EXPERIMENTAL INVESTIGATION ON PERFORMANCE AND EMISSION CHARACTERISTICS OF DIRECT INJECTION DIESEL ENGINE OPERATING ON DUAL FUEL MODE WITH POLANGA BASED BIODIESEL AND ETHANOL

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CERTIFICATE

This is to certify that the thesis entitled **"Experimental Investigation on Performance and Emission Characteristics of Direct Injection Diesel Engine Operating on Dual Fuel Mode with Polanga Based Biodiesel and Ethanol"** submitted by Deepak Kumar, to University of Petroleum and Energy Studies, for the award of the degree of Doctor of Philosophy is a bonafide record of the research work carried out by him under our joint supervision and guidance. The content of the thesis, in full or parts have not been submitted to any other institute or university for the award of any other degree or diploma.

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I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or any other institute of higher learning, except where due acknowledgement has been made in the text.

Date : (DEEPAK KUMAR)

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EXECUTIVE SUMMARY

The twin problems of environmental pollution and energy shortage need to be carefully planned for gradual shift from fossil fuels to renewable sources of energy. It has become highly prominent in the present situation to look for substitute fuels that has potential of justifiable development, energy protection, efficiency and ecological protection. The bio-origin fuels can provide a viable solution to this worldwide petroleum crisis and environmental safety.

The existing engines are normally designed and manufactured in accordance to diesel as fuel. The suitability of fuel obtained from alternative source is yet to be studied whether the new fuel gives desired performance and emission characteristics. In this work, low speed Direct Injection (DI) diesel engine has been modified to run on alternative fuel in dual fuel mode. This engine was tested with diesel/polanga biodiesel as primary fuel and ethanol as secondary fuel.

The chapter one presents the brief introduction of the research work undertaken. In this chapter, the importance of present study, objectives, its socio economic effect, historical support to inspire the work to be undertaken and the environmental concerns are described. The potential of the alternate fuel is assessed by viewing the important sources and also its availability in our country.

The brief summary of the research work carried out in this area is also overviewed in this chapter which gives the guide lines and supports to potential of this work in yielding the results targeted in this work. The observations and analysis made by researchers while using the dual fuel of different sources directly in the diesel engines are described. It has been observed that the dual fuel gives acceptable results when used in direct injection diesel engine. In this chapter, the emphasis is made to fulfill the global objective of searching the alternate fuel to have energy security by testing the technical feasibility and projecting biodiesel and ethanol as potential alternate fuel. As mentioned above, existing engine was modified to give efficient output with dual fuel so, based upon the analysis of experimental results and literature survey, the brief of the suggested modifications in existing engine are listed. The improvements in performance by suggested modifications are also commented briefly in this chapter.

The chapter two of the thesis deals with the detailed literature survey. The recent available literatures explain the limitations of dual fuel to be used as diesel replacement to the engines. The technical problems mentioned in the different sources of literatures observed by the researchers are taken as the basis for this work and also the basis for deciding the strategy of experiments of this work. The analysis of experiments conducted by the researchers available as literature and the experiments undertaken during this work has been analyzed and the feasible suggested modifications are decided. The identified modifications were matched with the available research data and comments on such modifications. The potential of considered alternate fuel is reviewed from the literature data. This chapter also describes the comparison of physical and chemical properties of polanga biodiesel with diesel. This chapter lists the various previous works related to the present work which are important in decision making and performance analysis process. The existing literatures in support of technical parameters used for modification in this work are extensively considered to be included in this chapter to orient the present work.

In chapter three, the methodology of this research work, the steps of experiments carried out at laboratory together with process of experimentation is laid down. The production of polanga biodiesel from polanga vegetable oil is also discussed. The methods of determining the different properties of biodiesel are mentioned so that the results can be compared with the corresponding diesel fuel properties. Initially, the physical properties like viscosity, density, calorific value, flash point and pour point of diesel and biodiesel are found out in the laboratory by the prescribed methods with the help of well calibrated precision equipment. The viscosity was measured by rotary digital viscometer. It was found that the kinematic viscosity of diesel was 3.2 cSt in comparison with the kinematic viscosity of polanga biodiesel 4.1 cSt at 40^{O} C as obtained in the laboratory. The densities of diesel and polanga biodiesel were measured by hydrometer. It was found that the density of diesel and biodiesel were 0.823 kg/l and 0.872 kg/l respectively.

The arrangements and modifications required in the associated engine systems for precise data collection is described in this chapter. The figures of such arrangement are included to make the description more understandable. The types of sensors, equipment, data acquisition system, different instruments used for measuring the technical parameters are described. The calculations and processing of observed data from experimentation is mentioned. To study the emission parameters of the baseline fuel and ethanol at different sets of experimentation, reliable instrument made by AVL Company was used. The details of these instruments and their technical capabilities are listed systematically. The technical specifications of engine and the dynamo as quoted by the manufacturer are listed. The external arrangements attached to the engine and used for observing the operating parameters are discussed in this chapter. All the sets of operating conditions as decided for experimentation is grouped in a sequence so that the observations can be made at all those operating points in a gradual ascending or descending order. This also helps in evaluation process of the engine output which can be viewed easily in the charts. The engine is designed to operate at different amount of ethanol in dual fuel mode using a separate injection system. The detailed process of designing of separate injection system is mentioned. The injection system in accordance to the design was fabricated and installed on the engine. In this study, the engine was operated at different ethanol percentage of 10%, 20% and 30% along with the base fuel. These sets of operating parameters were used in all the three stages i.e. when the unmodified engine was run for testing with petro diesel and biodiesel and also at the occasion when the modified engine (with additional injection system for ethanol) was tested with diesel and biodiesel.

Initially, the unmodified engine was tested while using the petro diesel as fuel and afterwards the same engine was tested using the biodiesel as fuel. After making the experimental set up ready with modification, the engine was tested with diesel and biodiesel in dual fuel mode. At last, the concepts and the formula used to generate the results are described.

The engine taken for the experiment is direct injection (DI) low speed diesel engine having rated output 3.5 kW when fuelled with diesel fuel. This engine is single cylinder, four stroke, vertical, water cooled system having a bore of 110 mm and stroke of 80 mm. The test engine is directly coupled to a DC electric dynamometer to absorb maximum power produced by the engine.

All the necessary arrangements were made to measure the temperatures, voltage, fuel consumption, air consumption etc. In the process of experiment, initially the DI diesel engine was operated with diesel/biodiesel in single and dual fuel mode at 0%, 50% and 100% of rated load. All the technical parameters such as pressure, heat release, brake thermal efficiency (BTE), emission parameters of CO, CO_2, UHC, NOx and smoke opacity were found out in the laboratory. The above process was repeated for both single and dual fuel mode. After completing the test cycle with diesel fuel, the engine was run with the biodiesel as primary fuel. The engine was tested under similar test environment as before for same test cycle. The test parameters were noted down again.

In chapter IV the properties of diesel and polanga biodiesel which are of importance to affect the combustion quality and fuel efficiency are compared. It has been found that the kinematic viscosities, density of biodiesel, calorific value are close to that of mineral diesel. The effects of these properties on performance and efficiency are discussed. It has been observed that the calorific value of polanga biodiesel is 40800 kJ/kg in comparison to 44000 kJ/kg for diesel. The possibilities of improvement in fuel properties to enhance the performance are discussed. The characteristics of biodiesel are close to diesel and therefore, biodiesel becomes a strong substitute to replace the mineral diesel if required. Flash point, density, pour point, cetane number, calorific value of biodiesel comes in very close range to that of mineral diesel. The performance parameters in single fuel and dual fuel mode were calculated in both the cases and compared. It was observed that the performance parameters such as pressure, heat release, the brake thermal efficiency, and also the emission parameters such as NOx, CO_2, and smoke were favorable in the case of dual fuel injection. The causes of favorable results were identified. It was revealed that the combustion quality of dual fuel could have been the major factor.

In this chapter, the effects of incorporating the dual fuel injection are explained. The logical conclusions based upon analysis of observed data are compared with the information available from existing literatures reported by the researchers. The other important factors governing the fuel performance, efficiency and engine output are discussed. A brief of that discussion is included here also.

The peak heat release decreases with dilution and increases with load for all fuel combinations. The ignition delays for both diesel and biodiesel in dual fuel mode were slightly longer than single fuel mode combustion. The increase in ignition delay is due to ethanol fuel in the intake and compression processes. It has been observed that the peak heat release is higher with pure diesel than that of diesel with ethanol and biodiesel with ethanol due to shorter ignition delay.

The peak pressure increases with load for all fuel combinations and decreases with dilution except at 50% load. All combinations of Polanga biodiesel with ethanol in dual fuel mode have less peak pressure than that of pure biodiesel in single fuel mode at all load conditions except for 10% ethanol combination, where peak pressure is slightly higher at half and full load. Peak pressure with biodiesel occurred early as compared to diesel as the combustion in biodiesel initiated somewhat early as compared to that in diesel. Also, both the oils in dual fuel mode give maximum peak cylinder pressure after the TDC which is encouraging. The peak pressure obtained is near to diesel and creates no danger to the engine structure. A slight improvement in the efficiency with increasing ethanol substitution at all loads can be observed for biodiesel. Also, for the same ethanol content, biodiesel gives higher BTE than diesel under similar loading conditions. It is observed that ethanol addition has almost similar effect on both diesel and biodiesel at all loads.

In comparison between single and dual-fuel combustions, the concentrations of CO emissions for the dual-fuel mode with both pilot fuels are considerably higher than those of the single-fuel mode under all loading conditions with one exception for each pilot fuel. For the single fuel mode, polanga biodiesel combustion emits somewhat less amount of CO at higher loads while it emits more amount of CO at lower loads as compared to diesel fuel combustion.

The induction of alcohol increases the specific heat capacity of the working fluid which thereby caused the slowing of the flame propagation and finally reduces the combustion temperature during the combustion process. Therefore, for dual-fuel operations, the concentrations of NOx emissions were obviously lower at all engine loads.

The UHC emission also increases like CO emission. The reasons behind the formation of UHC during combustion are same as for CO formation. Alcohol injection affects the UHC emission in the same way as it affects the CO emission. Alcohol fumigation significantly reduces the smoke opacity as compared to pure diesel/ biodiesel fuel. Reduction in smoke emission may be due to fact that less diesel/biodiesel fuel is consumed with increasing alcohol injection since a remarkable part of diesel fuel is replaced by alcohol. Therefore, less diesel fuel is burned in the diffusion mode and combusts together with the homogenous alcohol/air mixture which helps in fast burning and with higher availability of oxygen, leading to a reduction in smoke emission.

Chapter V concludes the investigation and confirms that biodiesel and ethanol can substitute mineral diesel with minor change in the inlet manifold.

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LIST OF SYMBOLS

%	Per cent
cSt	Centistokes
v	Kinematic viscosity
μ	Dynamic Viscosity
ρ	Density
λ	Surface tension
°C	Degree Celsius
Cal	Calorie
cc	Cubic centimeter
cm	Centimeter
g	Grams
h	Hour
j	Joule
kCal	Kilocalorie
kg	Kilogram
kW	Kilowatt
L	Stroke length
l	Liters
m	Meter
min	Minutes
MJ	Mega joule
MPa	Mega Pascal

ml	Milliliters
N	Newton
rpm	Revolutions per minute
s	Seconds
W	Watt
MHz	Mega Hertz

LIST OF ABBREVIATIONS

BTDC	Before Top Dead Centre
BDC	Bottom Dead Centre
B T E	Brake Thermal Efficiency
BSFC	Brake Specific Fuel consumption
BHP	Brake Horse Power
CI	Compression Ignition
EFI	Electronic Fuel Injection
DI	Direct Injection
LMTD	Log Mean Temperature Difference
LPG	Liquid Petroleum Gas
RPM	Revolution Per Minute
TDC	Top Dead Centre
CO	Carbon Monoxides
NOx	Oxides of Nitrogen
UHC	Unburned Hydro Carbons
CO_2	Carbon Dioxides
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
FFA	Free Fatty Acid
DME	Di-methyl-ether
EGR	Exhaust Gas Recirculation
HCCI	Homogeneous Charge Compression Ignition
DFDI	Dual Fuel Direct Injection
PAH	Polycyclic Aromatic Hydrocarbons

SO_2	Sulfur Dioxide
BSCO	Brake Specific Carbon Monoxides
NG	Natural Gas
PM	Particulate Matter
CNG	Compressed Natural Gas
DFDI	Dual Fuel Direct Injection
$BSCO_2$	Brake Specific Carbon Dioxides
VIT	Variable Injection Timing
EIC	Electronic Injection Controller
ECU	Electronic Control Unit
ROHR	Rate of Heat Release
CA	Crank Angle
LHV	Lower Heating Value

CHAPTER 1

INTRODUCTION

The demand of petroleum fuels is increasing rapidly with rising industrialization and motorization throughout the world. The reserves of Petroleum-based fuels are limited and are mainly located in certain part of the globe. Consequently, there is a big crisis of energy for countries not having petroleum reserves and are dependent on import of crude oil from oil producing countries. Henceforth, it has become necessary for these countries to go for alternative fuels which they can produce themselves from agricultural products such as ethanol, edible or nonedible vegetable oils etc.

In this research work, use of ethyl alcohol in combination with Polanga biodiesel is explored as an alternative fuel in order to improve performance and to decrease exhaust emissions of a diesel engine. This work also aims at developing a separate injection system for introduction of ethanol in the cylinder of a small capacity Diesel engine together with injection of biodiesel by the main injector. It also focusses on the production of Polanga based biodiesel.

1.1 PETROLEUM FUELS: PRESENT SCENARIO

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. Indiscriminate extraction and excessive consumption of fossil fuels have led to reduction in underground-based carbon resources.

According to an estimate, the reserves will last for 218 years for coal, 41 years for oil, and 63 years for natural gas, under a business-as-usual scenario [1]. The massive growth of world population, improved technical advancement, and high living standard in the industrial nations has led to this scary situation in the field of energy supply and demand. The prices of crude oil keep on rising and fluctuating on a daily basis. This requires developing and commercializing petro fuel substitutes from bio-resources. This may well be the main reason behind the growing awareness and interest for unconventional bio energy sources.

Greenhouse gases (GHG) limit the ability of earth to radiate back the thermal energy which comes from sun. CO_2 coming out of the engine is a greenhouse gas. We, as human being, have understood that it is very important to be cautious of changes in the ecosystem and atmosphere. In its Report, the IPCC (Intergovernmental Panel on Climate Change) stated that significant increase in regional and global temperature has been observed due to increased anthropogenic GHG emissions. It is therefore important to find ways to minimize the introduction of more GHG into the atmosphere. The transportation sector is a large GHG contributor, with about 13 percent of all anthropogenic GHG emissions [2]. The sector is highly dependent on fossil fuels, and not many realistic alternatives exist at this moment as compared to the rest of the energy sector, where numerous alternatives exist. Rather than focusing entirely on one aspect of the GHG issue, it is more appropriate to view the situation as a whole and include all aspects of the fuel life cycle. Durante and Miltenberger claimed that little or no GHG benefit is obtained when bioethanol is used as a fuel for transportation in its current form. They recommended for considering the perspectives of using biomass not for ethanol and transportation, but for other possible CO_2-mitigating applications as well [3].

1.2 ALTERNATE FUELS

Researchers around the world have discovered a number of alternate fuel sources that have the prospective to appease the constantly-growing energy demand of today's world. The biofuel sources discovered so far comprise vegetable oils, biodiesel, biomass, biogas, primary alcohols, etc. The exact applications, advantages and drawbacks of these environment friendly sources of energy are to be appraised on case-to-case basis. Some may be used directly while some need to be processed before using in engines to have properties closer to petro fuels. Because of the extensive application of diesel fuels in several segments currently, the main focus is on evaluating the feasibility of using substitute fuels in the prevailing direct injection diesel engines. The existing energy situation has encouraged strong research attention in renewable, clean and non-petro fuels.

