion of waste streams

Lipids have been drawing considerable attention as a substrate for biodiesel production owing to its sustainability, non-toxicity, and energy efficient properties. However, due to cost reasons, attention must be focused on the non-edible sources of lipids, in particular, oleaginous microorganisms. Such microbes have the ability to assimilate the carbon sources from a medium and convert the carbon into lipid storage materials. The lipids accumulated by these oleaginous cells can then be transesterified to form biodiesel.

1.4 Introduction to IC Engine

Any device which converts one form of energy into another form of energy is called an engine. In some engines, chemical energy is converted into mechanical energy so they are called as heat engines

When the combustion process takes place inside the engine cylinder then the engine is called as an IC engine. All the processes required to complete the cycle for the necessary power generation takes place inside the cylinder. Whereas in an external combustion engine the combustion process takes place outside the engine cylinder in a separate chamber known as the combustion chamber.

IC engine can be classified into different types based on no of cylinders, cylinder position, No of strokes, Type of ignition etc.

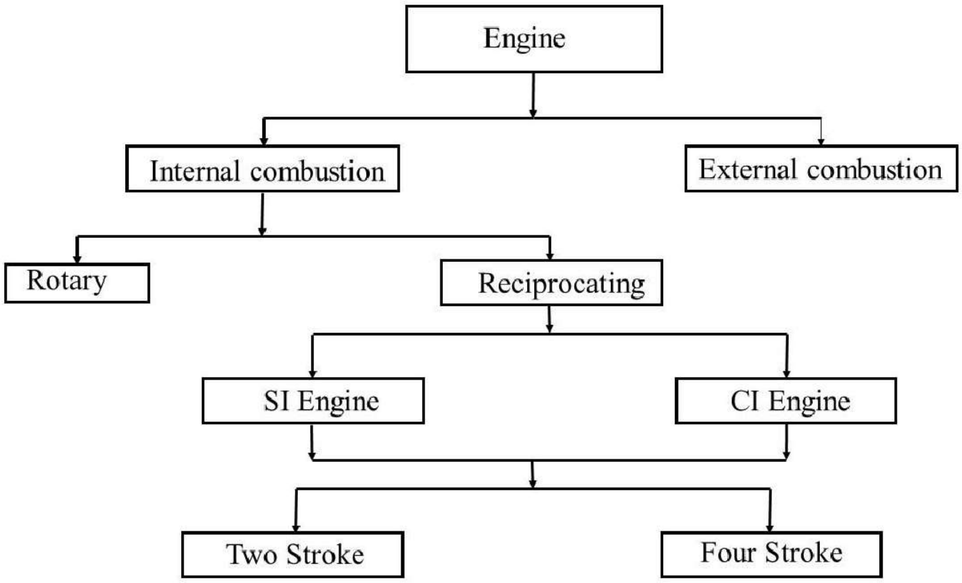


Figure: 1.3 Classification of Engines

In a four-stroke engine, all the processes take place within the four strokes of the engine or two crankshaft revolutions. The different process takes place in an engine are suction, compression, expansion, and exhaust. Whereas in a two-stroke engine it needs only one revolution of the crankshaft for the all the process to takes place.

The different process in a four-stroke engine is explained below:

Suction Stroke

Theoretically, suction stroke starts when the piston is at top dead center (TDC) and about to move towards the bottom dead center (BDC). But in actual case suction stroke starts before to TDC to improve the performance of the engine. In a suction stroke inlet valve opens just before TDC. Due to the suction created by the motion of piston towards BDC, fuel and air mixture enters the cylinder during this period.

Compression Stroke

Compression stroke starts just after Suction stroke. It starts when the piston is about to move from BDC to TDC. During this period the charge (I.e. air and fuel mixture) enters the cylinder gets compressed, while both the inlet and exhaust valves are in closed position.

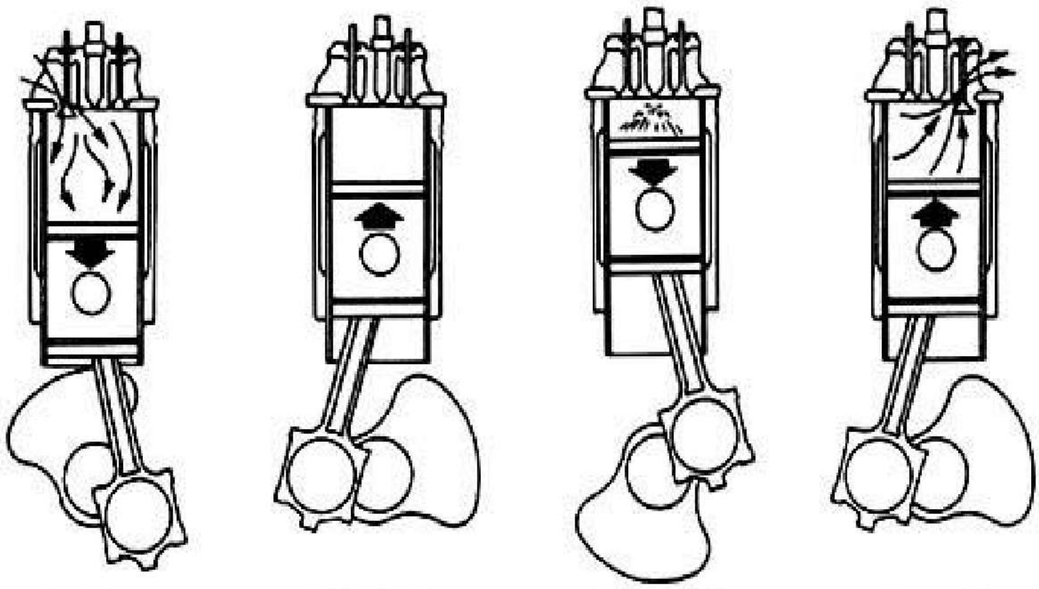


Figure: 1.4 Working of an IC Engine

Expansion Stroke

At the end of compression stroke, the combustion process takes place during which the charge gets ignited and the chemical energy in the fuel is converted into heat energy. In the expansion stroke due to combustion the high pressure and heat generated in the cylinder push down the piston from TDC towards BDC. In an engine expansion stroke is the power stroke. The power generated during this stroke is stored in the flywheel and it is used to power all the remaining processes.

Exhaust Stroke

During the exhaust stroke exhaust valve opens instantaneously while the inlet valve remains closed. Due to the burning of the charge exhaust gases release from it. When the piston moves from BDC to TDC the piston sweeps the burnt gases and it passes through the exhaust valve.

Valve Timing Diagram

In an IC engine valve timing diagram indicates when the inlet and exhaust valve opens and closes. Theoretically inlet valve opens at the start of suction stroke and closes at the start of compression stroke, exhaust valve opens at the start of exhaust stroke and closes at the end of exhaust stroke but in actual practice the inlet valve opens before suction stroke and closes after the suction stroke, exhaust valve also opens before expansion stroke and closes after exhaust stroke.

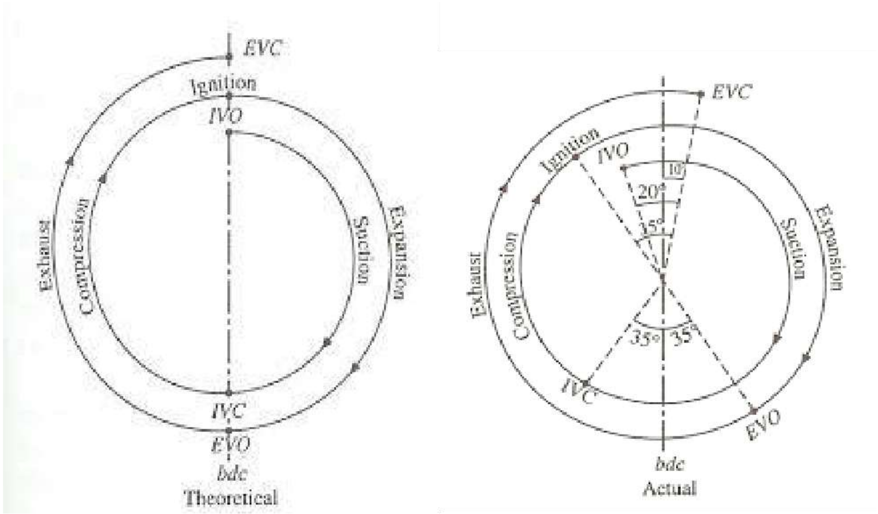


Figure: 1.5 Valve Timing Diagrams

IC engine works on Otto cycle. It consists of four processes namely:

i) Isentropic compression process: - process 1-2 (ii)

Heat addition at constant volume: - process 2-3 (iii)

Isentropic expansion process: - process 3-4 (iv)