The production of vegetable oil from seeds is quite simple. Obviously, only non-edible vegetable oils can be seriously considered as fuel for engines as the edible oils are already in great demand and are too expensive as fuel. Since vegetable oils are renewable and are produced easily in rural areas, these can be the perspective alternative fuels. Their usage has been studied ever since the advent of internal combustion engine. However, it is only in the recent years, systematic efforts have been made to utilize these oils as fuels in engines. Having comparable properties as diesel fuel, these can be used to run compression ignition engines either with little or without any modifications.

1.3 BIOFUELS AS A POSSIBLE SUBSTITUTE FOR DIESEL

Dr. Rudolf Diesel developed the diesel engine to run on a number of fuels such as coal dust suspended in water, heavy mineral oil, and vegetable oils. Initial trials of Diesel's engine were shattering disappointments. But in 1900, he presented his engine at the World Exhibition in Paris where it was working on peanut oil. Dr. Diesel being visionary stated ''the diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture sector of the countries". The use of vegetable oils as engine fuels may seem insignificant today but in course of time such oils may become as important as petroleum and the coal tar products of the present time. After early death of Dr. Diesel in 1913, petroleum fuel was used in his engine. However, his vision to run the engine on vegetable oil emphasizes the use of such renewable and locally produced fuels to have clean environment.

In emergency conditions, vegetable oils were utilized as alternate to diesel fuel during 1930s and 1940s [4]. In recent times, biofuels from vegetable oils and animal fats have become much focused due to limited resources and high cost of petroleum fuels. In comparison to biofuels, petroleum products result in more CO_2 and other emissions leading to more pollution of local air to amplify global warming. Biofuels can also reduce hazards level in some specific cases, such as the emission of pollutants in the closed situation of underground mines. Large numbers of biofuels are available but biodiesel and ethanol are the key biofuels being deliberated worldwide. Biofuels are broadly classified into two categories.

1. Primary biofuel
2. Secondary biofuel

1.4 SOURCES OF PRIMARY BIOFUELS

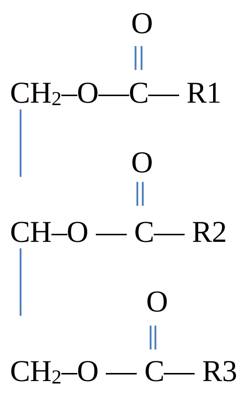
Primary biofuels (biodiesel) can be obtained from several sources for example non edible forest crops, vegetable oil crop and oil bearing biomass material. Most of the vegetable oils are edible oils and use of these edible oils will have adverse effect on food materials as well as on the cost of edible oils, which may not be acceptable. Some of the sources of non-edible oils are linseed oil, Mahua, Jatropha oil, Karanja oil, Polanga oil etc. Fats of animals and vegetable oils (waste) are also used to produce biodiesel [5].

In America, soyabean oil is the main source of biodiesel as soyabean is produced at a very large scale in this part of world. Palm oil is used as source of biodiesel in Indonesia and Malaysia. The rapeseed oil is the main source of biodiesel in Europe & Canada. Countries with tropical climate prefer to use coconut or Palm oil. Jatropha seeds are the main source for production of biodiesel in India. Argentina, Philippines, Malaysia, Brazil and Indonesia are key exporters and United Kingdom, Pakistan, Italy, China are the major importers of vegetable oil. A very few countries like Netherlands, Germany, United States of America and Singapore are both exporters as well as importers of vegetable oils [6]. Some of the nonedible oils which are commonly available include neem, polanga, karanja, jatropha, rubber seed, silk cotton etc. In developing countries, these are very cost-effective as compared to edible oils. Main sources for biofuel production from non-edible oils are the plant species such as Atrophy, ratanjyote, seemaikattamankku (Jatropha curcas), Karanja, Honge (Pongamia pinnata), Nagchampa (Calophyllum inophyllum), Rubber seed tree (Hevca brasiliensis), Neem (Azadirachta indica), Mahua (Madhuca indica and Madhuca longifolia), Silk cotton tree (Ceiba pentandra), Jojoba

(Simmondsia chinensis), Babassu tree, Euphorbia tirucalli, Microalgae, etc. Non edible oils produced from these plant species are cheaper than edible oils in India [6].

Due to inherent physical and chemical properties of vegetable oils, only a fraction of petroleum based fuels can be replaced by biodiesel derived from these vegetable oils in near future. Even though biodiesels derived from vegetable oils are costlier than petroleum based fuels at present, uncertainty regarding the availability of petroleum based fuels has drawn attention towards biodiesels as substitute fuel. Chemically, vegetable oils and animal fats are triglyceride molecules, in which three fatty acid groups / esters are attached to one glycerol molecule while straight chain organic compound and multifaceted protein and fat-soluble vitamins are found as mixture in vegetable oils [5]. They are mostly water insoluble and hydrophobic materials in the plant and animal realms. The molecules of petro diesel fuels are non-branched saturated molecules with 11 to 17 carbon atoms.

Most of the vegetable oils have structure with number of branched chain of triglycerides as follows:



Where R1, R2, R3, represent hydrocarbon chain of fatty acids. Carbon chain length and number of unsaturated bonds vary in different fatty acids.

1.5 SVO AS A FUEL AND LIMITATIONS

The heating value of vegetable oils is usually 10% less than that of diesel due to the presence of oxygen in the molecule. Due to high molecular weight and intricate molecular structure, the viscosity of vegetable oil is 30-55 cst which is very high in comparison to 4 cst for diesel at 40 ^{0}C [5]. Viscosity upsets the behavior of the fuel flow through injection system and the form of fuel spray. The high jet dispersion and reduced atomization results in bigger droplets. The fuel Jet injects a solid stream rather than spray of droplets of smaller size hence proper mixing of fuel with air required for combustion is affected. Engine power and fuel economy decreases due to poor combustion of bigger droplets. In small engines, fuel spray even may cause washing away of the lubricating oil from the cylinder wall, thus deteriorate the crank case oil leading to extreme wear of moving parts.

High flash point indicates inferior volatility characteristics. This results in excessive formation of carbon deposits, dilution of lubricating oil, degradation of main oil, choking of injector and chances of seizure of engine. Low volatility and high viscosity of vegetable oils result in misfire, ignition delay and poor cold starting [5].

Majority of petro diesel is consumed by the transportation and agriculture sector. These fuels are the greatest producer of ecological pollution. By using renewable energy source in place of petro fuels, this pollution can be largely reduced. In the sector of transportation and agriculture, biofuels and other renewable fuels are being promoted by Europe as a substitute fuel to diesel and gasoline [9].

Vegetable oil does not harm environment as it does not contain sulfur and therefore problems associated with sulfurous acid aerosols would be reduced[7].

Use of vegetable oils as a fuel has following benefits:

- These are renewable liquid fuels.
- These are clean fuels and do not pollute that much as petro fuels.
- Vegetable oils, having the property of obsession of nitrogen in the soil, can make land marginally productive.
- The production of vegetable oil needs very low energy input.
- Energy content in vegetable oils is higher than other energy sources. Compared to petro-diesel, heat content of vegetable oils is 90%.
- Prices of straight vegetable oils are approximately same as petroleum oils across the globe presently.
- Based on emissions, combustion of vegetable oil is cleaner than petroleum oil.
- Production of vegetable oil is also simple.

Economically, the use of vegetable oil as fuel is still not feasible and needs more R&D investigations for making these oils feasible to be used as fuel.

Owing to the speedy decline in crude oil resources, the use of vegetable oils as substitute to diesel fuels is encouraged in several countries. As per the climatic and soil conditions, different countries are working on several vegetable oils to replace petro-diesel fuels. America is using soybean oil, Europe is using rapeseed and sunflower, Southeast Asian countries are using palm oil and coconut oil as alternative fuel.

An adequate substitute fuel for engine needs to satisfy the ecological and energy security requirements without forfeiting operating routine. Successful utilization of vegetable oils in compression ignition (CI) engine can be achieved through engine adjustments and alterations of fuel. Engine adjustments comprise preheating of vegetable oil, dual fuel injection, injection method alteration etc. Fuel alterations include making of biodiesel by transesterification, blending with diesel in different proportions, cracking/pyrolysis and emulsification to decrease polymerization and viscosity.

An engine can not be run directly on straight vegetable oils. Vegetable oil needs to be transformed in to biodiesel, which is engine-friendly. Care is to be taken that these fuels can be employed in the prevailing diesel engine without considerable hardware change since even incorporating a minor change in the existing engines throughout the world incur high cost and time.

1.6 PRODUCTION OF PRIMARY BIOFUEL

The production of biofuel from the oil seeds is already established process as reported by several researchers over last many years [5-8].

Biodiesel production requires a feedstock (fat or oil) and an alcohol in presence of a catalyst in most of the cases. Depending on the quality of the feedstock, either esterification or transesterification reactions are used for biodiesel production. Most of the current biodiesel production operations use alkaline catalysis (transesterification). This method works well if the free fatty acid, moisture and phosphorous contents of oil/ fat are less than 0.1 percent, 0.1 percent and 10 ppm, respectively. Typical feed stocks for biodiesel production are soyabean, canola/rapeseed, sunflower, cotton seed, palm seed and palm kernel, corn and mustard seed oil. Pork, beef and poultry fat and grease also can be converted into biodiesel. Palm oil and animal fat may have a high free fatty acid content, which causes adverse effects on downstream processing and leads to yield reduction.

The free fatty acid (FFA) content in neem (*Azardirachta indica*) and rubber (*Hevea brasiliensis*) is high. The reaction of FFAs with alkaline catalysts results in soap formation which creates problem in separation of glycerol from biodiesel. The resulting soap products also cause an increase in viscosity [8].

The expertise for the use of vegetable oils as substitute to diesel fuel must be established first which may allow the production of those crops to continue in crisis condition as well. Now it has become essential that among all the oil seeds available in the world to produce vegetable oil, particular oil needs to be selected as a permanent energy crop which may have higher productivity and oil content. Advantages of biodiesels are portability, availability, biodegradability, high combustion efficiency, low sulfur and aromatic content and high cetane number. Other advantages of biofuels include its domestic origin (to reduce dependency on imported petroleum), high flash point, and inherent lubricity in the pure form[7].

1.7 SOURCES OF SECONDARY BIOFUEL (ALCOHOL) AND IT's PRODUCTION

Alcohol is made from renewable resources like biomass from locally grown crops and even waste products like waste paper, grass and tree trimmings etc. Variety of crops like sugar cane, maize (corn), wheat and sugar beet are used as the main source for production of bio-ethanol. In Europe, currently wheat and sugar beet are the foremost sources of ethanol [11]. Alcohol is an alternate transportation fuel since it has properties, which allows its use in existing engines with minor hardware modifications. Also, octane no of alcohols is higher than gasoline. A fuel with a higher-octane number can endure higher compression ratios before engine starts knocking, thus giving engine an ability to deliver more power efficiently and economically.

In comparison to ethanol, gasoline has many disadvantages as an automotive fuel. The gasoline has a lower octane rating than ethanol. It is more toxic (particularly when blended with tetra-ethyl lead and other compounds to enhance octane rating), and releases more harmful air pollutants after combustion. Gasoline is more likely to explode and burn accidentally, more difficult to store, forms gum on storage surfaces and results in more carbon deposition in the combustion chamber in comparison to ethanol.

Ethanol is isomeric with di-methyl-ether (DME) and both ethanol and DME can be expressed by the chemical formula C_2H_6O. The oxygen atom in ethanol possibly induces three hydrogen bonds. Although, they may have the same physical formula, the thermodynamic behavior of ethanol differs significantly from that of DME on account of the stronger molecular association via hydrogen bonds in ethanol.

While discussing the advantages and disadvantages of ethanol, the type of application is important. Generalization is not possible, because ethanol can be used in many forms. Further, a wide range of ethanol/gasoline blends has not yet been investigated thoroughly. The most favorable type of application is determined by infrastructural factors, especially vehicle fleet configuration. From a technical point of view, optimal usage involves a low degree of water content in the ethanol, and therefore excludes low percentage- ethanol fuels. The benefits seem strongly related to the amount of ethanol in a given blend, i.e. the more the better. Both engine efficiencies and emissions improve with more ethanol in the fuel. Wet ethanol constitutes an even cleaner fuel in both, the production and application phases. In summary, ethanol application has many possibilities, but with each type of application comes a set of challenges. Nevertheless, technical solutions for each challenge are either available or can be derived.

The past few years have seen an absolute explosion in the advocacy and use of bioethanol as a fuel in the industrialized world. Since the hydrogen society has yet to materialize, bioethanol seems to be a possible way of dealing with the rise in oil prices and increasing carbon dioxide (CO_2) emissions. In a remarkable way, this seems to transcend normal political divisions, appealing to environmental concerns over global warming and promising oil-importing countries a greater independence from oil-exporting ones.

Ethanol from biomass can provide substantial benefits to local, regional, and global societies, provided the methods by which ethanol is produced and used, are considered carefully.

1.8 BIODIESEL AS A FUEL

Biodiesel is quite similar to conventional diesel in its main characteristics. Biodiesel does not contain any petroleum product, but it is compatible with conventional diesel. Biodiesel is an alternative fuel, which has a correlation with sustainable development, energy conservation, management, efficiency and environmental preservation. It is completely free from sulfur, non-toxic and biodegradable and can be produced easily from agriculture which is renewable. It can be used in CI engine with no major modification in the engine hardware.

Before using any substitute fuel in the existing engine, following factors are to be considered.

- Requirement of minor modification in the existing engine; the modification in the engine has to be cost effective for the use of any substitute fuel.
- Infrastructure for processing of these substitute fuels.
- Environmental compatibility compared to conventional fuels. If the new fuel is more polluting then it will be unacceptable as a fuel.
- Additional cost to the user in terms of routine maintenance, equipment wear and lubricating oil life.

Diesel engine can perform satisfactorily for long run on biodiesel without any hardware modifications. Twenty percent biodiesel is the optimum concentration for improved performance in case of blending with diesel however blending increases the exhaust temperature which leads to increase in NOx emissions from the engine. While short-term tests are almost positive, long-term use of neat vegetable oils or their blend with diesel leads to various engine problems such as, injector choking, ring sticking, injector deposits etc. [7 & 12]. High viscosity, low volatility and a tendency for polymerization in the cylinder are root causes of many problems associated with direct use of these oils and their blends as fuels. The process of transesterification results in decreasing viscosity and increasing volatility of vegetable oil to yield vegetable oil ester, which has shown promises as alternative fuel. The yield of biodiesel in the process of transesterification is affected by several process parameters/variables. Several researchers investigated the different vegetable oil esters and found these esters comparable to mineral diesel [7-10].

Alton et al. [6] investigated the use of sunflower oil, cottonseed oil, soyabean oil and their methyl esters in a single cylinder, four-stroke direct injection diesel engine. They observed maximum torque and maximum power at the same speed but of less magnitude than those with the diesel fuel. These results were attributed to the higher viscosity and lower heating values of vegetable oils than diesel. Specific fuel consumption is one of the important parameters of an engine and is defined as the consumption of fuel per unit power output per unit time.

Biodiesel used in this investigation is prepared from Polanga (Calophyllum inophyllum L) oil. Since biodiesel has nearly similar properties as petro-diesel, compression ignition engines can run on biodiesel as well and fundamentally, needs no engine alterations. Storing biodiesel also does not require any special arrangement as it can be stored like petro-diesel. The IEA report "Biofuels for Transport" (2004) has summarized the potential benefits and costs of biofuels as documented below.

Potential Benefits of Biofuels (Source: IEA, 2004)

- Energy security
- Balance of trade
- Lower GHG (greenhouse gases) emissions
- Reduced air pollution
- Vehicle performance
- Agricultural sector income, jobs and community development
- Waste reduction

Potential Costs of Biofuels

- Higher fuel costs
- Increase in some air emissions
- Higher crop prices
- Other environmental impacts, such as land use change and loss of habitat.

The cycle time for fixation of CO_2 released after combustion of biodiesel is quite small i.e. few years whereas fixation time of CO_2 released after combustion of petroleum fuels is very large i.e. million years. Being the esters of vegetable oils or fats derived from renewable bio-resources, biodiesel produces less amounts of undesirable pollutants as compared to petroleum/diesel after combustion[13].

The energy concentration, cetane rating, vaporization heat and A/F ratio of biodiesel is almost similar to petroleum diesel. Now a days, refining of petroleum product is also facing restrictions for sulfur and aromatic contents of the fuel.

1.9 DIRECT INJECTION DIESEL ENGINE

A compression ignition diesel engine dominates spark ignition petrol engine in fuel consumption due to relatively higher compression ratio and relatively less losses achieved with throttling. Though, higher soot formation and high temperature inside the engine, are the drawbacks. NOx (oxides of nitrogen) which comes out as engine emission also creates problems as its rate of formation is high at the reacting jet periphery with stoichiometric air fuel ratio. As a result, diesel particulate filters and selective catalytic convertors are used to reduce soot particles and NOx in current diesel engines, which are costly components.

In order to solve this problem, efforts have been made to decrease formation of such pollutants inside the engine through different combustion methods, for instance low-temperature fuel combustion by means of recirculating large amount of exhaust gas (EGR). There have been investigations on homogeneous charge compression ignition (HCCI) method to have chemical kinetics controlled combustion modes. In this method, the charge is kept lean to have temperature below threshold limit. Although the first method is being implemented in compression ignition engines effectively, the second is still in an experimental phase. Furthermore, HCCI method of controlled combustion has the following limitations [27].

(a) Combustion process control: There is no proper method of dynamic control of the start of combustion which is required for kinetics controlled combustion process. This enforces a substantial challenge to accomplish a continuous transformation between different operational conditions of engine.

(b) Restricted working range: The impulsive ignition of the complete charge instantaneously results in a higher pressure upsurge that limits engine performance at higher loads. There is also a limit for low load engine operation due to excessively lean or diluted condition of the mixture, which results in misfire.

(c) Engine start in cold condition: In the case of liquid fuel, cold start due to wall wetting becomes a problem, and this requires an additional heating of the intake air.

1.10 DUAL FUEL DIRECT INJECTION (DFDI) DIESEL ENGINE

The most widely used methods of dual fuel operations are blending and fumigation. Different proportion of secondary fuel is mixed with diesel/biodiesel and then injected inside the cylinder in blending method. As blend of secondary fuel like alcohol with diesel is not stable, extra additives are added to stabilize the miscibility. This limits the amount of alcohol for blending operation. In fumigation method, secondary fuel is introduced in the engine through intake manifold by carburetion. This method of introduction of secondary fuel has the advantage of providing a portion of the total fuel supply premixed with the intake air, thus improving air utilization. Though minor alteration of engine is required in this method, it permits a large amount of secondary fuel like alcohol to be used in engine operation as additives are not required for stabilizing the miscibility of alcohol and diesel fuel.

In dual fuel injection, secondary fuel is injected through intake manifold and premixed secondary charge is supplied to the engine. The combustion is initiated near the top dead center by the injection of primary fuel through the main injector as in normal diesel engines. The combustion of the mixture of secondary fuel and air takes place either by turbulent flame propagation or by auto ignition sequentially after the injection of primary fuel. Preferably, by controlling the proportion of secondary fuel and primary fuel and the injection time of second fuel, the high rate of pressure rise can be controlled in the premixed combustion phase. Moreover, during the low load/cold start period, the engine can run by injecting primary fuel only to solve the wall-moistening and the misfiring problems.

Various secondary fuels have been used by researchers to investigate the possibility of dual-fuel diesel combustion. These are mainly natural gas, alcohols, LPG, and hydrogen. Since natural gas is widely available, it has been extensively investigated in dual-fuel mode. Tests revealed that combustion in dual fuel mode improves efficiency and decreases emissions such as smoke (opacity) and NOx in comparison to CI engine operating on pure diesel. Same advantages of improved efficiency and decreased engine emissions have also been reported with LPG and hydrogen as secondary fuels [14].

In recent times, Ethanol as secondary fuel is receiving much interest due to its availability. It can be produced mainly from many renewable feed stocks, thereby resulting in a good alternate to petro fuels. Its higher octane number and lower cetane rating than conventional fossil-fuels, helps in extended ignition delay. The problem of knocking or undesirable premature ignition that occurs with fuel having lower octane number may be avoided by using fuel with higher octane number in dual fuel mode. Ethanol having more oxygen also helps in reducing soot emissions. These investigations emphasize on injection of ethanol and air premix in the engine and its effect on engine performance and various engine emission species.

Different studies on diesel engine also suggest that atomization, size of droplets and secondary fuel vaporization play an important role in dual fuel engine applications. The position of injector which spray secondary fuel has significant role on the engine emissions particularly HC emission [15]. Studies show that if the injector is located away from the intake valves, the contact between the alcohol droplets and air will be longer causing better mixing while placement of the fuel injector nearer to the intake valves result in better engine stability and lesser hydrocarbon release due to the impact of fuel sprays upon hot intake valves causing improved fuel droplet vaporization.

In the present investigation, dual-fueling trials have been accomplished in a compression ignition single cylinder engine separately with diesel and polanga biodiesel as primary fuels and ethanol as secondary fuel. The DI engine is made to run as dual fuel engine by adding an additional injection system for ethanol. The injection of ethanol was controlled electronically through the injector fitted to intake manifold.

CHAPTER 2

LITERATURE SURVEY

Excessive use of petroleum fuels and coal lead to many ecological glitches including reduction in natural carbon based underground energy sources. This also leads to sinking of ground surface and changes in earth's surface layer after extraction of petroleum products and minerals etc. Due to these fossil fuels, the CO_2 level has increased from 280 PPM before industrial era to 350 PPM now and is still increasing to higher level resulting in greenhouse effect, acid rains and climate change throughout the world. Climate change leading to severe winters and summer are being sensed in day to day life as environmental implications. Foggy weather during winter months in several part of the world is also the result of these pollutants from fossil fuels. The vehicle travel and resulting petroleum fuel demand in next 30 years will be almost triple as per the projection [17-18] and may result in severe environment problems due to emissions. In spite of the severe emission norms, the demand of energy in most of the sector, particularly in automotive sector is the main reasons of increased pollution levels. The number of vehicles globally is 10 times more than the number that was in 1950. As per survey, it is around one billion throughout the world which brings a real concern to look into an alternate clean fuel to have sustainable development.

Ethanol has been considered an important alternative fuel for the engines for a long period of time, as it solves a number of problems that occurs with crude oil based fuels, such as emission of greenhouse gases and particulates.

Various methods of using ethanol as a fuel in compression ignition engines have been reported. Eugene Ecklund et al [18] sequenced the methods of using alcohol fuel in diesel engines (as per increasing substitution of diesel fuel by ethanol) as blends, emulsions, fumigation and dual fuel injection.

2.1 BLENDS

The reduction of emissions from engines has become a major factor in the development of new engines to meet the requirements specified by EPA. As a result, the use of alternative fuels as a means of meeting these requirements has generated much attention. Today, the economics are much more favorable in the production of ethanol and it is able to compete fairly well with standard diesel. Hence, there has been keen interest in the ethanol-diesel blends with particular emphasis on emissions reductions. In comparison of pure diesel, use of diesel – ethanol blends lead to an increase in HC and CO emissions but a decrease in NOx emissions [19]. Also, emission of alcohol – diesel blends is more of aldehydes than polycyclic aromatic hydrocarbons (PAH). Engine modification is not needed for low percentages of ethanol in diesel as ethanol and methanol have very limited solubility in diesel.

Czerwinski [20] used 30% ethanol blend in a 4-cylinder, heavy duty, direct injection diesel engine and found the blend causing longer ignition delay and lower combustion temperature. The emissions varied with loads; at higher loads and speeds less emission were observed but at lower loads and speeds, increase in CO and HC levels was observed. At full load all emissions were lower. The emission trends were at par with diesel with reduction in power up to 12.5%.

Ozer Can et al [21] investigated the effects of ethanol addition to diesel on the performance and emissions of a four stroke turbocharged indirect injection diesel engine with different fuel injection pressures at full load. They found that the ethanol addition reduces Carbon monoxide (CO), soot and Sulfur Dioxide (SO_2) emissions, but increases NOx emissions. They also found that increase in injection pressure reduces the CO and smoke emissions with some reduction in power. Andrzej Kowalewicz [22] reported that the injection of ethanol with diesel fuel as well as with rape oil methyl ester into the inlet port reduces CO_2, NOx, CO emissions and smoke at higher loads.

Jincheng Huang et al [23] studied the performance and emissions of a diesel engine using ethanol-diesel blends. They found that the thermal efficiency of the engine fuelled with blends is comparable to that fuelled with diesel, but with slight increase in fuel consumption. They also observed a decrease in smoke emissions and CO emissions but an increase in HC emissions above half load as compared to pure diesel fuel.

Some typical observations from the engine tests suggested that biodiesel blends generally improve the thermal efficiency of the engine, increase the cooling losses and exhaust gas temperature and reduce smoke opacity. Possible reason may be additional lubricity properties of the biodiesel; hence reduced frictional losses. The energy thus saved further increases thermal efficiency, cooling losses and exhaust losses from the engine. The thermal efficiency starts reducing after a certain concentration of biodiesel [12-13].

2.2 EMULSIFICATION

The solubility of ethanol in diesel is affected by temperature and water content of the blend. Moses et al. [24] investigated micro emulsions of aqueous ethanol and diesel using a commercial surfactant. Ethanol has an octane number of more than 100, while it has a cetane number of 6. A blend of 20 percent ethanol and 80 percent diesel fuel has a cetane number of 40 which is the minimum requirement as per ASTM. The calorific value of ethanol-diesel blends decreases with increasing percentage of ethanol in the blends. Irshad Ahmed [25] observed that ethanol diesel formulations for 10 and 15 percent ethanol reduce overall emissions of diesel engines.

2.3 FUMIGATION

Fumigation is a process of introducing ethanol in diesel engines using a constant volume carburetor in the inlet manifold and injecting the diesel in the cylinder through conventional injection system. A fraction of the energy is supplied by inducting ethanol through a carburetor and the rest of the energy is supplied by diesel injected through the conventional fuel injection system. Injected diesel fuel serves as an ignition source like millions of spark plugs [26].

An additional advantage of fumigation on mixing is that it is possible to alter the amount of alcohol injected to match the actual requirement. Also, because the alcohol is not premixed, an emulsifier is not necessary to ensure proper mixing Zhang et al [27]. Experiments suggest that fumigated engine exhibits better performance with substantial saving of the diesel, lower NOx, CO, CO_2 emissions and lower exhaust temperature with reasonable amount of unburned HC at part load and no load [28].

Hayes et. al. [29] studied 100%, 125%, 150%, 175% and 200% proof ethanol as fumigants by directly inducting into the intake port of a 6-cylinder turbocharged diesel engine at 2400 rpm. They found that the lower proofs reduce the maximum rate of pressure rise. Lower proofs of fumigated ethanol exhibit lower NO_x level than that with pure diesel at low loads. HC emissions increase with increase in ethanol content during fumigation irrespective of proof of samples. Brake thermal efficiency was lower as compared to pure diesel. Lower proofs of ethanol are found to be the feasible alternate fuel for diesel engine. Fumigating ethanol and methanol in amounts up to 55% of the total fuel energy results an increase in ignition delay, CO emission and a decrease in NOx and thermal efficiency at high loads [30]. Test results with ethanol fumigation to indirect injection diesel engine also leads to decrease in brake specific fuel consumption, NOx concentration and particulate emission with modest gain in thermal efficiency [31].

K. R. Houser et al [32] conducted tests on an Oldsmobile 5.7l V-8 Diesel engine. Fumigation with methanol in amounts up to 40% of fuel energy results in decreased NOx emissions and positive effect on fuel efficiency at high loads.

Tests were conducted by Rodica A. Baranescu [33] in a turbocharged single cylinder DI Diesel engine fumigated with methanol, ethanol and aqueous ethanol to address the impact of alcohol fumigation on rate of pressure rise, peak cylinder pressure, specific energy consumption and gaseous emissions of CO, HC and NOx. They found a decrease in peak pressure and increase in specific fuel consumption with reduction in CO, HC and NOx. Fumigation of alcohol with diesel significantly reduces smoke and inlet manifold temperature without affecting the brake thermal efficiency and HC emissions [34]. Studies suggest that fumigation has the potential as an emission control technique to reduce NOx in diesel engines [35].

Experimental studies conducted on a turbocharged diesel engine fumigated with ethanol by changing the diesel injection timing indicates that advancing the injection timing helps in decreasing CO and HC levels in the exhaust. The usual expected increase in NO_x levels due to advances in injection timing with pure diesel is compensated with the decrease in NO_x due to ethanol addition [36].

Comparative studies on the performance of DI engine by Zhang et al. [27] reveal an increase in brake specific CO emission with increase in engine loads as well as with increase in level of fumigated methanol when compared to pure diesel fuel. BSCO emissions increase five times for 30% methanol fumigation at 0.13 MPa however, emissions decrease with increasing pressure.

2.4 DUAL FUEL INJECTION

Lots of literature is available pertaining to conversion of existing engines to dual fuel operation as the use of ethanol as diesel engine fuel causes problems of rapid wear or jamming of the plunger due to physical and chemical properties of ethanol. The article [37] provides an overview of designing and developing an innovative additional fuel supply system.

A typical investigation includes a simple conversion of a diesel engine to dual fuel operation with the aid of port injectors or a gas mixer. The engine is operated and the effect of a few, easily controlled parameters, typically pilot amount, pilot timing, intake temperature, load and speed with respect to emissions and efficiency are investigated [37-43]. It is shown that such applications represent in principle a very attractive mode for the utilization of the fuel for power outputs at relatively high efficiencies with good exhaust emissions characteristics.

Workman et al. [44] studied the performance and emission characteristics of ethanol–diesel dual fuel CI engine. They found that addition of ethanol as a diesel fuel supplement increases the thermal efficiency due to enhancement in volumetric efficiency with more air utilization, increase in ignition delay and increase in rate of pressure rise with low peak pressure. This is attributed to the decrease in temperature of ethanol air mixture with increasing ethanol content.

Mustafi and Raine [45] investigated the exhaust emission characteristics of a direct injection (DI) diesel engine operated with natural gas–diesel and biogas–diesel in dual-fuel mode. The study shows that stable engine operation is possible with natural gas (NG) and biogas without any modifications to the engine. Also the PM (about 70% by mass) and NOx emissions (maximum of 37% by mass) in dual-fueling are much smaller than those of pure diesel fueling operating under the same conditions.

Investigation on compressed natural gas (CNG) as secondary fuel reveals substantial reduction in the noise level, specific fuel consumption and NOx emission with increase in UHC after 75% substitution of diesel by CNG [46].

Sayin et al. [47] investigated the influence of the CNG/diesel ratio, the advance of the pilot injection for diesel fuel and the intake temperature of fuel mixture on the combustion process, emissions, and engine performance of a dual-fueled engine. The results show that the CNG ratio, pilot injection timing and intake temperature play important roles in the formation of pollutant emissions and performance of an engine. Reduced smoke emissions and carbon monoxide (CO) were achieved with the optimized CNG injection timings. The use of CNG manifold injection in the modified CI engine improves the performance and reduces the exhaust emissions from the engine except for HC and NOx emissions. Andrzej K et al [48] compared the engine performance for dual fuel mode with ethanol as secondary fuel and standard single fuel mode with pure diesel. They found that performance of dual fuel engine is better than single fuel engine as in dual fuel mode it is more efficient and ecofriendly due to improved combustion process.

Chauhan B. S. [28] used a constant volume carburetor to introduce ethanol in a small capacity diesel engine to study its effect on performance and emissions. They found that with optimum ethanol content of 15%, diesel engine exhibits better engine performance with lower NOx, CO, CO_2 and exhaust gas temperature than that with pure diesel.