Heat rejection at constant volume: - process 4-1

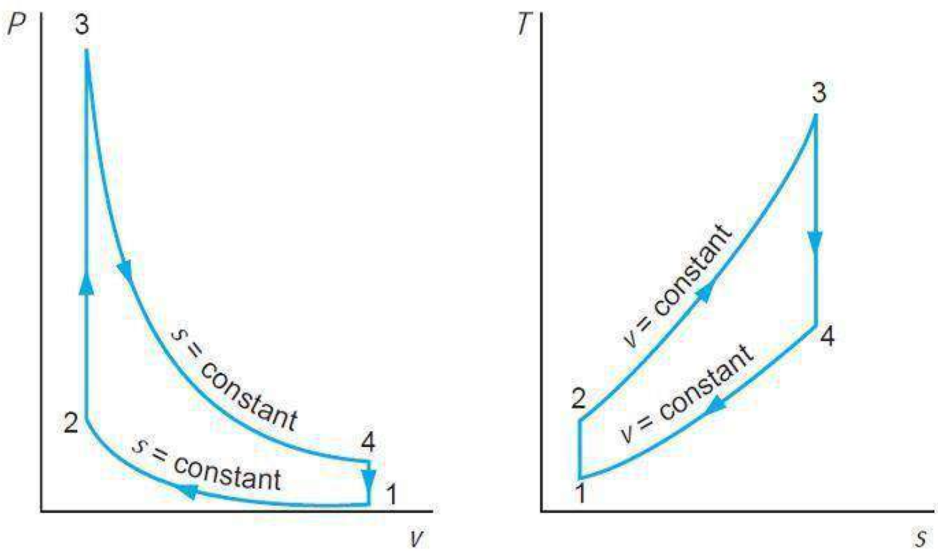


Figure: 1.6 P-V & T-S Diagrams

1.4.2 Engine parameters

To understand the combustion, performance and emission characteristics of an IC engine, certain parameters have to be defined. They are as follows:

(a) Indicated thermal efficiency ( ):

Indicated thermal efficiency is the ratio of energy in the indicated power to the product of the mass of fuel and calorific value of fuel

$$\eta_{ith} = \frac{\text{Indicated power}}{\text{mass of fuel} * \text{calorific value of fuel}}$$

(b) Brake thermal efficiency ( ):

Brake thermal efficiency is the ratio of energy in the brake power to the product of the mass of fuel and calorific value of fuel

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

(c) Mechanical efficiency ( ):

Mechanical efficiency is defined as the ratio of brake power to the indicated power.

$$\eta_{m} = \frac{\text{Brake power}}{\text{Indicated power}}$$

(d) Volumetric efficiency ( ):

Volumetric efficiency is defined as the ratio of the actual volume flow rate of air into the intake system to the rate at which the volume is displaced by the system.

$$\eta = \frac{\text{Actual air flow rate}}{}$$

(e) Indicated mean effective pressure (IMEP):

Mean effective pressure is the average pressure inside the cylinders of an IC engine based on the calculated or measured power output.

$$\text{IMEP} = \frac{\text{Indicated power}}{\text{swept volume}}$$

(f) Brake mean effective pressure (BMEP):

$$\text{BMEP} = \frac{\text{Brake power}}{\text{swept volume}}$$

(g) Brake specific fuel consumption (BSFC):

Brake specific fuel consumption is the ratio of the mass flow rate of fuel to the brake power.

$$BSFC = \frac{\text{Mass flow rate of fuel}}{\text{Brake power}}$$

(h) Coefficient of variation (COV):

Cyclic variability limits the range of operating conditions of spark ignition engines, especially under lean and highly diluted operation conditions. The cyclic combustion variations can be characterized by pressure parameters, combustion-related parameters, and flame-front related parameters. The coefficient of variation (COV) in indicated mean effective pressure (IMEP) defines the cyclic variability in indicated work per cycle.

(i) Heat release rate:

Heat release rate is the rate at which the chemical energy of the fuel released by the combustion process. The heat release rate is evaluated from the engine cylinder pressure data with respect to a crank angle using the following equation:

$$\frac{dQ_{net}}{d\theta} = \frac{\gamma}{\gamma - 1} p \frac{dV}{d\theta} + \frac{1}{\gamma - 1} v \frac{dp}{d\theta}$$

Where

P- In cylinder gas pressure

V- Instantaneous cylinder volume

- Ratio of the specific heat for ideal gas

(j) Cumulative heat release rate:

Cumulative heat release rate is the sum of heat release rate with respect to crank angle. The cumulative heat release rate is estimated by integrating the heat release rate with respect to crank angle degrees.

$$= \int \qquad = \int \left(p \frac{\gamma}{\gamma - 1} dV + \frac{1}{\gamma - 1} VdP\right)$$

1.5 Problem Statement:

Topic selection is made keeping in view the declining fossil fuels in the world. Lemon peel oil is selected for the project because it is made from lemon rinds as they are thrown out as wastage and because of its low viscosity, high octane number and high calorific value when compared with other biofuels used in SI engine. The main aim of the project is to study the performance, combustion characteristics and exhaust emissions of an SI engine at different ignition timings and to find the optimum ignition angle at different loading conditions. Petroleum deposits are declining throughout the world. The world is looking for alternative fuels to replace fossil fuels. This project aims to reduce the consumption of fossil fuels by blending the gasoline with Lemon peel oil.

1.6 Objectives of the Present Work:

- Investigate different biofuels used in spark ignition engine.
- Study the fuel properties of lemon peel oil.
- Preparation of lemon peel oil fuel.
- Blending of lemon peel oil with gasoline.
- Conduct experiments at different ignition timings and different loading conditions using different blends.
- Determine the brake thermal efficiency, brake specific fuel consumption, combustion pressure and exhaust emissions.
- Conclude by comparing performance parameters for different fuel blend percentages under different loading conditions.

1.7 Thesis layout:

This thesis has four chapters. All the basic information regarding the IC engine and introduction to alternative fuels and other related information to understand the basics and necessity of this project was given in the first chapter.

The second chapter deals with the literature related to alternative fuels in spark ignition and other literature on lemon peel oil.

The third chapter deals with the experimental apparatus, the experimental procedure and, the process required for the preparation of the fuel.

The fourth chapter involves the main parts of this thesis which is the result and discussion. The obtained data have been compared to get the results. The graphs obtained has been shown and discussed.

In the fifth chapter, a brief conclusion of our work has been made.

It has been many years since the research has been started to find out an alternative fuel for the fossil fuel. Many fuels have been proposed and proved theoretically and experimentally to be used as an alternative to fossil fuels. Especially alcohols i.e., ethanol, methanol, butanol has been used as an alternative to gasoline. They can be used as a fuel as well as fuel additives in the gasoline fuel running engine. Lemon peel oil has been proposed as an alternative fuel for gasoline due to high research octane number.

2.1 Literature survey based on Lemon oil methyl ester (LOME)

B. Ashok Kumar et al. [1] conducted a study to find out the novelty of lemon peel oil as fuel for diesel engine and showed that maximum increase in BTE is 12% at LPO 100% but the increase in BTE was not very significant from LPO 50% which is 10.6%. Carbon monoxide (CO) and Hydrocarbon (HC) emissions were very much low for pure lemon oil as a fuel but the decrease in emissions was not significant when compared to LPO 50% blend and the NOx emission has increased.

A. Naresh Kumar et al. [2] studied the performance and emission characteristics of lemon peel oil in CI engine by coupling it with exhaust gas recirculation and observed that by using 20% EGR with LPO 20 there is a drastic decrease in oxides of nitrogen and increase in unburned hydrocarbons. The specific fuel consumption increase with LPO but with LPO 20 and 20% EGR it is same as diesel and brake thermal efficiency with LPO 20 is decreased while using EGR but still it is higher than the rest of the blends.

R. Sathiyamoorthi et al. [3] performed an experimentation to find out how the performance and emissions are affected by using antioxidants (butylated hydroxyanisole and butylated hydroxytoluene) with lemongrass oil blends and observed that butylated hydroxyanisole is better than butylated hydroxytoluene with LGO 25 blend and there is an increase in CO, HC and smoke emissions significant increase in NOx emissions. There is an increase in Brake thermal efficiency by 1.29 %and decrease in specific fuel consumption by 1.66%.

2.2 Literature Survey on Alcohols

M. Al Hasan et al. [4] studied the effect of ethanol-unleaded gasoline blends on engine performance and exhaust emissions on an SI engine and showed that with an increase in speed there is an increase in brake power, torque and brake specific fuel consumption and hydrocarbon emissions and a decrease in carbon monoxide emissions. optimum results were observed at E20 blend at a speed of 3000 RPM.