Abu-Qadais M. [49] experimented on both blend and injection of ethanol in the intake manifold and reported that there is more improvement in performance and emission with fumigation as compared to blend. The optimum percentage of ethanol injection was found to be 20% with an increase of 7.5% in brake thermal efficiency, 55% in CO emissions, 36% in HC emissions and reduction of 51% in soot mass concentration as compared to 3.6% in brake thermal efficiency, 43.3% CO, 34% HC and a reduction of 32% in soot mass concentration in 20% of ethanol as a blend in diesel fuel. The result clarifies that blending is a better option than injection to reduce emissions while injection is better than blending for engine performance.

While these publications served to confirm the general trends for DFDI operation, they commonly lack depth and do not advance the understanding of the combustion process. The results in these studies are also quite specific to the engine setup used and may for these reasons appear contradictory if this fact is not taken into account. These publications all have in common that the models are validated against small data sets and no conclusions can be made regarding the validity over a wider range of conditions. Some of the models are validated for irrelevant operating conditions. Based on the available literature, it appears that dual fuel combustion is not sufficiently studied and needs in depth study for understanding.

2.5 EMISSIONS FROM DUAL FUEL INJECTION

The pollutants contribute towards several regional and global environmental effects. Regional environmental effects such as summer smog are because of aldehydes, carbon monoxides, nitrogen oxides etc. Winter smog is because of particulate. Acidification is caused by nitrogen oxides, sulfuric oxides etc. Several global effects like ozone layer depletion, global warming etc. are caused by CO_2, CO, methane, non-methane hydrocarbons, nitrogen oxides etc. [50-51].

Surawski et al. [52] conducted experiment at 1700 RPM with different engine load of 20% (idle), 50% and 100% using ethanol fumigation of 0%, 10%, 20%

and 30% and reported that CO emission increases at all loads except idle mode. With 10% ethanol 15% reduction of CO was achieved at idle mode. At higher ethanol fumigation rate of 30% CO emission increased significantly at all loads. They observed that CO emission increases significantly with increasing level of methanol fumigation. Cheng et al. [53] also reported the increase in CO emission using 10% fumigation of methanol with biodiesel. They found increase in average CO emission from 6.14g/kWh with ultra-low sulfur diesel fuel to 12.72g/kWh for 10% fumigation of methanol with biodiesel.

Chauhan et al. [28] reported the CO emission characteristics for ethanol fumigation at five different loading conditions of 0%, 20%, 45%, 70% and 100% of full load with various percentages of ethanol fumigation. Their results were contradictory to other researchers. They observed that at all loading conditions except no load, CO emission decreases up to certain level of fumigation initially, and then increases with increasing level of fumigation. They found that $BSCO_2$ decreases at all load conditions. At low to medium engine load, the average reduction has been found up to 4.3% for all percentage of fumigation whereas the average reduction has been found up to 7.2% at high engine load with 30% fumigation methanol.

Ajav et al. [54] investigated on a modified CI engine for engine emissions using ethanol as a supplementary fuel. Results showed that NOx emission increases 0.4% with unheated ethanol vaporization and decreases by 0.7% with ethanol preheating when compared with diesel fuel. The better results with ethanol heating were attributed to the displacement of more diesels in preheating condition.

Cheng et al. [53] also reported 6.2% to 8.2% decrease in NOx emission using canola biodiesel with 10% fumigation of ethanol when compared with ultra-low sulfur diesel fuel with increasing engine load. Zhang et al. [27] also analyzed the effect of ethanol fumigation on NOx emission. They observed that ethanol fumigation increases the NOx emission in comparison to methanol fumigation. Since ethanol has lower latent heat of vaporization than methanol, there is an increase in combustion temperature which increases NOx emission. Chauhan et al. [28] experimentally investigated the NOx emission for ethanol fumigation. They observed that at all load conditions, NOx decreases up to a certain level of fumigation then increases. At 20% load, NOx emission was minimum with 22% fumigation of ethanol but at 45% load, NOx emission was minimum with 20% of ethanol substitution. At 70% load and at full load, NOx emission decreased up to 16% ethanol fumigation and then starts increasing.

Most of the authors also reported an increase in HC emission like CO emission. Zhang et al. [27] tested four cylinder inline DI engine at 1920 rpm with five steady conditions. They revealed that HC emission increases with increase in methanol fumigation as compared to pure diesel. Moreover, the increasing engine load decreases HC emission whereas it increases with increasing level of fumigation. Their report revealed that HC emission increases from 5.4g/kWh with pure diesel to 52g/kWh for 30% methanol fumigation at engine load of 0.13MPa while it varies from 0.8g/kWh with pure diesel to 2.4g/kWh for 30% methanol fumigation at 0.63MPa. Abu-Qudais et al. [49] conducted the experiment on a single cylinder DI diesel engine at various engine speeds to analyze the effect of ethanol fumigation and ethanol-diesel blends on HC emissions. Their results showed that ethanol addition to diesel fuel, increases HC emission with increasing engine speed in both the methods. However, increase of HC in fumigation method is less than blending method.

The increase of HC emission due to ethanol fumigation was also reported by Tsang et al. [55]. They found an increase of about 1.6 and 3.3 times in BSHC with 10% and 20% fumigation respectively at engine load of 0.08MPa when compared to Euro V diesel fuel while the corresponding increase at 0.70MPa is 1.1 and 2.4 times to that of diesel fuel. Cheng et al. [56] also observed increase in HC emission due to use of 10%, 20% and 30% of methanol fumigation as compared to diesel fuel. They found that HC emission increases with level of methanol fumigation but decreases with increasing engine loads. They found maximum increase of 600% in HC emission with fumigation and maximum reduction of 200% in HC emission with increasing load. Zhang et al. [27] also investigated the BSHC emission characteristics with ethanol and methanol fumigation under similar operating conditions. They observed an increase in HC emission with alcohol fumigation however, increase with methanol fumigation was more as compared to ethanol fumigation since ethanol has lower latent heat of vaporization than methanol. HC emission increases from 8.9 g/Kwh with pure diesel to 39.5 g/kWh and 37.8 g/kWh respectively for 20% fumigation of methanol and ethanol, at 0.08MPa. They observed drastic reduction in relative increase of HC emission with increasing load as HC emission were 1.4 g/kWh and 1.3 g/kWh respectively for 20% fumigation of methanol and ethanol at a higher load of 0.7 MPa.

Majority of the authors reported a decrease in smoke opacity with substitution of diesel by alcohol. Zhang et al. [27] experimentally investigated the effect of alcohol fumigation in four cylinders inline DI engine using 10%, 20% and 30% fumigation of methanol with diesel fuel at a speed of 1920 rpm under five steady conditions. For all fumigation ratios, PM emission decreases as compared to diesel fuel. They observed that reduction was more significant at medium load with all percentage of fumigation. About 14–31% reduction was measured with 10% fumigation of methanol whereas reduction was about 27–57% with 30% fumigation of methanol. Abu-Qudais et al. [49] experimented on fumigation of ethanol with diesel and compared its effect on PM emission with ethanol–diesel blend as fuels. They reported that smoke opacity and soot mass concentration decreases with increasing engine speed. They measured maximum respective decrease of 48% and 51% in smoke opacity and soot mass concentration for 20% ethanol fumigation whereas for ethanol–diesel blend, the maximum reduction was measured as 33.3% and 32.5% respectively for smoke opacity and soot mass concentration with 15% ethanol blend. Tsang et al. [55] found that alcohol fumigation helps in reducing the PM emission where reduction varies from 15% to 32% with methanol fumigation of 10% to 30%. Chauhan et al. [28] reported that smoke opacity increases with increasing engine loads and decreases with increasing ethanol fumigation. At higher load of 70% and 100%, smoke opacity decreases very quickly up to 14% ethanol fumigation and afterwards reduction is not very significant. It may be due to increase in oxygen content at higher level of fumigation causing better combustion leading to lower opacity.

2.6 POLANGA BIODIESEL

Biodiesel is nearly free from sulfur hence reduction in sulfate emissions and particulate matter is reported in the exhaust of the engine. Due to absence of sulfur, using biodiesel as fuel helps in reducing the problem of acid rain. The lack of aromatic hydrocarbon (benzene, toluene etc.) in biodiesel reduces unregulated emissions like ketone, benzene etc. as well [13].

Polanga biodiesel which is made from a low cost nonedible polanga vegetable oil is an alternate fuel consisting of alkyl monoesters. The biodiesel is produced by Trans-esterification process.

2.6.1 Polanga Oil

Polanga oil, Calophyllum Inophyllum L., falls in a group of coastal family and now-a-days planted throughout the tropics. Its origin is uncertain but believed to be indigenous to India, Malaysia, Indonesia and the Philippines [12]. It grows in humid tropics with 1000-5000 mm annual rain fall at altitude up to 200m. It grows on sandy beaches and on a river margins. It is tolerant of wind and salt which makes it suitable for dune stabilization. It is a medium sized tree, 25-35m tall with diameter up to 150cm. The tree flowers throughout the year in Indian condition. Its fruit is little toxic.

2.6.2 Characteristics of Polanga Oil

2.6.2.1 Chemical composition

Polanga oil is a triglyceride of various fatty acids consisting of approximately 12% Palmitic acid, 38.26% Linoleic acid, 34% Oleic acid, and 12.95% stearic acid [12]. The very high viscosity of Polanga oil is to be addressed while making the biodiesel.

It has very high proportion of saturated fatty acids. The main reason of high FFA is high Oleic (HO), Linoleic and Linolenic acids. The composition of Polanga oil along with other common non-edible oil is given in the Table-2.1.

Table 2.1: Constitutional chemical composition and Acid value of Polanga and other oils

Product	Fatty acid by weight (%)					Acid Value (mgKOH/gm)	Reference
	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid		
Polanga	12.01	12.95	34.09	38.26	0.3	40-44	Sahoo, 2007 [12]
Jatropha	16.9	6.5	43.5	34.4	0.80	3.8	Sahoo, 2007 [12]
Karanja	11.65	7.5	51.59	16.49	2.65	5.06	Sahoo, 2007 [12]
Rapeseed	3.49	0.85	64.40	22.30	8.23	4.34	Goering, 1982 [57]
Tallow	3-6	20-25	37.43	2-3	-	47-43	Canakci, 2001 [8]

2.6.2.2 Physical properties

Polanga oil is a viscous, non–drying, and odorless oil. The refined one is initially dark green in color and unpleasant in taste. Later in processed state it becomes clear. It has very high viscosity and is soluble in alcohol. High cetane number and high calorific value is an advantage of being used as feed stock to biodiesel production. The main disadvantage is the high viscosity which may cause problem in extraction and injection. Another problem is the water content of the oil which may cause filtration and corrosion problems. It has high flash point of 221^0C, far higher than the diesel fuel indicating that it is not inflammable but combustible. The cloud point and pour point are higher than that of the diesel fuel. The remaining proprieties are fairly close to diesel fuel. The different physical properties in comparison with other are given in Table 2.2 [58].

Table 2.2: Physical properties of Polanga oil along with other non-edible oils.

Product	Kinematic viscosity (mm^2/sec)	Heating Value (MJ/ kg)	Flash point (°C)	Density (kg/l)
Polanga	27.40	39.5	221	0.941
Jatropha	52.76	38.2	210	0.933
Karanja	27.84	34.0	205	0.912
Rapeseed	37.00	39.7	246	0.912
Tallow	39.6	37.5	271	0.946

2.7 ETHANOL AS SECONDARY FUEL

Alcohols such as Ethanol and Methanol are considered as substitute fuel for CI engines [59, 60]. Following are the features of alcohols which support complete combustion to make them feasible as substitute fuel.

1. It is easier to inject alcohol as compared to diesel as alcohol has low viscosity than diesel hence better atomization and mixing with air.
2. Higher oxygen atoms, A/F ratio, hydrogen-carbon ratio and low sulfur content of ethanol results in lesser emissions than diesel.
3. Cooling effect during intake and compression stroke due to higher heat of vaporization of alcohol results in increase of volumetric efficiency and reduction in work input during compression stroke.
4. Alcohol has high laminar flame propagation speed, which results in fast combustion process. This improves engine thermal efficiency [61, 62].

Alcohol fuels such as ethanol and methanol have the same physical properties as that of petroleum fuels.

2.8 CONCLUSION FROM LITERATURE SURVEY

- Blending and emulsification both have limited scope due to phase separation problem.
- Fumigation using carburetor may lead to improper control of ethanol quantity because carburetor works on the principle of venturi effect which induces a pressure difference due to air movement.
- The literature confirms that diesel engines can also be operated in dual fuel mode without requiring much modification in the existing engine. Though smooth operation of dual fuel direct injection (DFDI) with satisfactory performance is confirmed by few researchers, in depth and advance understanding of emission and combustion processes requires thorough investigation.
- Like normal diesel and SI engines, dual fuel injection is not an established technology. Hence, all the challenges and limitations are not yet identified.
- There is a huge potential in duel fuelling using alternate secondary fuel as it will reduce the burden of energy demand to be met by petro-diesel.

2.9 OBJECTIVES

1. Production and physical characterization of Polanga oil based biodiesel and to evaluate its compatibility with alcohol for use as primary fuel.
2. Development of an auxiliary fuel supply system to inject controlled quantity of alcohol in dual fuel direct injection diesel engine.
3. Evaluation of performance and emission characteristics of DI diesel engine fueled with pure diesel and pure biodiesel in single fuel mode and diesel + Ethanol & biodiesel + ethanol in dual fuel mode.
4. Comparison of performance and emission characteristics between pure diesel & diesel + ethanol, biodiesel and biodiesel + ethanol and finlly between diesel & ethanol and Polanga biodiesel & ethanol.
5. Optimization of fuel ratio (biodiesel and ethanol) for maximum power and minimum emissions.

CHAPTER 3

EXPERIMENTAL WORK

3.1 EXPERIMENTAL SETUP FOR BIODIESEL PRODUCTION AND MEASURING DEVICES

3.1.1 Biodiesel Reactor

The setup used in present study is shown in Fig. 3.1. It has a reactor with controlled heating, controlled stirring and cooling facility. It also has a water cooled condenser to send back the vaporized methanol to the reaction mixture. The same reactor was used for both pretreatment and transesterification process. The capacity of the reactor was 1 liter per day.

Figure 3.1: Biodiesel Reactor

3.1.2 Measurement of Viscosity of Biodiesel

Apparatus and working Principle

The kinematic viscosity of the test fuels was determined with the help of digital rotary viscometer which follows ISO 2555 and ASTM 1084. The setup used is shown in Fig. 3.2. The resistance offered by the fuel to the rotor due to viscosity is used for measuring the kinematic viscosity. The kinematic viscosity is displayed on the screen.

Figure 3.2: Viscometer

The procedure includes following steps to measure viscosity.

1. 20 ml of oil sample was taken and maintained at 40^0 C by using water bath.
2. Then probe was put in the oil and rotated at different RPM ranging from 20 to 160 depending on the viscosity.

3. The speed and the density were entered as input and viscosity of the oil was determined and displayed on the screen.

Initially, the diesel fuel was put into the chamber and the viscosity was found. Similar process was used to find the viscosity of biodiesel at same temperature. Six samples of each fuel i.e. diesel and biodiesel were taken and average value is reported in the results.

3.1.3 Measurement of Calorific Value

Apparatus and working Principle

A bomb calorimeter (Make Rajdhani Scientific Instruments, Model BSB5) is used to measure the calorific value. The amount of heat generated is measured by burning a known amount of fuel in a sealed chamber in an atmosphere of pure oxygen gas and is converted into calorific value. It is a simple inexpensive yet accurate method for determination of heat of combustion, i.e. calorific value.

Essentially the apparatus consists of following part Bomb, Water jacket, offset stirrer, Calorimeter vessel, bomb firing unit, vibrator, timer, illuminator with magnifier, pressure gauge on stand, gas release valve, pellet press, crucible, ignition wire as shown in Fig. 3.3. The chemicals generally used for determination of calorific value are benzoic acid, naphthalene, sucrose or cane sugar, standard alkali solution, methyl orange or methyl red indicator. Benzoic acid was used for determining the calorific value in the present study.

A known amount of sample fuel is burnt in a sealed chamber (bomb). The air is replaced by pure oxygen. The sample is ignited electrically. As the sample burns, heat is produced. Since the amount of heat produced by burning the sample must be equal to the amount of heat absorbed by the calorimeter assembly; knowledge of the water equivalent of the calorimeter assembly and of the rise in temperature enables one to calculate the heat of combustion of the sample.

If, W= water equivalent of calorimeter assembly in calories per degree C;

T= Rise in temperature registered by a sensitive thermometer in degree C;

H= heat of combustion of material in calories per gram and

M= Mass of sample burnt in gram.

$$WT=HM$$

H can be calculated easily since W, T and M are known.

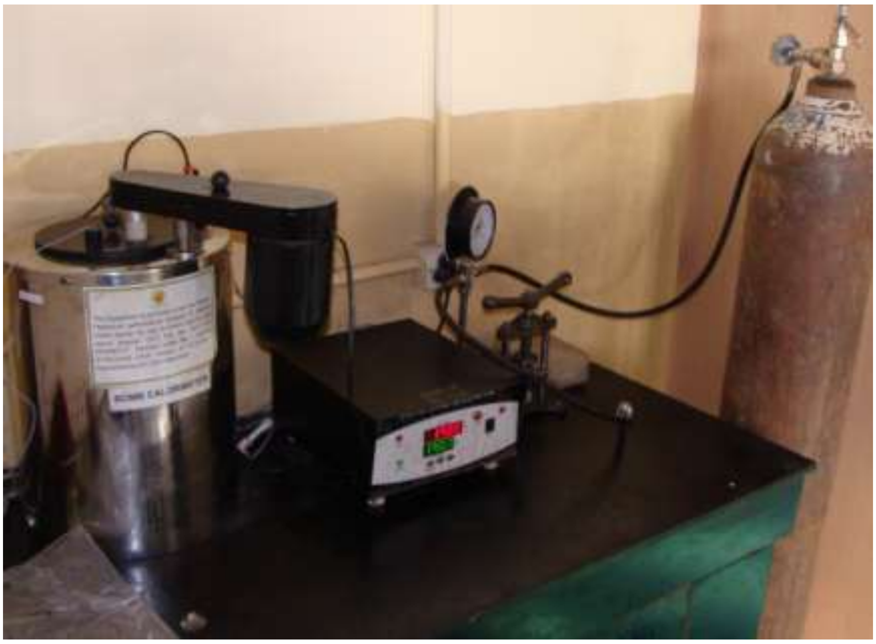


Figure 3.3: Bomb Calorimeter

Procedure

One gram of air dried sample was compressed into a pellet using the pellet press. The pellet was accurately weighed in the stainless steel crucible and the crucible was placed inside the bomb of 300 ml capacity. A piece of the firing wire (Nichrome wire) of known length was stretched across the electrode within the bomb. A known length (15 cm) of cotton thread was tied around the wire. The crucible was placed in position and the loose ends of the thread were arranged so that they are in contact with the material. The same length of thread was used in each determination. 5 ml of distilled water was introduced into the bomb to absorb vapours of sulfuric acid and nitric acid formed during the combustion. The bomb was reassembled avoiding excess pressure. The bomb was charged slowly with oxygen from a cylinder to a pressure of 25 atmospheres without displacing its original air content. The valve was effectively closed at as little pressure as possible and the bomb was detached from the oxygen supply.

Sufficient quantity of water was weighed in the calorimeter vessel which was sufficient to submerge the nut of the bomb to a depth of at least two millimeter leaving the terminals projecting. The same weight of water was used in all the tests. The calorimeter vessel water jacket was transferred and the bomb was lowered carefully into the calorimeter vessel. The bomb was connected to the ignition circuit through a switch for subsequent firing of the charge. The stirrer was adjusted and the thermometer was placed in its position. The stirring mechanism was started which was kept in continuous operation at a constant speed of 450 rpm during the experiment. After an interval of not less than ten minutes, the temperature was read to 0.001^0C and continued the readings for five minutes, at equal intervals of not more than one minutes, tapping the thermometer lightly during 10 seconds prior to each reading. Over a period of five minutes, the average deviation of the individual values of the rate of change of temperature was less than 0.00072^0C per minute and the circuit was closed momentarily to fire the charge and continued the observations of the temperature at intervals of similar duration to those of the preliminary period. In the chief period which extended from the instant of firing until the time after which the rate of change of temperature again becomes constant, the earlier readings were taken to the nearest 0.01°C since it would not be possible to take the earlier readings to 0.001°C. The readings were resumed to this precision as soon as possible. The rate of change of temperature was determined in the after period (which follows the chief period by taking readings at 1 minute intervals for at least five but preferably ten minutes). The jacket temperature and the room temperature were kept as close to the calorimeter temperature as possible. The jacket temperature and room temperature were recorded.

The bomb was removed from the calorimeter and after a lapse of about half an hour from the time of firing allowing the acid mist to settle, the pressure was released by opening the valve. It was verified that the combustion had been completed by noting the absence of any sooty deposit within the bomb as the presence of any trace of sooty deposit indicates incomplete combustion and invalidates the test.

The effective heat capacity of the system was determined by burning pure and dry benzoic acid weighing not less than 0.9 and more than 1.1 gram. The corrected temperature rise was determined (T), from the observed test data, and the unburnt fuse wire was measured, the energy equivalent was computed by substituting in the following equation.

$$W = \frac{HM + E_1 + E_2}{T}$$

W = Energy equivalent of calorimeter in calories per degree centigrade;

H = Heat of combustion of standard benzoic acid in calories per gram;

M = Mass of standard benzoic acid sample in grams;

T = Corrected temperature rise in degrees centigrade;

E_1 = Correction for heat of formation of nitric acid in calories; and

E_2 = Correction for heat of combustion of firing wire, in calories

$$CV = \frac{T_1 \times W - E_1 - E_2}{M_1}$$

T_1 = Rise in temperature of sample in °C;

M_1 = Mass of sample in grams.

Calculation of CV for diesel

M = 0.998 gm

H = 6319 cal/gm

E_1 = 21 cal

E_2 = 9.32 cal

T = 2.4°C

$$W = \frac{HM + E_1 + E_2}{T}$$

$$= \frac{6319 \times 0.998 + 21 + 9.32}{2.4}$$

$$= 264.28$$

For CV of diesel

T_1 = 4°C

M_1 = 1gm

$$CV = \frac{T_1 \times W - E_1 - E_2}{M_1}$$

$$= \frac{4 \times 2640.28 - 21 - 9.32}{1}$$

$$= 10530\ cal$$

$$= 10530 \times 4.18 = 44000\ Jule$$

Six samples of each fuel were tested and average value has been reported in the results.

3.1.4 Measurement of Fuel Density

Apparatus and procedure

A density meter was used to determine density as shown in Fig. 3.4. The specifications are given in Table 3.1. This device consists of the control panel with holder, base, a built in Bluetooth channel for data transfer and the measuring chamber with sensor. 200ml of oil was taken as sample in the housing and the temperature of housing was maintained at 40^{o} C.

1. The sensor which is made up of stainless steel was completely immersed in the liquid fuel.
2. The density meter which is based on the measuring of resonant oscillation frequency of mechanical oscillation system records the density.

Six samples were taken and average value has been reported in the result.

Figure 3.4: Density Meter

Table 3.1: Specifications of Density Meter

Sl. No.	Particulars	Specifications
1	Make	Lemis, Instruments DM300
2	Density range	0 to 3 g/cm^3
3	Density accuracy	± 0.0002 g/cm^3
4	Temperature range	0 ^{o}C to 50 ^{o}C (+ 32 ^{o}F to +122 ^{o}F)
5	Temperature accuracy:	± 0.1 ^{o}C
6	Data handling:	back Lighted LCD 4 x 20
7	Ambient temperature range:	10 ^{o}C to 40 ^{o}C
8	Sensor material	stainless steel 316L, Ni-Span C, Hastelloy C22
9	Power supply	110-220V AC

3.2 EXPERIMENTAL PROCEDURE / METHODOLOGY FOR PRODUCTION OF POLANGA BIODIESEL

The polanga oil was first obtained by crushing the Polanga seed in an oil expeller. The oil from Polanga seed was used as feed stock for biodiesel production. The acid value of Polanga oil used in present study was determined by titrimetric method and found to be 40 mg KOH/g. Thus the FFA content in the oil was found to be 20%.

As per the literature, the high content of FFA was not favorable for production of biodiesel through transesterification. The production of biodiesel was carried out in two steps; pretreatment to remove high FFA content from polanga oil and trans-esterification to produce biodiesel. Before trans-esterification, a pretreatment process has been used to reduce the high FFA content of oil to a reasonable level for transesterification. Various parameters which affect the reduction of FFA such as time, molar-ratio, amount of catalyst and alcohol are studied and best strategy has been decided. With this strategy FFA of the Polanga oil was reduced to 2% which was ideal for trans-esterification to produce biodiesel.

A. Pretreatment process

The presence of moisture and organic materials pose difficulty in biodiesel production these were removed by heating the oil for 1 hour at around 70^0C followed by a chemical pretreatment. For alkali based catalysis, the oil should not have more than 1-2 % of FFA. So the aim of pretreatment was to reduce FFA at this level to get satisfactory result.

The pretreatment was carried out with following four variables

1. Catalyst amount
2. Volume of methanol
3. Temperature
4. Time

The catalyst used for the pretreatment was H_2SO_4 in amount ranging 5%, 10%, 15% and 20% of FFA. The amount of methanol was varied from 350 ml to 75 ml. As FFA is found to be 20% i.e. 200 ml for 1-liter oil, the H_2SO_4 taken was varied as 10 ml, 20 ml, 30 ml and 40 ml [12].

Table 3.2 Shows the amount of FFA when quantity of H_2SO_4 is varied keeping methanol volume as 105 ml for a reaction time of 1 hr. at 60 ^{0}C.

Table 3.2: FFA content of oil with increasing Acid Catalyst (H_2SO_4)

H_2SO_4	FFA (mg KOH)	FFA
5%	18 mg KOH	9%
10%	10 mg KOH	5%
15%	6 mg KOH	3%
20%	3.4 mg KOH	1.7%

Figure 3.5: Feed stock in two layers after pretreatment

After 1 hr. reaction the mixture was allowed to settle as shown in Fig. 3.5. The mixture of water and methanol that settled at the bottom was taken out. After separating the mixture, the acid values of oil were recorded and found to reduce with increase in % of H_2SO_4 (acid-catalyst). The target of 2% FFA was achieved with 20% of H_2SO_4.

B. Transesterification

The alkali-based transesterification was conducted after reducing FFA to less than 2% by pretreatment. The reaction was again conducted in the same reactor with different amount of methanol and KOH (alkali catalyst). The amount of methanol was varied from 90 ml to 150 ml per liter of oil and the amount of KOH was varied from 10gm to 16gm per liter of vegetable oil. The maximum yield of 90% biodiesel was obtained with 120 ml of methanol and 12 gm of KOH at 60^0C for a reaction time of 1 hr. as shown in Fig. 3.6.

Figure 3.6: Biodiesel after trans-esterification and washing

3.3 ETHANOL

For the present research work, ethanol with a purity of 99% is used as secondary fuel for dual fuel mode of diesel engine. The comparative Physico-chemical properties of ethanol with diesel fuel are given in Table 3.3.

Table 3.3: Properties of ethanol fuels used in tests compared to diesel.

	Ethanol (C_2H_5OH)	Diesel ($C_{12}H_{26} – C_{14}H_{30}$)
Boiling temperature (^0C)	78.3	170-198
Density (kg/cm^3)	0.811	0.820-0.845
Flash point (^0C)	13	52
Auto ignition temperature (^0C)	425	300-340
Lower Heating Value (MJ/kg)	27	44
Cetane No	5-15	45-50
Octane No	100-115	15-25
Latent heat of vaporization (KJ/kg)	921	620

3.4 EXPERIMENTAL SETUP FOR ENGINE TEST

3.4.1 Engine Test Set Up

The engine as shown in figure 3.7 used for experimentation is a single cylinder, four stroke, direct injection diesel Engine. The specifications of the engine are given in Table 3.4. This DICI diesel engine with online data acquisition system was used for evaluating performance and emission characteristics. An additional injector is attached to the intake manifold to inject secondary fuel in the engine.

Figure 3.7: Engine test setup

Table 3.4: Engine specifications

Sl. No.	Particulars	Specifications
1	Make	Kirloskar AV 1
2	Rated Brake Power (BHP/kW)	5 HP/3.7kW
3	Rated speed (rpm)	1500
4	Number of cylinder	One
5	Compression ratio	16.5:1
6	Cooling System	Water Cooled
7	Cubic Capacity	0.553
8	Bore x Stroke	80 x 110
9	Specific Fuel Consumption	185+5% gm/hp-hr

The schematic representation of the experimental setup is as shown in Fig. 3.8.

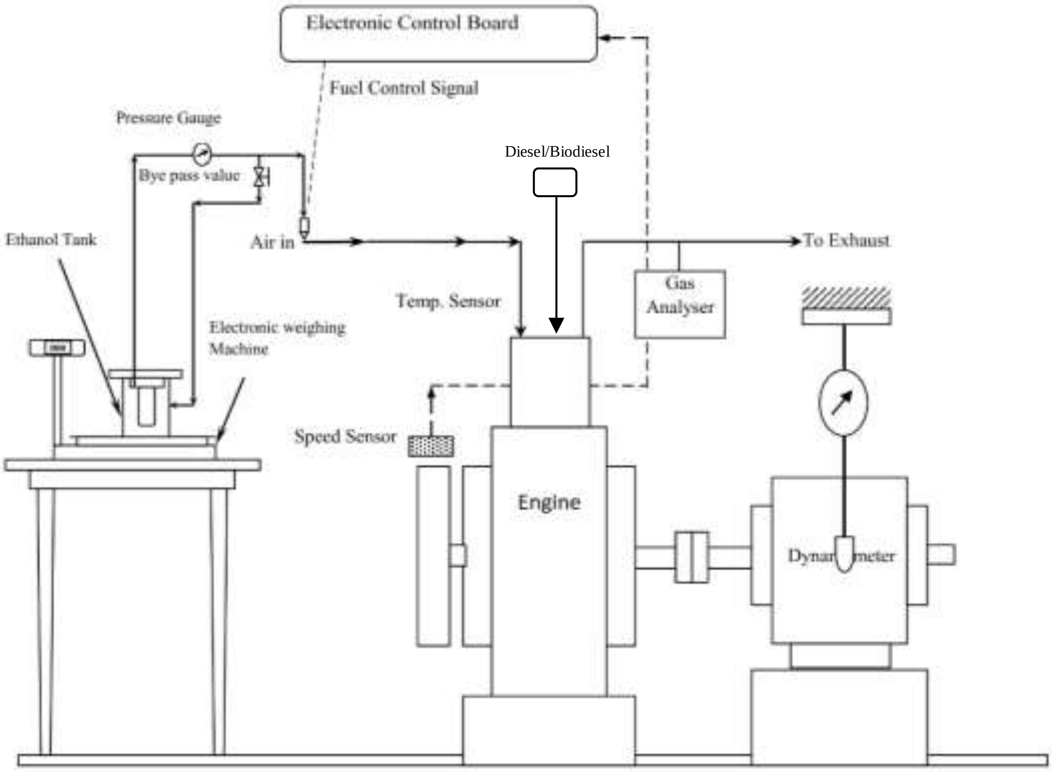


Figure 3.8: Schematic representation of the experimental setup

3.4.2 Dynamometer

The engine setup also has a DC electrical dynamometer as shown in Fig 3.9 to measure its output. The dynamometer is calibrated statistically before use. The engine and air cooled eddy current dynamometer are coupled using a tyre coupling. The output shaft of the eddy current dynamometer is fixed to a strain gauge type load cell for measuring the loads that are applied to the engine.