Wei-Dong Hsieh et al. [5] conducted experiments to study the performance and exhaust emissions using ethanol and gasoline blends ranging from 5% to 30% on an SI engine. They observed that there is an increase in fuel consumption and brake power. CO emissions were decreased by 10-90%. Co2 emissions were increased by 5-25%, HC emissions were decreased by 20-80%.

Mustafa Koc et al. [6] studied the effects of ethanol-unleaded gasoline blends on engine performance and exhaust emissions on an SI engine by conducting experimentation using two different blends E50 and E85 at two different compression ratio 10:1 and 11:1. With 10:1 fuel consumption was increased by 20.3% and 45.6% respectively and brake power was increased by 2%. CO was increased by 1% volume with both compression ratios. HC has decreased by 24% at 10:1 ratio. 11:1 has higher NOx formation compared to 10:1. With 11:1 the fuel consumption was increased by 16.1% and 36.4% and brake power was increased by 2.3% and 2.9% respectively.

I. Schifter et al. [7] studied the combustion and emission behavior of ethanol-gasoline blends in a spark ignition engine at a constant mass flow rate and found that there is a 2% increase in fuel consumption. Carbon monoxide was reduced by 52%, Hydrocarbons were reduced by 19% and there is an increase in NOx b 60%. The best results were obtained at E20 blend.

Liu Shenghua et al. [8] conducted experiments to study a spark ignition engine fueled with methanol and gasoline fuel blends. They found out that M30 blend with cold start and warming process at 5^0 C there is a 30% reduction in HC and 25% reduction in CO. efficiency increases.

Muharrem Eyidogan et al. [9] studied the impact of different alcohol-gasoline fuel blends on the performance and combustion characteristics of an SI engine. The tests were conducted with two different blends 5% and 10% at two different speeds 80 Km/h and 100 Km/h and compared both alcohols fuel consumption increased by 3.60% for ethan0l and 0.60% methanol. CO was decreased by 17% and 14%, CO_2 was decreased by 8% and 11.30%, HC was decreased by 32% and 35% and NOx was decreased by 15.5% and 9% for ethanol and methanol respectively.

Xiaolei Gu et al. [10] conducted a study to find out the emission characteristics of an SI engine fueled with gasoline and n- butanol blends when combined with EGR. It has been observed that there is an increase in specific CO with and without EGR and HC was decreased but while using EGR HC was increased. NOx was decreased with and without EGR.

Mustafa Kemal Balki et al. [11] conducted an experiment find out the performance of the experimental engine with different alcohols compared it with gasoline. There was a significant increase in combustion efficiency specifically with methanol but the BSFC was very high at about 84%. High HRR was constituted at 3^0,7^0,14^0 ATDC at the three different speeds they conducted.

C. Wu, R.Chen, J.Pu et al. [12] investigated the effect of ethanol and gasoline blends compared the performance and emission values as a function of percentage throttling and equivalence ratio at different speeds performance and NO_x emissions is higher at 100% throttle at all blends ,CO, HC has fewer emissions at 80% throttle. The torque for pure gasoline is slightly lower than Ethanol blends especially when the throttling position is very low i.e., 20%

F. Yukisel et al. [13] designed a new carburetor to produce stable homogeneous liquid phase to study the effect of ethanol and gasoline blends due to this new type they increased the maximum amount to 40% and achieved 80% and 50% reduction in CO and HC emission respectively.

Hakan Bayraktar [14] conducted a theoretical and experimental investigation of the effect of ethanol and gasoline blends and by comparison found out that 16.5% ethanol blend was best suited theoretically and 7.5% blend experimentally at a compression of 7.75 and 8.75. agreement of 6% was determined between experimental and theoretical results.

Tolga Tupgul et al. [15] studied the effect of ignition timing on ethanol-unleaded gasoline blends observed that with E10 blend there is a 4.26% increase in brake torque by advancing 10^0 CA but the increase is not very significant with further increase in ethanol blend up to 60% only 1.82% increase in brake torque.CO emissions were reduced by 31.8% with 40% blends at compression ratio 9:1

Huseyin Serder Yucesu et al. [16] investigated the effect of compression ration engine performance and emissions with different ethanol-gasoline blends ranging from 11:1 to 13:1 and compared with a ratio of 8:1

Mingzhang et al. [17] studied the effects of EGR, compression ratio on a port fuel injection engine with wot operation using CFD tools and an experimental engine. It was observed that the maximum EGR rate that can be used is up to 20% after that cov% increases more than 10%

which causes difficulties in the operation of the vehicles for all the different compression ratios changing from 8:1 to 10:1

Ahmet Necati Ozsezen et al. [18] conducted experimentation in the study of the performance and combustion characteristics of alcohols-gasoline blends with wide throttle operation. The unstable performance was observed at 5% alcohol blends proportionate to gasoline at WOT condition

2.3 Literature Survey on Other Fuels Related to CI Engine

Hamit solmaz [19] analyzed fusel oil as an alternative fuel for spark ignition engine. It has been observed due to water content and low heating value there is a drop in the performance of the engine and an increase in CO and HC emissions by 21% and 25% respectively. But due to worse combustion performance, there is a significant decrease in NOx.

Vallinayagam Raman et al. [20] proposed a study that utilizing α-pinene as novel biofuel for spark ignition engine. He conducted experimentations using α-pinene and compared it with FACE A gasoline, Euro V gasoline, and ethanol. They found that BSFC is low when compared with ethanol Break thermal efficiency is reduced due to the high reactivity of the pinene. α-pinene has higher HC emissions when compared with gasoline. The emission value of NOx emissions for α-pinene is situated in between Euro V gasoline and FACE A gasoline for the same operating conditions.

O.Arpa et al. [21] studied how turpentine oil and gasoline as fuel obtained from lubrication fuel effects the performance and exhaust emissions. They observed that there is an increase in BMEP, Brake thermal efficiency and decrease in BSFC with the increase in speed. It was observed that 30% blend has the best performance. CO was increased while NOx was increased.

2.5 Problem Statement

Depletion of petroleum products throughout the world is a major cause for concern as most of the countries depend on these products for fuel. Most of the countries stockpile their crude oil resources so that they don't suffer any fuel crisis in the future. Developed countries like the USA they already producing alternative fuels like shale oil and mixing with gasoline so that they could reduce their fossil fuel consumption.

Biofuels looks promising as an alternate source for fuels but fuels produced from consumables like vegetables and other food products may lead to starvation in some parts therefore the fuels used as biofuels must be a non-consumable. Lemon peel oil which is used as biofuel is made from rinds of the lemons which is a bi-product and wastage so it doesn’t cause any concern. Lemon peel oil has a low viscosity and high calorific value because of this reason it was tried as an alternative fuel in this research

2.4 Problem definition from the literature review

From the above literature review concluded that there are fewer biofuels available for spark ignition engine with the exception of alcohols due to the requirement of low viscous fuels for better atomization of the fuel but the alcohols have low calorific value. There is a need for low viscosity fuels with better atomization and better calorific value. Lemon peel oil has low viscous properties and the calorific value of the fuel was comparable high compared to alcohols.

CHAPTER 3 EXPERIMENTAL SETUP AND PREOCEDURE

3.1 Experimental Setup

The experimental setup consists of a four-stroke vertical single cylinder engine, AVL gas analyzer, Port fuel injection system, exhaust gas recirculation system, a computer equipped with the lab view software and IC engine tools etc.

Equipment description:

The experiments were carried out on a single cylinder four stroke engine, multi-fuel with variable compression ratio and injection angle with eddy current dynamometer for loading purpose. The setup consists of two fuel tanks for both diesel and gasoline. The engine was equipped with port fuel injection system and exhaust gas recirculation system. Exhaust gases were analyzed by AVL gas analyzer. The pressure sensor was attached to the engine head to measure the combustion pressure in the engine cylinder.

The experimental set up was equipped with several Data acquisition system (DAQ) which were connected to a dedicated workstation. All the DAQs are placed in a box which is attached to the fuel tanks. The exhaust gas circulation system and fuel system were all controlled by Software provided by the manufacturer. The setup consists of two fuel tanks for both diesel and gasoline. Different instruments have been provided to measure the air flow, fuel, and load. The crank lever is provided to crank the engine. The battery was provided for the spark ignition purpose.

The setup enables the study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance and combustion analysis.

Figure: 3.3 AVL Digas 444 Gas Analyzer

Avl gas analyzer has been used to measure the exhaust gas emissions emitted by the engine. It has been used to measure HC, NOx, CO and CO_2 emissions emitted by the engine it measures the exhaust gases by % volume or in PPM

The port fuel injection system provides precision control on fuel delivery thereby improving the efficiency and provides better atomization fuel so that complete burning may occur reducing the emissions in the process.

Table: 3.1 Engine Specification

Engine Type	Single cylinder, 4- stroke CI engine
Cylinder Bore	87 (mm)
Stroke length	110 (mm)
Connecting rod length	234 (mm)
Compression ratio	10:1
Swept volume	661 (cc)
Rated power	4.50 kW @1800 rpm
Throttle orifice diameter	20 (mm)
Orifice Coefficient of discharge	0.6

Dynamometer arm length	185 (mm)
Fuel Pipe Diameter	12 (mm)

3.2 Experimental Procedure

The study was conducted using a four-stroke vertical cylinder spark ignition engine which was coupled to an eddy current dynamometer for load measurement. Hydrocarbons, carbon monoxide, carbon dioxide and NOx were measured using an AVL exhaust gas analyzer. Each time the experimentation is conducted it can be made into two stages for gasoline and for lemon peel oil. The first stage is the load test and the second stage is exhaust gas measurement for lemon peel oil

3.2.1 Procedure for load test

A. Make sure that gasoline in the fuel tank is filled up to the level.
B. Switch on the water pump to supply water for cooling purposes.
C. Make sure that power supply to the control panel is switched on.
D. All the DAQ’s should be connected to a laptop and lit blue.
E. Start the port fuel injection kit switch on the fuel pump.
F. Open the lab view software installed on the laptop and connect it to the engine for reading.
G. Input the calorific value, compression ratio, density of fuel, stroke length, bore and other parameters into the software for calculation purposes.
H. Input the ignition angle into the system and upload it to the engine control unit.
I. Start the engine by cranking it.
J. Control the fuel flow by regulating the throttle valve until the engine reaches rated RPM.
K. Allow the engine to run at rated speed for a particular period so that steady state can be achieved.
L. Maintain the fuel supply so that the equivalence ratio should be 1 or near to 1.
M. Apply the load to the engine by rotating the load knob very slowly.
N. At the same time slowly control the throttle valve so that engine maintains the rated speed.
O. View the speed, load and combustion pressure in the lab view software window.

P. Fuel supply and air flow rate are measured using the sensors and are displayed on the software window.
Q. Brake power, brake thermal efficiency, and volumetric efficiencies are displayed on the software.
R. Export the data into the desired failure.
S. Repeat the same procedure for different sets of loads, and ignition timings.
T. After taking the reading close the software and stop the engine.

3.2.2 Procedure for Exhaust gas analysis

A. Connect the exhaust gas analyzer to the power supply and switch it on.
B. Make sure that filters fitted to the exhaust gas analyzer are clean.
C. Conduct leak check tests and HC residue test
D. Perform to the load test as per the above procedure
E. Put the sample probe into the exhaust gas outlet then view the emissions on the digital display. Hold the probe for 3-5 minutes until the readings will be stabilized.
F. Note down the maximum value of the HC, CO, Co2 and NOx emissions
G. Take out the sampling probe from the exhaust gas outlet eventually the emissions will become zero
H. Repeat the same procedure for different conditions of the test
I. At the end switch off the power supply.

3.3 Fuel Preparation

3.3.1 Lemon peel oil extraction process:

Lemon peel oil was made from rinds of lemon which are abundantly available throughout the world. Lemon peel oil was made through the steam distillation process. Fuel preparation set up consists of a steam boiler, Distillation chamber, cooling chamber and a Collection tank.

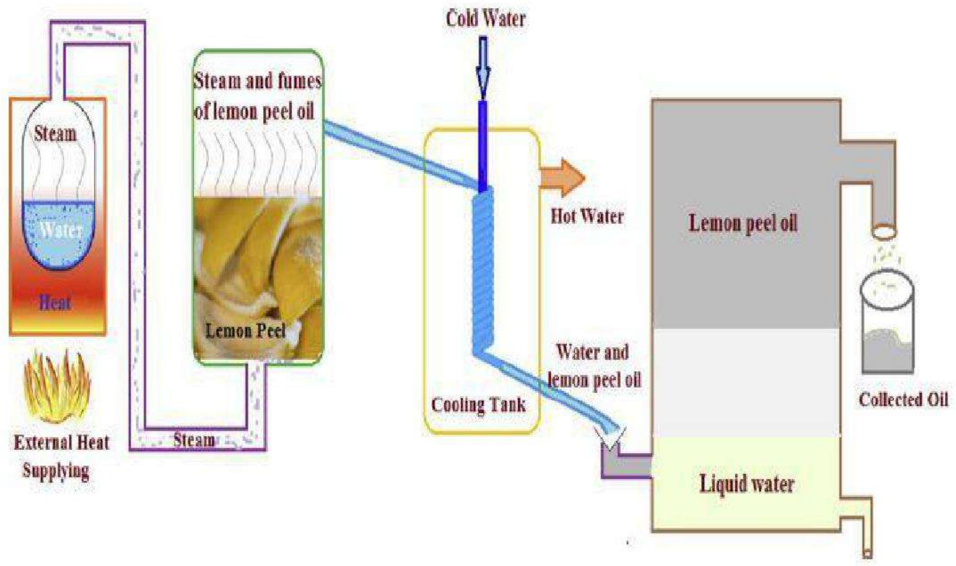


Figure: 3.5 LOME Extraction Setup

The steam from the boiler is passed through the distillation chamber. The distillation chamber consists of lemon rinds placed on a grid the steam is passed through the bottom of the rinds when it is passing through the rinds it collects the essence from the lemon rinds and goes to the cooling chamber by cooling the steam which containing lemon essence it converts into liquids and stored in the Collection tank. By allowing the liquid to settle in the Collection tank after some time due to the density difference both water lemon peel oil gets separated lemon peel floats on the top of the water and it was collected from there using valves.

The lemon peel oil with impurities is collected is mixed with small quantities of water. By treating with a bath of water the heat from a bath of water evaporates the water removes the volatiles present from the oil. Finally, by passing through filter paper all the solid particles will be removed.

3.3.2 Test fuel preparation

Gasoline is mixed with lemon peel oil to prepare the test fuel by volume ratio. LPO 10 and LPO 5 consists of lemon peel oil 5% & 10% and 95% & 90% gasoline by volume.

Mass conservation method has been used to determine the density of the fuel. A bomb calorimeter is being used to determine the calorific value of gasoline and fuel mixture. Calorimeter test has been done to three to five times to check for accuracy and to get an average reading of calorific fuel of gasoline and LOME 10 fuel mixture.

Table: 3.2 LOME Properties

Density @ 15 ^{0}C (kg/m3)	853
Kinematic viscosity @ 40^0 C (cSt)	1.06
Flash point (^{0}C)	54
Fire point (^{0}C)	64
Final boiling point (^{0}C)	176
Conradson carbon residue (%)	0.02
Lower calorific value (kJ/kg)	41510
Research octane number	73.7
Moisture content	0.05%
Ultimate analysis	
Carbon (%)	89.93
Hydrogen (%)	9.25
Sulphur (%)	0.01
Oxygen (%)	0.81

The experiment has been conducted using LOME and Diesel mixture and compared with diesel as base fuel. The results have been plotted for better understanding each one has been shown separately:

4.1 Effect of BMEP

4.1.1 Brake thermal efficiency

Brake thermal efficiency is the ratio of brake power produced and the amount of energy supplied. Brake thermal efficiency depends on the mass of fuel consumed, speed and the calorific value of the fuel. As the speed of the engine is made constant 1500 RPM so it doesn't affect the brake thermal efficiency of the engine.

By varying the spark angle between 18 to 24 maximum brake torque has been found out for the gasoline and lemon peel oil blends at each load condition. It has been found out that the maximum brake torque has occurred at 22^0 for gasoline fuel and 20^0 for gasoline and lemon peel oil blends at each load condition. (i.e. both LOME 5% and LOME 10%).