Figure 3.9: Dynamometer

Load is applied directly by entering a known value in the software of computerized data acquisition system. The dynamometer is reversible i.e. it works as monitoring as well as an absorbing device. Load is controlled by changing the field current. Eddy-Current Dynamometer's theory is based on Eddy-Current (Fleming's right hand law). The eddy-current dynamometer has a notched disc (rotor) which is driven by a prime mover (such as engine, etc.) and magnetic poles (stators) are located around the stator with suitable gap between the two. The coil which excites the magnetic pole is wound along circumferential direction. When current runs through exciting coil, a magnetic flux loop is formed around the exciting coil through stators and the rotor. The rotation of rotor produces magnetic flux density difference and eddy-current then passes through the stator. The electromagnetic force is applied opposite to the direction of rotation by the generation of this eddy-current. The specifications of dynamometer used in present investigation are given in Table 3.5.

Table 3.5: Dynamometer specification

S. No.	Particulars	Specifications
1.	Make	Power Mag
2.	Cooling	Air
3.	Load measurement method	Torque is measured using a load cell transducer. The transducer is a Strain Gauge base. The output of the load cell is connected to the load cell transmitter. The output of the load cell transmitter is connected to the USB port through interface card.
4.	Max Speed	3000 RPM
5.	HP	10 HP
6.	Coupling Type	Direct

3.4.3 Calorimeter

A small shell and tube (gas to liquid) heat exchanger used as a calorimeter for conducting the heat balance is shown in Fig. 3.10.

Temperature of exhaust gas and water at inlet and outlet of calorimeter were measured using K type thermocouples.

Figure 3.10: Calorimeter

3.4.4 Thermocouples

Thermocouples are one type of temperature sensors used to convert thermal potential difference into electric potential difference. For experiment, Type K thermocouples have been used as shown in Fig 3.11. The main limitation is precision otherwise it is cheap, interchangeable and can measure wide range of temperature. A system error of less than 1^0C is difficult to achieve. It is important to note that thermocouple measures the temperature difference between two points, not absolute temperature.

Figure 3.11: Thermocouples

To measure different temperature sensed by respective thermocouples, temperature transmitters are located at the different points in the engine. Thermocouples are calibrated after each set of experiments. Table 3.6 gives the location of different thermocouples.

Table 3.6: Measurement of temperature at different points

S. No.	Particulars	Specifications
1.	Location Type Range Signal conditioning/ transmitter	Water inlet of calorimeter "K" 0 – 300^{0}C Standalone
2.	Location Type Range Signal conditioning/ transmitter	Water outlet of calorimeter "K" 0 – 300^{0}C Standalone
3.	Location Type Range Signal conditioning/ transmitter	Engine exhaust "K" 0 – 1500^{0}C Standalone
4.	Location Type Range Signal conditioning/ transmitter	Calorimeter gas exhaust "K" 0 – 1500^{0}C Standalone
5.	Location Type Range Signal conditioning/ transmitter	Engine cooling water outlet "K" 0 – 300^{0}C Standalone
6.	Location Type Range Signal conditioning/ transmitter	Engine cooling water outlet "K" 0 – 300^{0}C Standalone
7.	Location Type Range Signal conditioning/ transmitter	Ambient temperature "K" 0 – 300^{0}C Standalone

Temperature transmitters are connected to data acquisition system.

3.4.5 Pressure Transducer

The combustion pressure inside the engine is measured using pressure transducer mounted into the engine head as shown Fig 3.12. The pressure transducer has an inline signal conditioner and amplifier. The pressure transmitter contains a piezoelectric sensor of voltage output range from 0-5 V and an integrated charge amplifier. The integrated charge amplifier provides a uniform output and can be connected directly to a data acquisition unit.

Figure 3.12: Pressure Transducer

3.4.6 Fuel Measurement

The fuel consumption is measured as volume flow per unit time (ml / hr). It is measured using optical sensors. The system shown in Fig. 3.13 consists of a burette fitted with two optical sensors one at the high level and the other at low level of the fuel in the burette. As the liquid passes through the high level optical sensor, the sensor gives a signal to the computer to start the time. Once the liquid reaches the low level optical sensor, the sensor gives a signal to the computer to stop the time and refill the burette. The time taken for consumption of fuel for a fixed volume is recorded to calculate the volume flow per unit time.

Figure 3.13: Burette with optical sensors

3.4.7 Speed Measurement

A non-contact PNP sensor as shown in Fig. 3.14 was used to measure the engine RPM. A PNP sensor gives a pulse output for each revolution of the crankshaft. The frequency of the pulses is converted into voltage output and connected to the computer. The range of the sensor used was 0-3000 RPM.

Figure 3.14: Non-contact PNP sensor

3.4.8 Data Acquisition System

Data acquisition collects signals & waveforms and processes them to obtain desired information. Data acquisition system is shown in Fig. 3.15. The computer is integrated with software which reads the signals received form the hardware and converts them into significant numerical information. The engine software, Engine Test Express V5.76 (developed by legion brothers, Bangalore) is a C language based software. Acquired data is displayed, analyzed, and stored in a computer. The specifications of data acquisition system are given in Table 3.7.

Figure 3.15: Data Acquisition System

Table 3.7: Specification of Data Acquisition System

Resolution	12bit
Specification	Operating 45 MHz 12 bit 8 channel ADC 12 bit 2 channel DAC 4 digital input 4 digital output USB controller operating 24 MHz
Software	Windows based
Type	Run Time
Operating System	Windows XP

Windows based real time software is capable of acquiring, processing and exporting data to Microsoft excel. The powerful software presents the key engine performance parameters both in tabulated and graphical from. The performance parameters computed and displayed by the system are listed as follows:

1. Engine speed
2. Engine Fuel flow rate
3. Engine air flow rate
4. Engine Exhaust temperature
5. Engine water inlet temperature
6. Engine water outlet temperature
7. Calorimeter exhaust gas outlet temperature
8. Calorimeter water outlet temperature
9. Engine power
10. Specific fuel consumption
11. Brake thermal efficiency
12. Volumetric efficiency
13. Heat balance
14. Air-fuel ratio

3.4.9 Emission Testing

All emissions like Carbon monoxide, Carbon dioxide, Un-Burnt Hydrocarbons, Nitrogen oxide and unused oxygen were measured in 5 gas emission analyzer model (AVL DIGAS-4000) shown in Fig. 3.16. The measuring method is based on the principle of light absorption in the infrared region, known as "non-dispersive infrared absorption". The broadband infrared radiation produced by the light source passes through a chamber filled with gas, generally methane or carbon dioxide. This gas absorbs radiation of a known wavelength and this absorption is a measure of the concentration of the gas. There is a narrow bandwidth optical filter at the end of the chamber to remove all other wavelengths before it is measured with a pyro-electric detector. The range of measurement of AVL-Gas analyzer for different type of emissions is given in Table 3.8.

Figure 3.16: Exhaust Gas Analyzer

Table 3.8: Measurement Range of AVL-Gas Analyzer for different emissions

Exhaust Gas	Measurement Range	Resolution
NO_x	0 – 4000 Vol. ppm	1 vol. ppm
CO	0 – 10 vol. %	0.01 vol. %
CO_2	0 -20 vol. %	0.1 vol. %
HC	0 – 20,000 ppm	1ppm
O_2	0 – 22 vol %	0.01ol %

3.4.10 Variable Fuel Injection Timing Kit for Ethanol

The Variable Injection Timing (VIT) kit is an attachment to the engine for varying the injection timing. The VIT kit as shown in Fig. 3.17 consists of all components necessary for injection of ethanol at desired rate. The heart of the system is the electronic injection controller (EIC). The various components of VIT are

1. Low pressure System,
2. Electronic Control Unit,
3. Crank angle Encoder and
4. Injector.

Figure 3.17: Variable injection timing kit

3.4.10.1 Low pressure system

The low pressure circuit is used to transport the fuel from the fuel tank to fuel injectors. The low pressure circuit consists of a separate fuel tank for ethanol and pre supply pump as shown in Figs. 3.18 and 3.19 respectively.

Figure 3.18: Fuel tank for ethanol

Figure 3.19: Gear with push/pull design

The pre-supply is an electric driven push/pull type internal gear pump very similar to the roller except with limited pressure sustainability and flow volume. This internal gear turns within a stationary outer gear creating the pulling/pushing of the fuel. This is used in "in-tank" fuel pumps. The pre-supply pump is used to transport the fuel from the fuel tank to the high pressure pump. A nylon filter is provided at the suction of the pre-supply pump to remove dirt and contaminants from the fuel before delivering to the high pressure pump.

3.4.10.2 Electronic Control Unit (ECU)

The electronic control unit as shown in Fig. 3.20 is a pre-programmed micro controller used to send signal for start of injection and to set the duration of injection. The Electronic Control unit is provided with two variable controls:-

1. Start of injection: Electronic Control unit receives the signal from the crankshaft position sensor and detects the engine crank angle. The user can change the start of injection (Advance or retard) by using a graduated potentiometer knob. The potentiometer is connected to the ECU.
2. Injection Duration (Throttle): The injection duration can be controlled by using another graduated potentiometer knob provided on the ECU.

Figure 3.20: Electronic Control Unit

3.4.10.3 Injector

Bosch make injector of series 0280150400 having maximum flow rate of 20 liters / hr was used.

3.5 EXPERIMENTAL PROCEDURE/ METHODOLOGY

3.5.1 Engine Test in Dual Fuel Mode

The engine was modified to work in dual fuel mode by connecting ethanol line to the intake manifold with injector. The engine was fully equipped with necessary accessories for measurement of all operating parameters and emission characteristics. The details of accessories used for measurements are already discussed earlier.

The entire test process was carried out in following steps:

1. The engine was started and allowed to run for 15-20 minutes to attain steady state. Initially, engine was tested at constant speed using pure diesel fuel at different loads to determine the engine operating characteristics and pollutant emissions. The engine speed was maintained at 1500 RPM.

   Loading of engine was done in two steps:

   1. Apply first load and then offload the engine.
   2. Next load is applied after offloading the engine completely.

2. The same procedure was repeated in dual fuel mode with varying the percentage of ethanol through a separate injection system. The percentage of ethanol was varied up to 30% in three different fractions of 10%, 20% and 30%.
3. In this step the diesel oil from the engine cylinder and engine tank has been completely drained out. The filters were cleaned and fresh biodiesel was filled in the tank. The engine was run for sufficient time i.e. about 15 min to ensure that the diesel phase is over and again was allowed to run for another 15-20 minutes to attain steady state.
4. All the engine operating characteristics and emission parameters are recorded at different loads by keeping the speed constant at 1500 rpm.
5. The injection timing of the primary fuel was maintained at 23° BTDC for both single and dual-fuel modes.

6. In the last step, the engine was run in dual fuel mode with varying quantity of ethanol. The percentages of ethanol taken were varied in three steps of 10%, 20%, and 30%.

The ignition delay i.e. the period between the start of fuel injection and the start of combustion, was identified as the point at which 10% of the accumulated rate of heat release rise deviates sharply after the injection of the pilot fuel and then evaluated accordingly by the software. As per the definition, the end of combustion was taken as the crank angle of 90% of the accumulated heat release. The combustion duration is defined as the angle interval between 10% and 90% of the accumulated heat release in this study.

Before each experiment, the engine was regulated according to the catalogue values. All the data were collected after stabilizing the engine.

Each test was carried out three times and average value has been reported.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter the observations made during the experimental work, both to find the properties of biodiesel fuel produced as well as experiments on the engine to study the performance and emission characteristics are discussed. The fuel properties were determined using the calibrated instruments. The engine performance like peak pressure, heat release and Brake Thermal Efficiency and emission characteristics were evaluated on the basis of the experiments conducted on existing engine taking diesel, biodiesel in single fuel mode and ethanol as secondary fuel separately with diesel and biodiesel in dual fuel mode. After the analysis of results and support from the literatures available, the mechanisms and key factors responsible for observed trends were identified. Finally, the results obtained from the modified engine are compared with the results obtained from unmodified engine.

4.1 CHARACTERISTICS OF POLANGA BIODIESEL

The characteristics of Polanga biodiesel produced are listed and compared with other biodiesels as given in Table 4.1. Polanga biodiesel has low heating value, (10% lower than diesel) on weight basis because of the presence of substantial amount of oxygen in the fuel but at the same time biodiesel has a higher specific gravity (0.88) as compared to mineral diesel (0.85) so overall impact is approximately 5% lower energy content per unit volume than diesel.

Table 4.1: Properties of Polanga oil methyl ester along with other biodiesel and Petro- Diesel.

Biodiesel	Density (kg/l)	Calorific value (MJ/kg)	Viscosity (cSt)	Flash point (^{0}C)	Cloud point (^{0}C)	Pour point (^{0}C)
Polanga	0.872	40.8	4.1	129	12.9	3.9
Jatropha	0.873	42.67	4.23	148	10.2	4.8
Karanja	0.883	42.13	4.37	163	14.6	5.1
Rapeseed	0.882	41.55	4.2	80	13.2	3.8
Diesel	0.823	44.00	3.21	75	6.3	-3.3

The characteristics of biodiesel are close to mineral diesel, and, therefore, biodiesel becomes a strong candidate to replace the mineral diesel, if the need arises. The conversion of triglycerides into methyl or ethyl esters through the transesterification process reduces the molecular weight up to one-third to that of the triglycerides, the viscosity by a factor of about eight and increases the volatility marginally. Biodiesel has viscosity close to mineral diesel. These vegetable oil esters contain 10–11% oxygen by weight, which may encourage more combustion than that of hydrocarbon-based diesel in an engine. The cetane number of biodiesel is around 50 in comparison to 45 of diesel. Biodiesel has lower volumetric heating values (about 10%) than mineral diesel but has a high cetane number and flash point. Biodiesel viscosity comes very close to that of mineral diesel, hence no problems in the existing fuel handling system. Flash point of the biodiesel gets lowered after esterification and the cetane number gets improved. Even lower concentrations of biodiesel act as cetane number improver for biodiesel blend. Calorific value of biodiesel is also found to be very close to mineral diesel. Flash point, density, pour point, cetane number, calorific value of biodiesel comes in very close range to that of mineral diesel

[61–62]. The esters have cloud point and pour points higher than those of mineral diesel.

4.2 ENGINE PERFORMANCE AND EMISSIONS

4.2.1 Rate of Heat Release

The rate of heat release (ROHR) for the single-fuel mode and dual-fuel mode fueled with pure diesel, pure biodiesel, diesel with ethanol and biodiesel with ethanol had been studied.

4.2.1.1 Rate of heat release in single and dual fuel mode with diesel as primary fuel.

Peak het release rate with corresponding crank angle and ignition delay for different alcohol-diesel fuel combinations at different load conditions are given in Table 4.2 (Appendix Table A1-A3).

Table 4.2: Peak heat release at different loads in single and dual fuel mode with diesel as primary fuel

Fuel	Load (%)	Peak Heat Release (J/deg)	Crank Angle (deg)	Ignition Delay (deg)
Diesel	0	16.04	360	18.44
	50	31.92	357.12	15.69
	100	45.45	355.83	14.88
Diesel + 10% Ethanol	0	13.5	362	20.71
	50	30.38	359.55	17.66
	100	43.14	357.8	16.37
Diesel + 20% Ethanol	0	13.08	363	20.95
	50	29.45	360.22	18.32
	100	42.37	357.58	16.17
Diesel + 30% Ethanol	0	13.39	362	21.17
	50	29.46	357.34	15.9
	100	39.91	358.23	16.38

As observed from the Table 4.2, the peak heat release is decreasing with dilution and increasing with load for all fuel combinations. Ignition delay decreases with increase in load whereas it is increasing with increasing ethanol addition in dual fuel mode.

The heat release rate for diesel with varying percentage of ethanol at different load conditions in dual fuel mode are shown in Figs. 4.1 (a-c).

As shown in Fig. 4.1(a) the peak heat release for diesel with ethanol in dual fuel mode is less than that of diesel in single mode at no load condition.

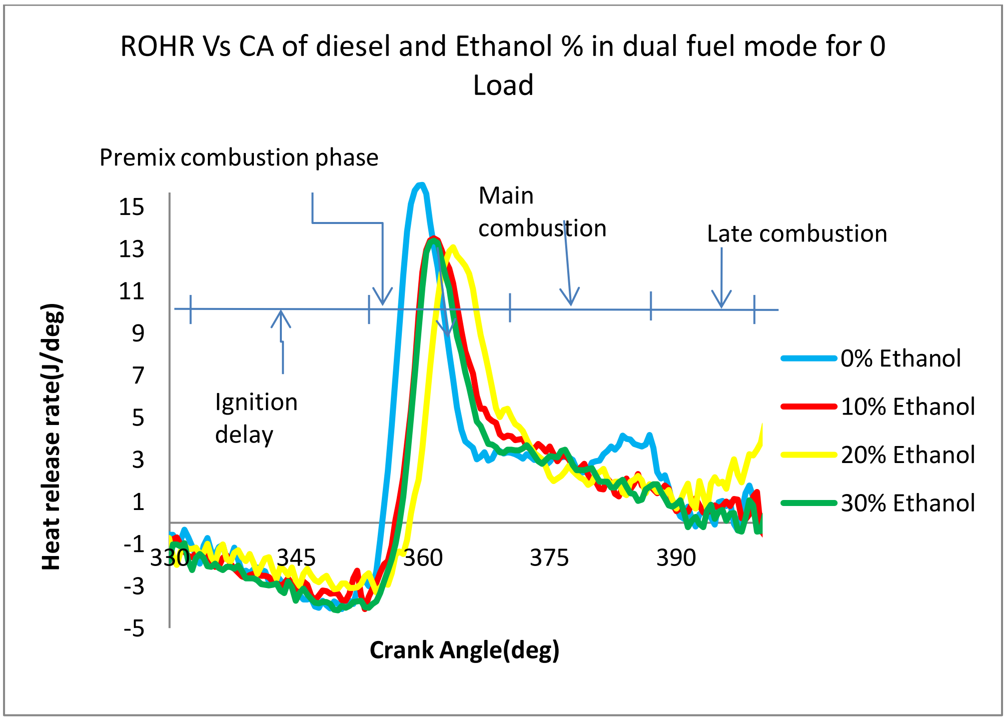


Figure 4.1(a): ROHR vs Crank angle for varying ethanol in dual fuel mode with diesel at no load

At this load condition, peak heat release of 16.04 J/deg is observed for pure diesel at 360° CA whereas the minimum of 13.08 J/deg is recorded with 20% ethanol at 362° CA. In general, a reduction in peak heat release rate is observed with percentage increase in ethanol injection. However, a slight increase in heat release rate is observed at 30% ethanol injection as compared to 20%. The ignition delay increases by 3-4^o with injection of ethanol in dual fuel mode. Increase in heat release during controlled combustion and late combustion in dual fuel mode can also be noticed.

At 50% load as shown in Fig. 4.1(b), the additional injection of ethanol in dual fuel mode with diesel slightly reduces the peak heat release as compared to single fuel mode.

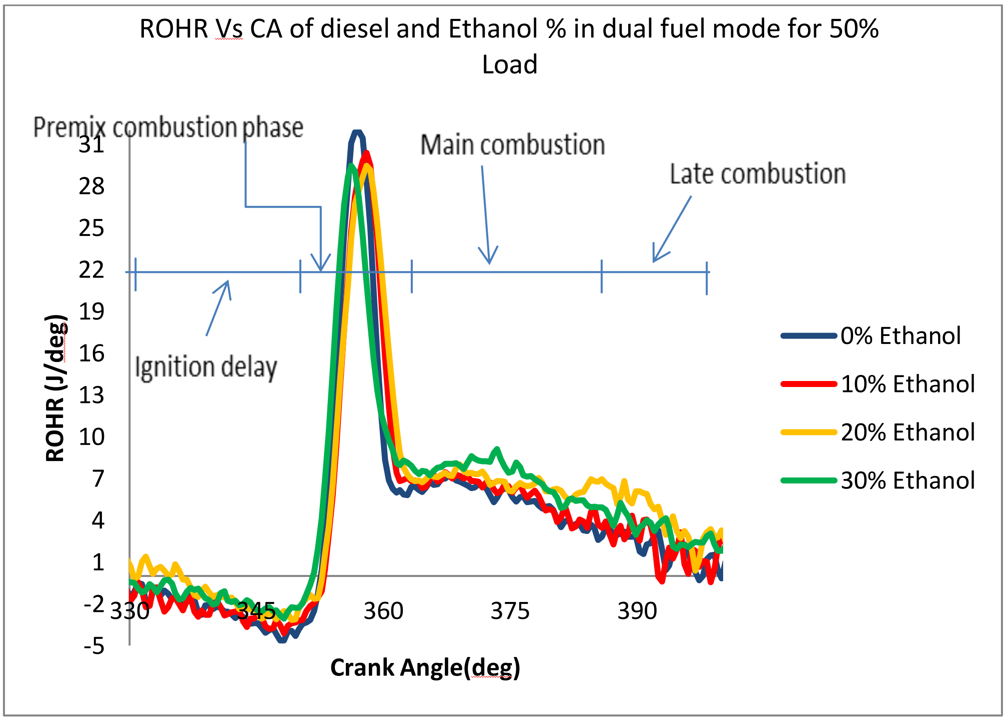


Figure 4.1(b): ROHR vs Crank angle for varying ethanol in dual fuel mode with diesel at half load

Pure diesel produces peak heat release of 32 J/deg at 357.12^o CA and minimum is recorded as 29.46 J/deg at 360^o with 30% ethanol addition. Here it can be noted that the heat release in controlled combustion is high for dual fuel injection. Also, the ignition delay increases with increase in ethanol percentage.

The peak heat release rate for diesel with ethanol in dual fuel mode is slightly less than that of diesel in single mode at full load condition [Fig.4.1(c)].

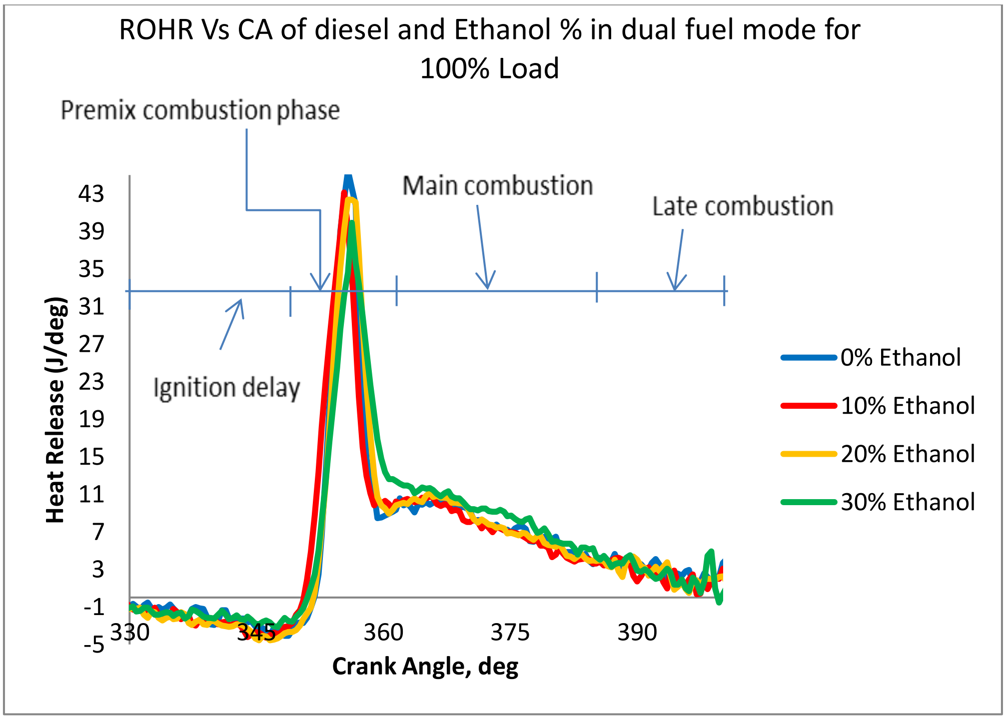


Figure 4.1(c): ROHR vs Crank angle for varying ethanol in dual fuel mode with diesel at full load

The maximum peak heat release of 43.14 J/deg was recorded for pure diesel at 355° CA whereas minimum is recorded as 39.91J/deg at 359° with 30% ethanol injection. Slight increase in ignition delay by 1-2° can be observed with injection of ethanol in dual fuel mode. Increase in heat release during controlled combustion and late combustion in dual fuel mode can also be noticed.

4.2.1.2 Rate of heat release in single and dual fuel mode with biodiesel as primary fuel

Peak heat release rate with corresponding crank angle and ignition delay for different alcohol-biodiesel fuel combinations at different load conditions are given in Table 4.3 (Appendix Table A4-A6).

Table 4.3: Peak heat release at different load in dual fuel mode with biodiesel as primary fuel

Fuel	Load (%)	Peak Heat Release (J/deg)	Crank Angle (deg)	Ignition Delay (deg)
Biodiesel	0	14.16	358.41	17.68
	50	22.04	357.26	15.16
	100	34.28	356.26	14.31
Biodiesel + 10% Ethanol	0	13.66	360.91	19.72
	50	25.53	357.27	16.19
	100	34.1	358.23	15.79
Biodiesel + 20% Ethanol	0	13.16	362.49	20.00
	50	21.56	357.5	16.42
	100	34.80	358.01	15.80
Biodiesel + 30% Ethanol	0	12.68	359.55	18.98
	50	24.11	356.81	15.71
	100	31.91	357.56	15.59

Trend of peak heat release is similar to that of diesel except at 100% load where peak heat release for biodiesel with 10% and 20% ethanol is more than that of pure biodiesel.

The heat release rate for biodiesel with varying percentage of ethanol at different load conditions in single and dual fuel mode are shown in Figs. 4.2 (a-c).

The Peak heat release rate for biodiesel with ethanol in dual fuel mode is less than that of biodiesel in single mode at no load condition as shown in Fig. 4.2 (a).

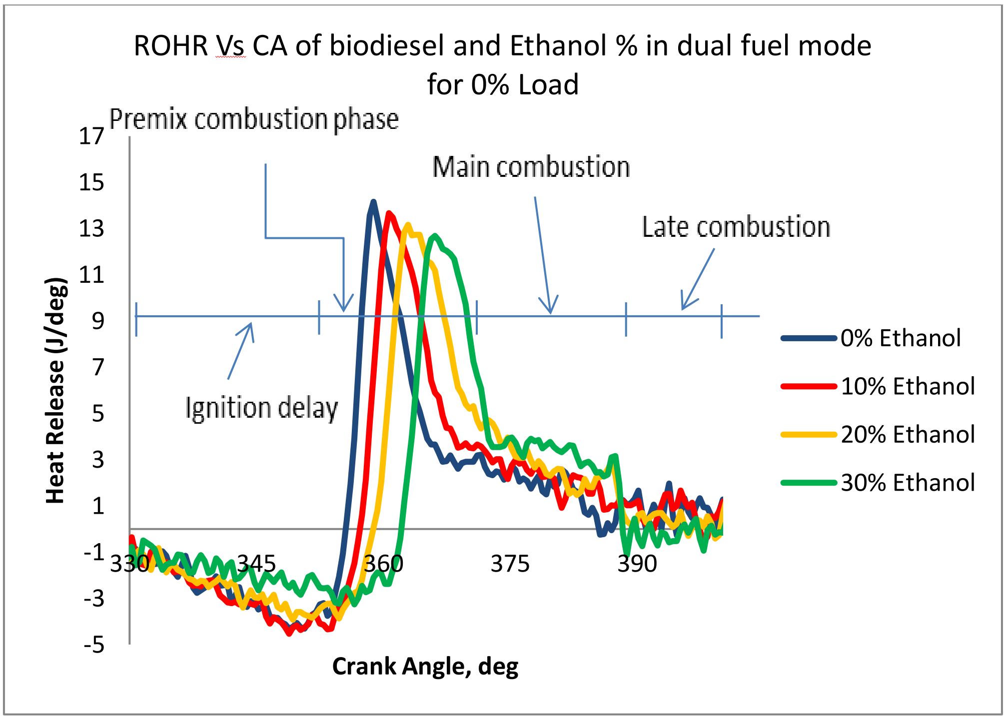


Figure 4.2(a): ROHR vs Crank angle for varying ethanol in dual fuel mode with biodiesel at no load

The peak heat release rate for pure biodiesel in single fuel mode at no load is 14.16 J/deg that occurs at 359^o CA. With introduction of ethanol, maximum heat release of 13.66 J/deg with 10% of ethanol injection and minimum heat release of 12.68 J/deg with 30% of ethanol occurs at 360^o and 362^o CA respectively. A reduction in peak heat release rate is observed with increase in ethanol injection. The ignition delay increases by 3-4^o with injection of ethanol as compared to pure biodiesel. In addition, increase in heat release rate during controlled combustion and late combustion in dual fuel mode is also observed.

At 50% load as shown in Fig. 4.2(b), the injection of ethanol in dual fuel mode with biodiesel slightly increases the peak heat release rate as compared to biodiesel in single fuel mode.

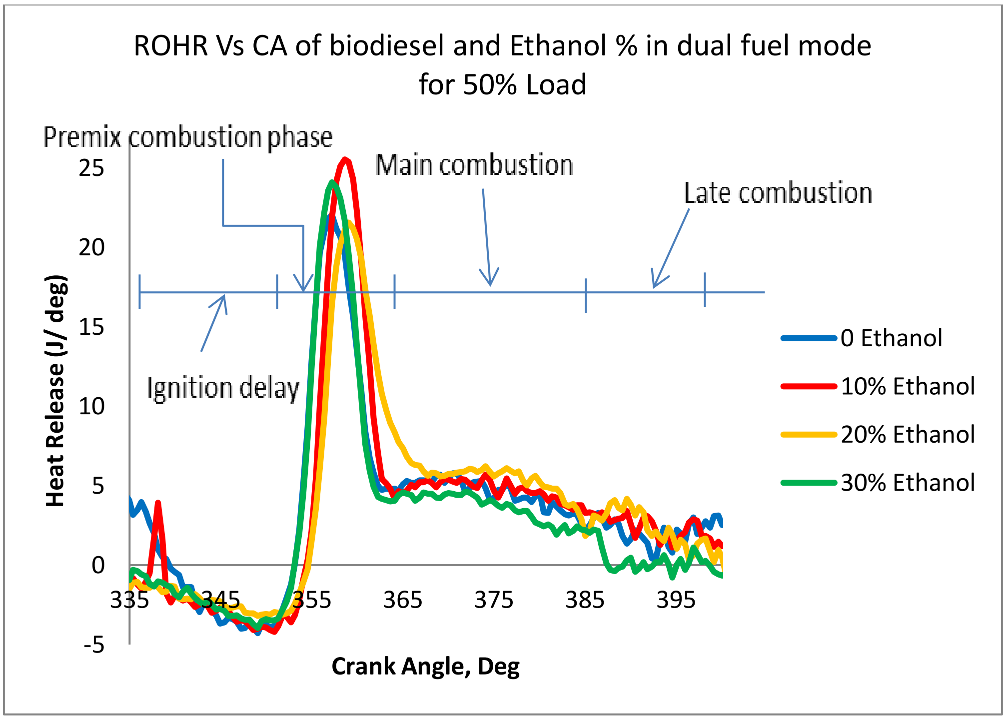


Figure 4.2(b): ROHR vs Crank angle for varying ethanol in dual fuel mode with biodiesel at half load

With pure biodiesel, peak heat release rate of 22 J/deg occurs at 357.26° CA. In dual fuel mode, maximum heat release rate of 25.53 J/deg occur with 10% of ethanol at 357.8° CA and minimum of 21.56 J/deg occurs with 30% of ethanol at 357.5° CA. Here also, the heat release during controlled combustion is high for dual fuel injection.