Break Mean Effective Pressure (bar)	Brake Thermal Efficiency (%)		
	LOME 0%	LOME 5%	LOME 10%
1.14	18.87	17.11	15.5
2.34	24.93	24.06	20.45
3.75	30.02	28.088	25.88

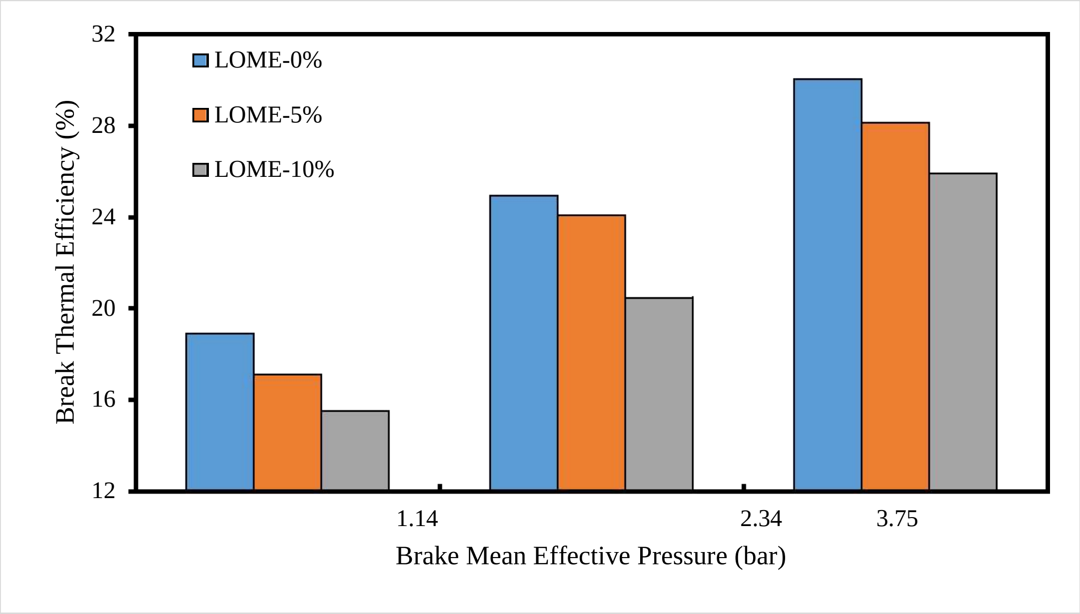


Figure: 4.1 Variation of Brake Thermal Efficiency with Break mean effective pressure

Brake thermal efficiency has been plotted with respect to the percentage of the blend at each load condition. It can be seen that with an increase in the percentage of blend there is a decrease in brake thermal efficiency at each load condition. This is due to an increase in the percentage of the blend there is a decrease in the calorific value of the fuel which in turn affects the mass fuel consumption thereby increasing it. It has been observed that there is a 2% decrease in efficiency at low load condition and 4% decrease in both medium and high load condition.

4.1.2 Brake Specific Fuel Consumption

The variation of brake specific fuel consumption with respect to change in blend percentage at different loads has been shown in the Figure: 4.2.

It is observed that with an increase in the percentage of blend in the gasoline in fuel there is an increase in brake specific fuel consumption. BSFC is inversely proportional to the brake thermal efficiency. At lower loads, there is a high increase in brake specific fuel consumption with an increase in blend percentage that is due to the vaporization of lemon peel oil is slow thereby increasing the fuel consumption.

Break Mean Effective Pressure (bar)	Brake Specific Fuel Consumption (Kg/Kwh)		
	LOME 0%	LOME 5%	LOME 10%
1.14	0.433	0.48	0.529
2.34	0.335	0.341	0.402
3.75	0.272	0.29226	0.317

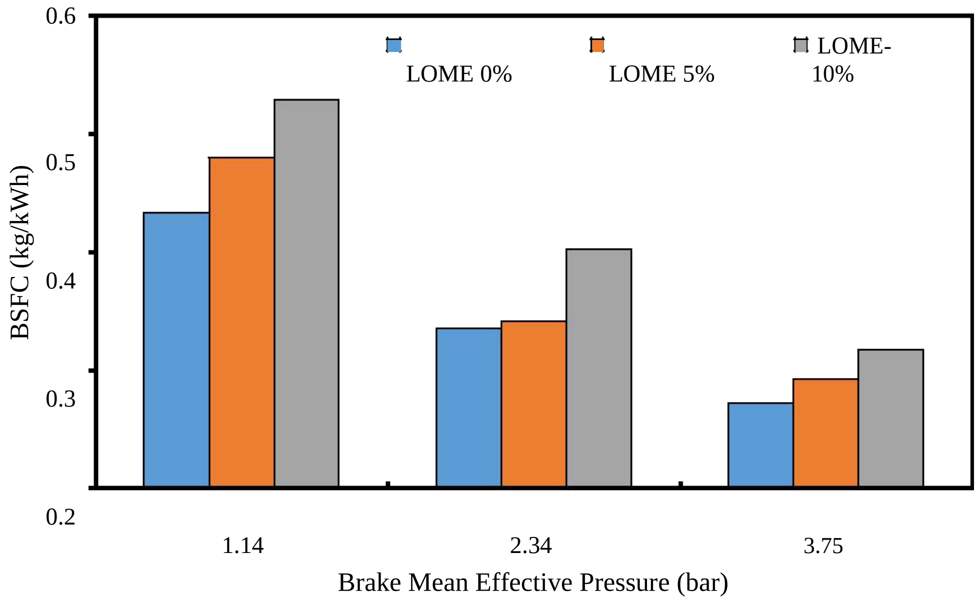


Figure: 4.2 Variation of BSFC with Break mean effective pressure

Combustion characteristics:

The combustion characteristics consist of engine parameters like in-cylinder pressure, maximum in-cylinder pressure, heat release rate etc.

4.1.3 In-cylinder Pressure

The growth of in-cylinder pressure after complete combustion and release of pressure in a proper way (depending on piston position with respect to TDC) as per the engine requirement has the vital role on engine power development.

The variation of in-cylinder pressure with different lemon peel oil blend percentages at different load conditions have been shown in Figure: 4.3, 4.4 & 4.5.

At low load conditions the peak pressure inside the cylinder is advanced towards TDC by 1^0 CA for both LOME 5% and LOME 10% and the peak pressure inside the cylinder gets increased with blend percentage. But at medium load conditions the in-cylinder pressure data for LOME 0% and LOME 5 % looks similar but the peak pressure inside the cylinder retards further away from TDC by 2^0 CA. At high load conditions the peak in-cylinder pressure retards away from TDC with an increase in blend percentage for LOME 5% it retarded by 1^0 CA and for LOME 10% it retarded by 2^0 CA when compared with LOME 0% indicating increasing in compression work decrease in efficiency.

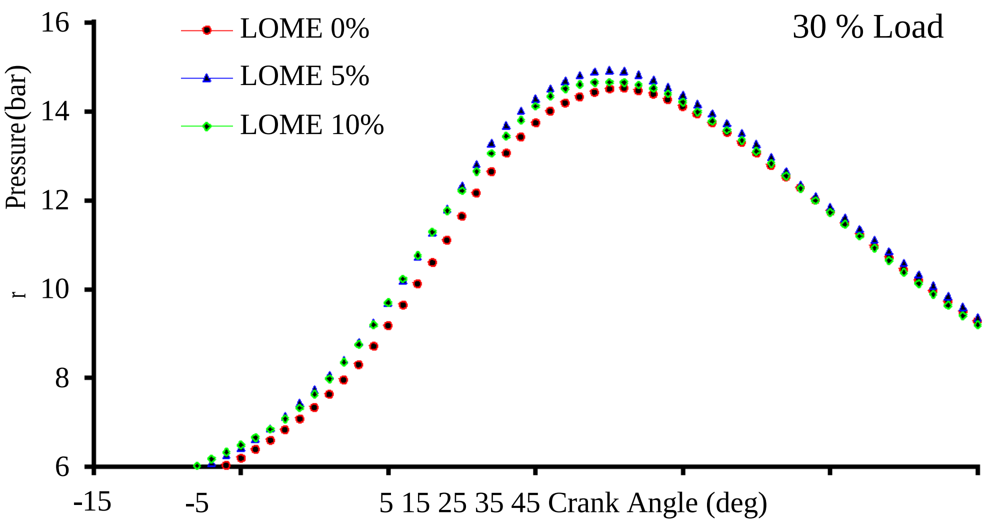


Figure: 4.3 Variation of In-cylinder Pressure with Crank angle (deg) at 30% Load

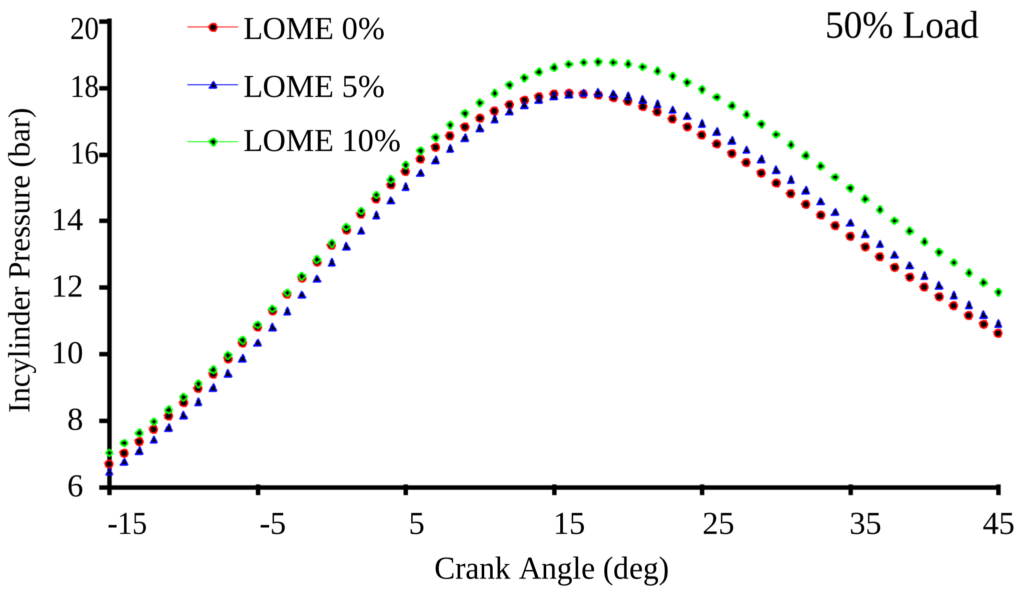


Figure: 4.4 Variation of In-cylinder Pressure with Crank angle (deg) at 50% Load

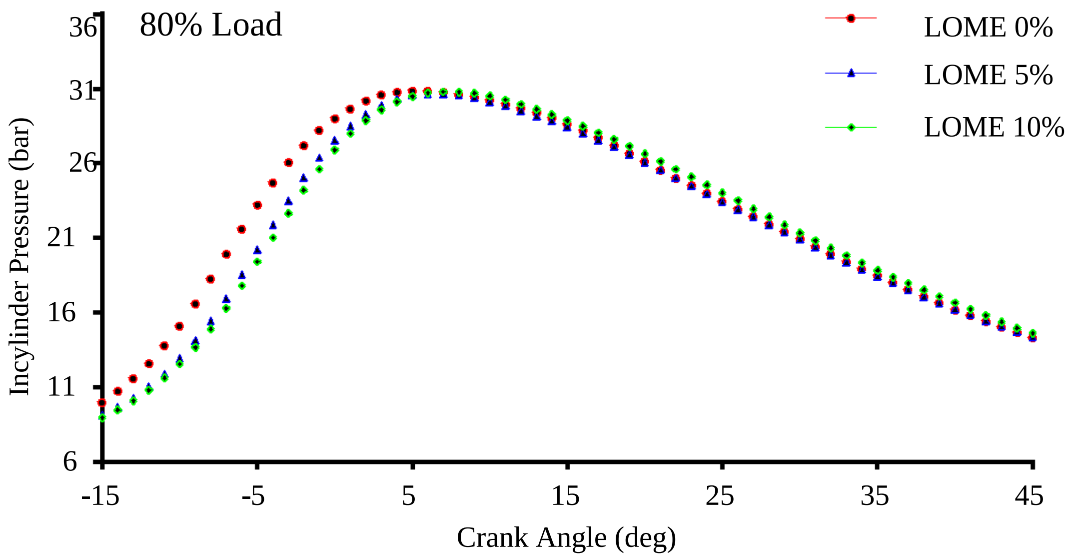


Figure: 4.5 Variation of In-cylinder Pressure with Crank angle (deg) at 80% Load

4.1.4 Heat Release Rate

Heat release rate is the rate at which the chemical energy of the fuel released by the combustion process in spark ignition engine. It is calculated based on the first law of thermodynamics.

The heat release rate is evaluated from the engine cylinder pressure data with respect to a crank angle using the following equation:

$$\frac{}{} = \frac{\gamma}{\gamma - 1} \; \frac{}{} + \frac{1}{\gamma - 1} \; \frac{}{}$$

The variation of heat release rate with crank angle was shown in figures: It has been observed that at low load condition the heat release rate was reduced with increase in blend percentage but at higher medium and higher load conditions heat release rate increased with increase in blend percentage even though there is decrease in efficiency it may be due to the vaporization of lemon peel oil is low so thereby it takes more time to evaporate so that there will be more fuel available to burn inside the cylinder thereby increasing the heat release rate even though the efficiency is decreasing.

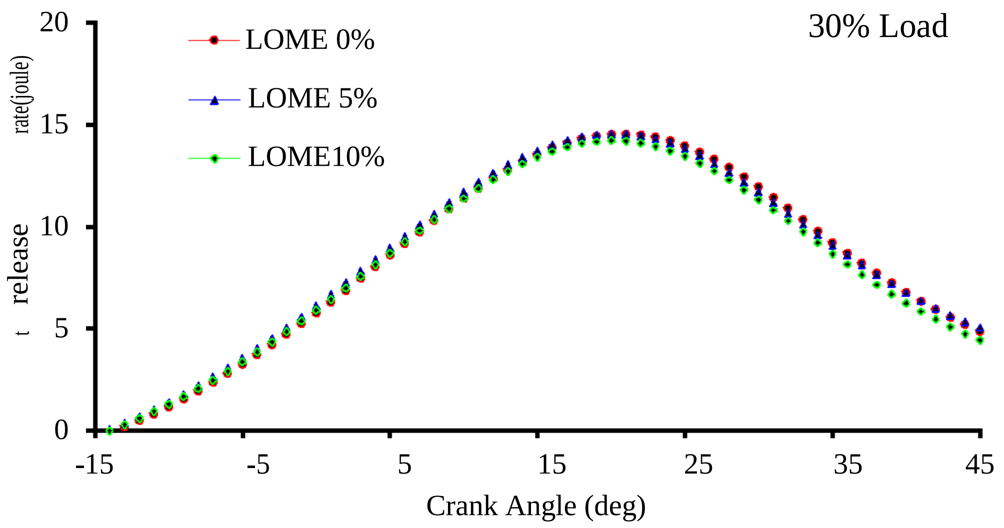


Figure: 4.6 Variation of Heat release rate with Crank angle (deg) at 30% Load

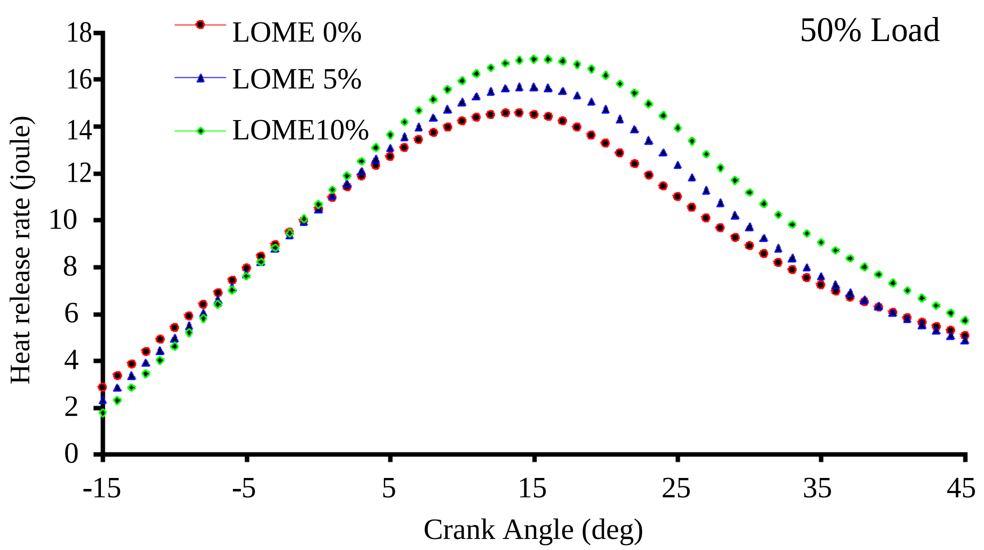


Figure: 4.7 Variation of Heat release rate with Crank angle (deg) at 50% Load

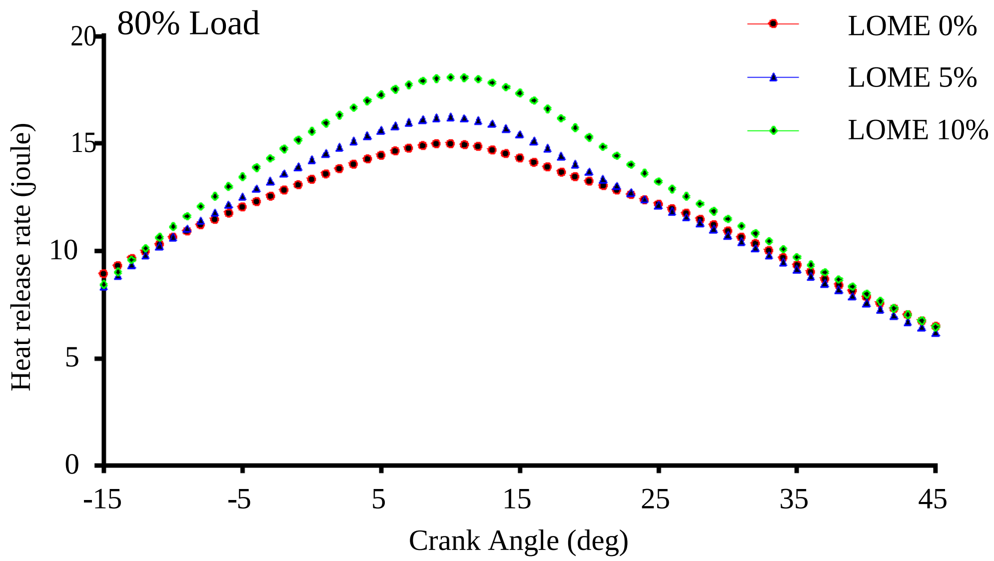


Figure: 4.8 Variation of Heat release rate with Crank angle (deg) at 80% Load

Emissions:

4.1.5 Carbon monoxide

Carbon monoxide emission depends on air-fuel equivalence ratio, the oxygen content of the fuel. CO emission concentration increases with fuel-rich mixtures (i.e. increase in excess fuel) in the exhaust gases. The influence of lemon peel oil on carbon emission at different load conditions has been shown in the figure: There is an increase in percentage emission of carbon monoxide with an increase in percentage blend at lower loads. This is happened due to the high boiling point of lemon peel oil and less temperature inside the engine cylinder at lower loads. It is observed that at higher loads there is a decrease in CO with an increase in blend percentage. It may be due to with an increase in load the temperature inside the cylinder increases and in lemon peel oil the oxygen content is somewhat higher compared to other alternative fuels and the carbon percentage is low compared to gasoline this will lead to a reduction in the carbon monoxide emissions. The carbon monoxide emission has been increased by 22% and 38% for LPO 5% and LPO 10% respectively at low (30%) load. The CO emission decreased by 11% and 17% at medium (50%) load and by 15% and 38% at high (80%) load for LPO 5% and LPO 10% respectively.

Break Mean Effective Pressure (bar)	Carbon monoxide (%)		
	LOME 0%	LOME 5%	LOME10%
1.14	1.02	1.25	1.41
2.34	1.08	0.9625	0.892
3.75	0.38	0.3175	0.233

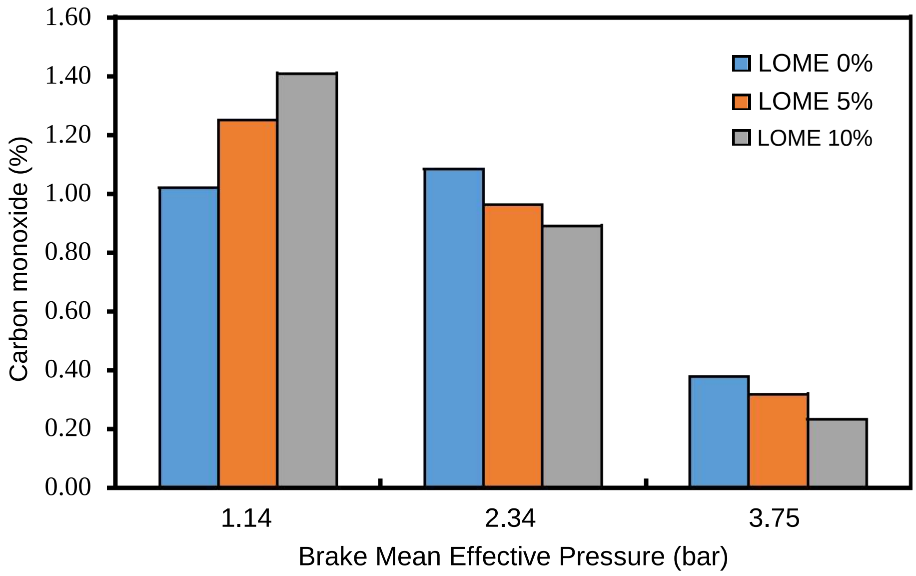


Figure: 4.9 Variation of CO emission with different load conditions

4.1.6 Hydrocarbons

Hydrocarbon emission depends on a lot of factors crevices, load, wall temperature, deposits, chemical composition (i.e. paraffin's and olefins) etc. The variation between hydrocarbons at different lemon peel oil percentage blend has been compared at different loads has been shown in the figure. It has been observed that with an increase in load the hydrocarbon emissions decreased at different blend percentages. Load conditions affect the hydrocarbon emissions at low load conditions produce higher hydrocarbon emissions than high load conditions. At high load condition there is an increase in hydrocarbon emissions with an increase in blend percentage. The Volatility of the lemon peel oil is low when compared with gasoline if you see that at higher load conditions there is an increase in heat release rate but the peak of it retards further indicating a delay that is it takes more time for LPO 5% and LPO 10% blends to get combusted at these higher pressure the fuel may flow into the crevices leading to incomplete combustion of the fuel thereby increasing the hydrocarbon emissions. But the hydrocarbon emission gets decreased at low (30%) load with LPO 5% which couldn't be accounted for at this time.

Break Mean Effective Pressure (bar)	Hydrocarbons (ppm)		
	LOME 0%	LOME 5%	LOME 10%
1.14	363.44	215.18	369.82
2.34	137.5	166.5	186.4
3.75	119.77	145.19	204.24

4.2 Effect of Injection Angle:

4.2.1. Brake Thermal Efficiency

Brake thermal efficiency is the ratio of brake power and product of the mass of fuel consumed and its calorific value it has been observed that with an increase in blend percentage there is a decrease in the efficiency and with an increase in spark angle the efficiency increased and then decreased by LOME 5% and LOME 10% blend percentages. Maximum efficiency is obtained at 20^0 BTDC spark angle for LOME 5% and LOME 10% blends. This is due to change in ignition angle there is a delay in injection due to the low calorific value of the fuel the injection angle needs to be retarded thereby increasing the efficiency but further retardation leads to incomplete combustion leading to decrease in efficiency.

Spark Angle (deg)	Brake Thermal Efficiency (%)		
	LOME 0%	LOME 5%	LOME 10%
18	23.67	23.51	19.99
20	23.15	24.06	20.45
22	24.93	23.11	19.99

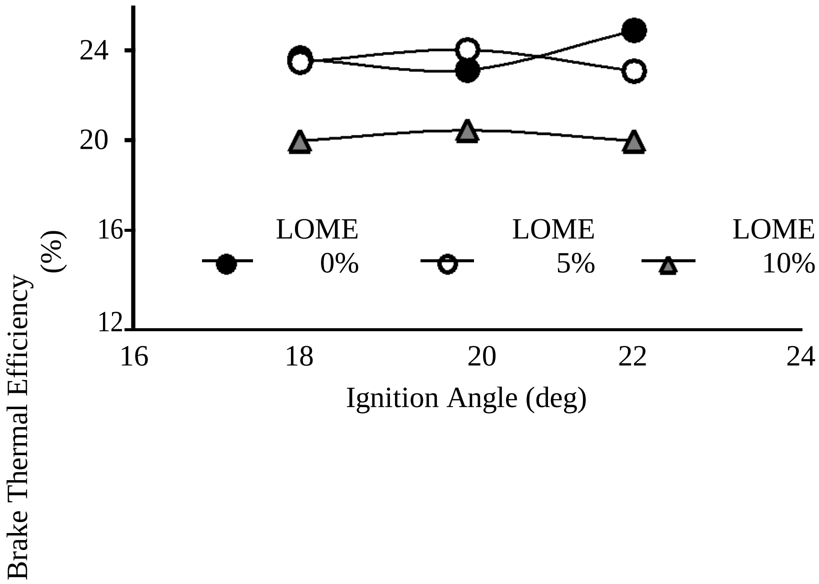
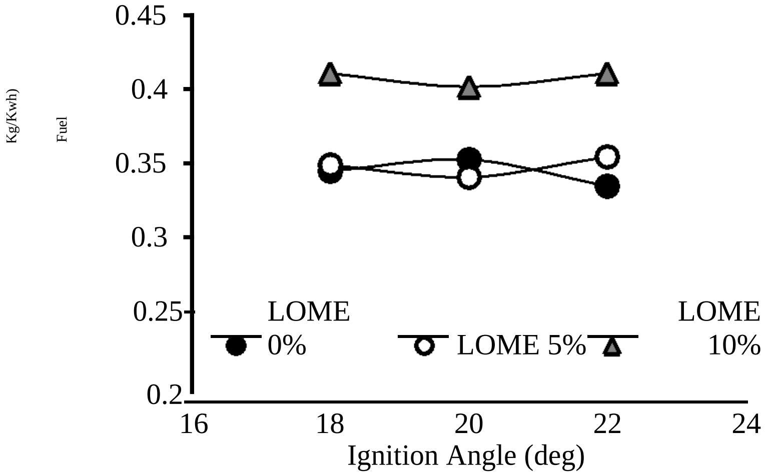


Figure: 4.11 Variation of Break thermal efficiency with injection angle for different blends

4.2.2. Brake Specific Fuel Consumption

Brake specific fuel consumption is the ratio of brake power to the mass of fuel consumed. It is the vice versa of brake thermal efficiency. It is observed that with an increase in blend percentage there is an increase in fuel consumption due to its less calorific value. For LOME 0% brake specific fuel consumption is minimum at 22^0 BTDC ignition angle. But for LOME 5% and LOME 10% the minimum brake specific fuel consumption was obtained at 20^0 BTDC ignition angle.

Spark Angle (deg)	Brake Specific Fuel Consumption (Kg/Kwh)		
	LOME 0%	LOME 5%	LOME 10%
18	0.345	0.349	0.411
20	0.353	0.341	0.402
22	0.335	0.355	0.411



4.2.3. Carbon Monoxide

Variation of carbon monoxide with different injection angles for different blends of LOME and diesel has been studied as shown in Figure:4.13. Carbon monoxide emission has been decreased with increase in blend percentage and it is also observed that with increase in injection angle the amount of carbon monoxide emission has also been decreased. Maximum carbon monoxide emission is obtained at 18^0 for all blends. For LOME 5% and LOME 10% blends the decrease in CO emissions for change in injection angle is very less when compared to the LOME 0% blends.

Spark Angle (deg)	Carbon monoxide (%)		
	LOME 0%	LOME 5%	LOME 10%
18	1.02	1.25	1.41
20	1.08	0.9625	0.892
22	0.38	0.3175	0.233

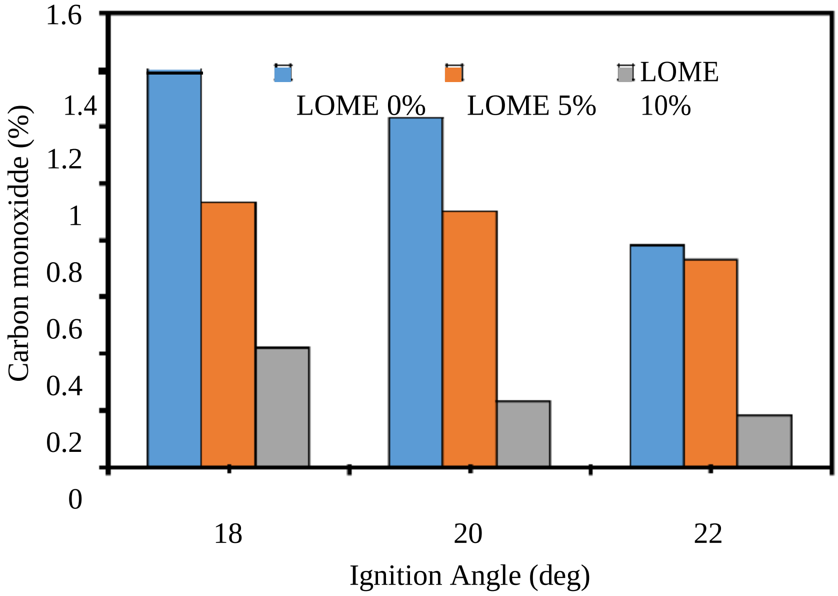


Figure: 4.13 Variation of Carbon monoxide with ignition angle for different blends

4.2.4. Hydrocarbons

Variation of Hydrocarbons with different CI angles for different blends of LOME and diesel has been studied as shown in Figure:4.14. Hydrocarbon emission has been decreased for LOME 5% blend, and increased for LOME 10% blend when in compared with diesel and it is also observed that with increase in injection angle the amount of hydrocarbon emission has also been decreased for all blend percentages.

Spark Angle (deg)	Hydrocarbons (ppm)		
	LOME 0%	LOME 5%	LOME 10%
18	363.44	215.18	369.82
20	137.5	166.5	186.4
22	119.77	145.19	204.24

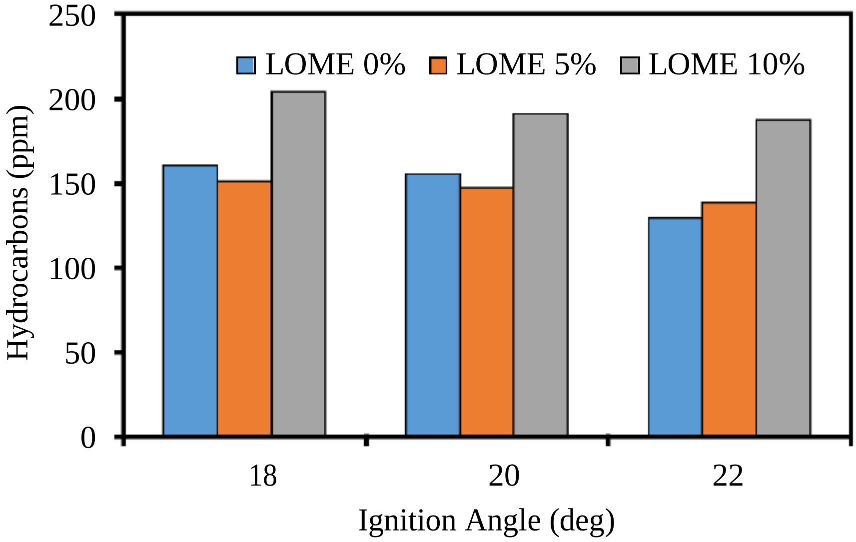


Figure: 4.14 Variation of Hydrocarbons with ignition angle for different blends

4.2.5. Carbon Dioxide

Variation of Carbon dioxide with different CI angles for different blends of LOME and diesel has been studied as shown in Figure:4.15. Carbon dioxide emission increased for LOME 5% blends with an increase in injection angle and decreased by LOME 10% blend percentage. At injection angle 18^0 emissions increased with increase in blend percentage. For the remaining two angles the emission increased for LOME 5% blend and decreased by LOME 10% blend percentages.

Spark Angle (deg)	Carbon dioxide (%)		
	LOME 0%	LOME 5%	LOME 10%
18	12.4	12.2	12.34
20	13.15	13.3	13.2
22	12.55	13.2	13.2

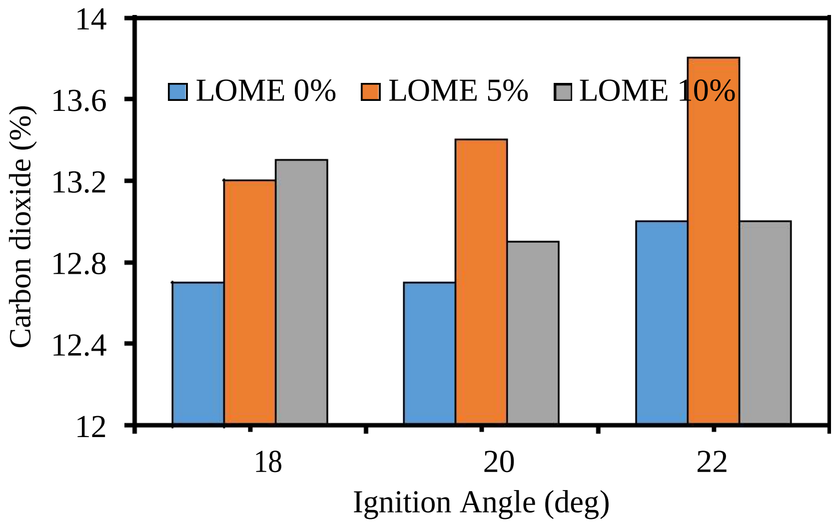


Figure: 4.15 Variation of Carbon dioxide with ignition angle for different blends

In this study lemon oil methyl ester (LOME) was used as an alternative fuel in this experiments because of its low viscosity and it's high Cetane rating when compared with other fuels. The experiments were carried out at 30%, 50% and 80% loads because of an assumption that vehicles mostly operate at these load conditions and safety considerations. It is observed that at LOME 5% blend there is a 6% decrease in brake thermal efficiency and LOME 10% blend has 16% decrease in brake thermal efficiency and there is a 6% increase in BSFC for LOME 5% blend and 19% increase in BSFC at LOME 10% blend when compared with diesel. The peak of heat release increased with increase in blend percentages at 50% and 80% load conditions. Maximum heat release was obtained for LOME 10% load. In-cylinder peak pressure retarded at 50% and 80% loads, there is any significant change in in-cylinder pressure for LOME 5% and LOME 10% blends. Carbon monoxide emissions are increased at low load conditions and decreased at medium and high load conditions with an increase in blend percentage Hydrocarbon emissions are increased with increase in LOME blend percentage.

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