The peak heat release for pure biodiesel at full load is 34.28 J/deg that occurs at 356° CA as shown in Fig. 4.2(c). In dual fuel mode with ethanol injection of 10%, 20% and 30%, the peak heat transfer rates are 34.10 J/deg, 34.8 J/deg and 31.91 J/deg that occurs respectively at 358°, 358° and 357° CA. A reduction in peak heat transfer rate is observed with percentage increase in ethanol injection. The peak heat release for biodiesel with 20% of ethanol in dual fuel mode is slightly higher than that of pure biodiesel at full load condition.

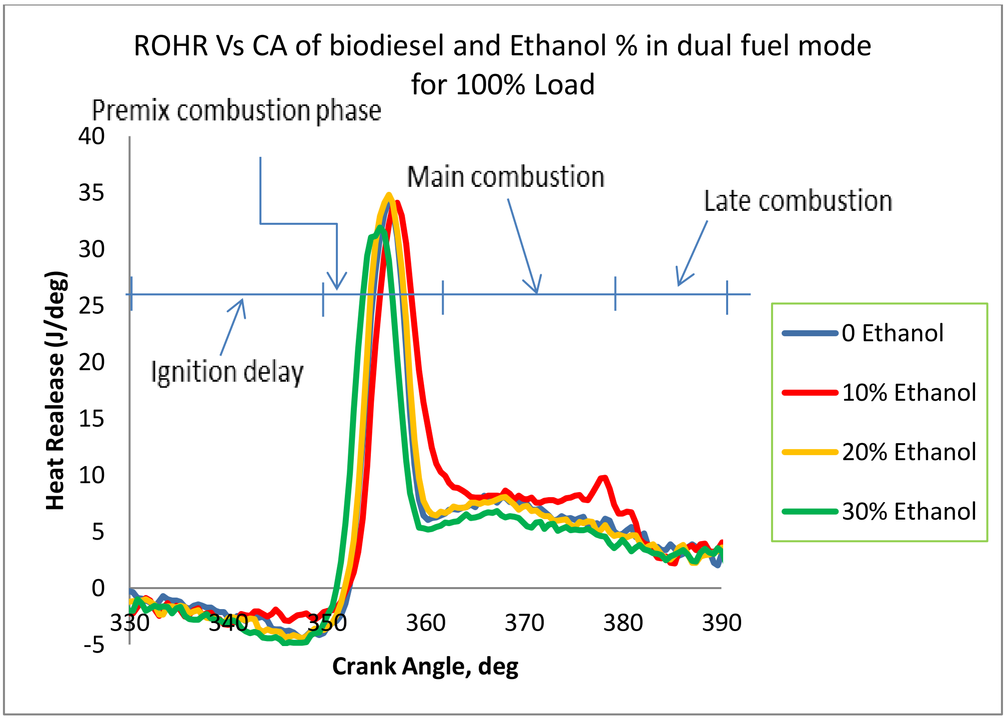


Figure 4.2(c): ROHR vs Crank angle for varying ethanol in dual fuel mode with biodiesel at full load

Slight decrease of 1-2^o in ignition delay is observed with injection of ethanol in dual fuel mode. Increase in heat release during controlled combustion and late combustion in dual fuel mode is also noticed.

Discussion

Trend of peak heat release is similar to that of diesel except at 100% load where peak heat release for biodiesel with 10% and 20% ethanol is more than that of pure biodiesel.

Figures reveal that the ignition delay for biodiesel is shorter than that of diesel. Because of the shorter delay, maximum heat release rate occurs earlier in biodiesel than diesel i.e. the premix combustion phase of biodiesel is less intense. Although the maximum heat release rate of biodiesel is substantially lower than that of diesel, the heat release during the late combustion phase for biodiesel is marginally higher as revealed from the results. This is because the constituents with higher oxygen content are adequate to ensure complete combustion of the fuel that is left over during the main combustion phase and continue to burn in the late combustion phase. On the other hand, while running with diesel, accumulation of fuel during relatively longer delay period resulted in higher rate of heat release.

The combustion performance of polanga biodiesel was lower than diesel due to comparatively Lower Heating Value (LHV) of (40.8 MJ/kg), which is only about 92.4% of petro diesel (44 MJ/kg).

Results of heat release rate also indicate that the ignition delays for both diesel and biodiesel in dual fuel mode were slightly longer than single fuel mode combustion. The increase in ignition delay is due to various factors; larger amount of ethanol fuel in the intake and compression processes, temperature of the ethanol–air mixture in dual fuel mode being less than that of air in single fuel mode during injection. The inducted alcohol also altered the physical properties of the charge being compressed due to pre-ignition reactions leading to the formation of intermediate compounds during the compression of the alcohol–air mixture prior to injection of the pilot fuel.

In particular, single and dual-fuel combustion with biodiesel were slightly shorter in duration than those with diesel in entire test range due to short ignition delay, high cetane number and the high oxygen content of biodiesel fuel.

The observed higher peak heat release rate of pure diesel than that of diesel with ethanol and biodiesel with ethanol is a consequence of the shorter ignition delay at higher loads and higher self-ignition temperature of ethanol. Also the premix combustion phase (phase of combustion causing rapid pressure rise in the cylinder) for diesel/biodiesel with ethanol is less intense. As for a CI engine, the air is not throttled so the load is varied by changing the amount of fuel injected. Increasing the load increases the residual gas and wall temperature which results in higher charge temperature at injection thus decrease in the ignition delay.

The combustion duration for the dual-fuel mode was considerably longer than that of single fuel mode at all the corresponding loads. This is mainly due to the fact that the ethanol was supplied during the intake process and then mixed with air, hence replacing some fraction of intake-air. As ethanol displaced more intake-air, the fuel–air equivalence ratio is increased. Furthermore, as the engine load is increased with constant ethanol flow rate, the engine requires more fuel to satisfy the imposed engine load–speed condition. Hence more pilot fuel must be injected into the combustion chamber. It leads to increase in fuel-air equivalence ratio of the engine.

4.2.2 Combustion Pressure

The significant feature of peak pressure related to combustion aspects is summarized. The peak pressure achieved using diesel and biodiesel in single fuel as well as dual fuel mode with varying quantity of ethanol at zero, half and full load conditions are analyzed which gives very significant information on the engine operations.

4.2.2.1 Peak pressure at different load and different content of ethanol with diesel as primary fuel

Peak pressure with corresponding crank angle for different alcohol-diesel fuel combinations at different load conditions are given in Table 4.4 (Appendix Table A7-A9).

Table 4.4: Peak pressure at different load in dual fuel mode with diesel as primary fuel

Fuel	Load (%)	Peak Pressure (bar)	Crank Angle (deg)
Diesel	0	50.79	363.64
	50	60.566	362.43
	100	65.95	364.16
Diesel + 10% Ethanol	0	44.86	365
	50	56.81	363
	100	63	364.85
Diesel + 20% Ethanol	0	44.39	365.68
	50	57.78	364.23
	100	62.56	365.29
Diesel + 30% Ethanol	0	42.41	366.16
	50	57.8	364
	100	61.33	364.87

The peak pressure increases with load for all fuel combinations and decreases with dilution except at 50% load where 20% and 30% dilution gives slightly higher peak pressure than that of 10% ethanol combination. At half load condition, combustion duration higher in comparison to other load conditions. And when the mixture of air and ethanol mixes with the injected diesel, mixing of ethanol is better with diesel due to the surface tension difference.

At no load as shown in Fig. 4.3 (a), maximum peak pressure of 50.794 bar is observed for pure diesel at 363.64^o CA whereas the minimum is recorded as 42.42 bar for 30% ethanol at 366.2^o CA. A reducing trend of peak pressure is observed with increasing percentage of ethanol injection.

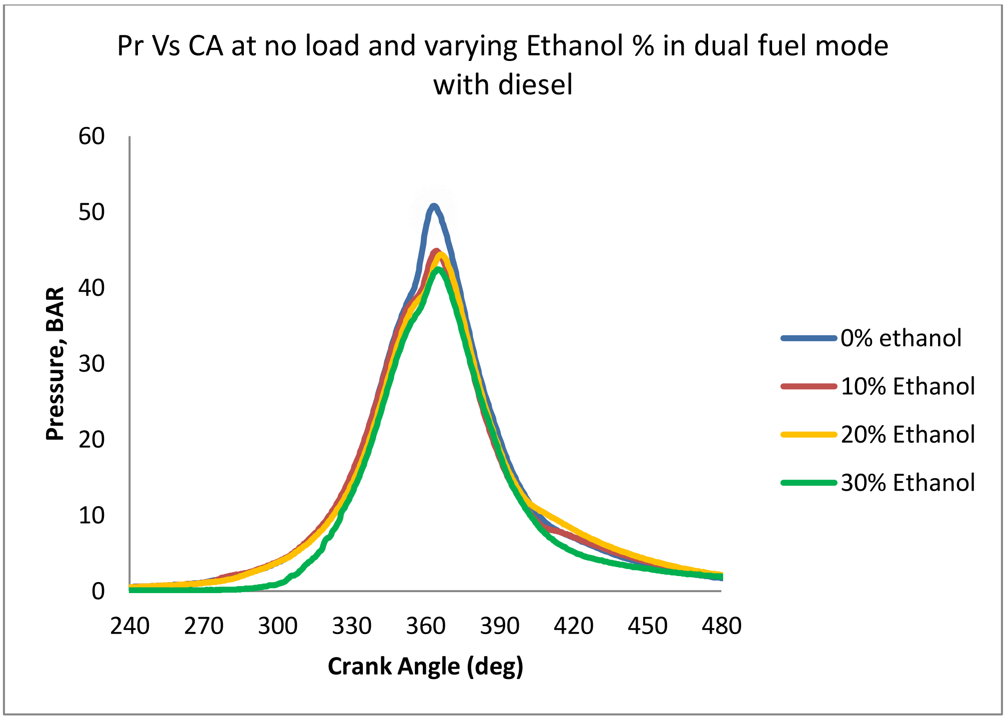


Figure 4.3(a): Pressure (bar) vs Crank angle at no load for diesel with different ethanol content in dual fuel mode.

As shown in Fig. 4.3(b), at 50% load a slight reduction in peak pressure is observed from single mode to dual mode. Increasing injection of ethanol in dual fuel mode slightly reduces the peak pressure as compared to single fuel mode. In single fuel mode, engine produces 60.566 bar at 362.43^o CA with pure diesel and in dual fuel mode max peak pressure of 57.8 is observed with 30% of ethanol injection at 364^o.

At 100% load the peak pressure recorded is 65.95 bar at 364^o for pure diesel as shown in Fig. 4.3(c). Though peak pressure decreases with ethanol content in dual fuel mode but there is no substantial effect of ethanol percentage on peak pressure at 100% load as peak pressure observed for 10%, 20% and 30% ethanol is respectively 62.95, 62.56 and 61.33 bar at 364.85^o, 365^o, and 365^o CA.

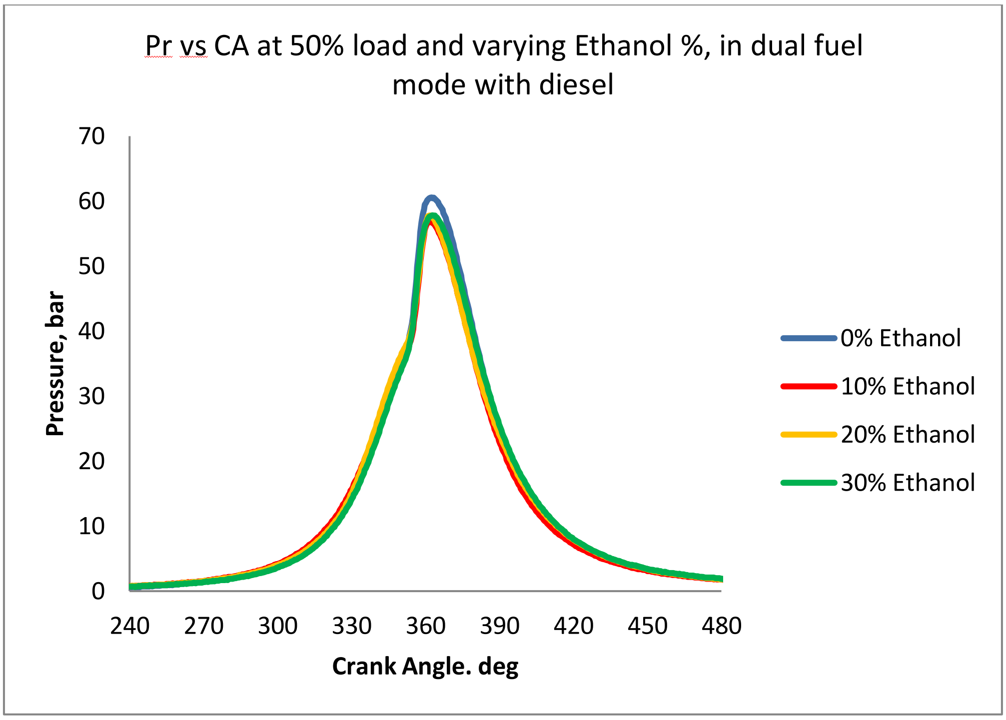


Figure 4.3(b): Pressure (bar) vs Crank angle at half load for diesel with different ethanol content in dual fuel mode.

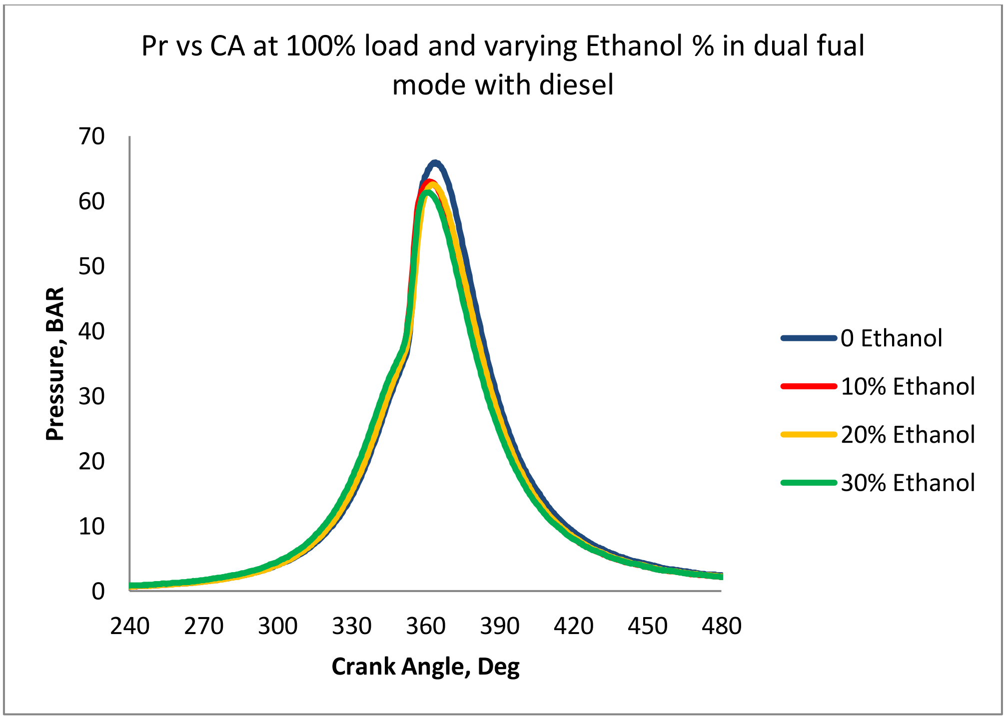


Figure 4.3(c): Pressure (bar) vs Crank angle at full load for diesel with different ethanol content in dual fuel mode.

4.2.2.2 Peak pressure at different load and different content of ethanol with biodiesel as primary fuel

Peak pressure with corresponding crank angle for different biodiesel-alcohol fuel combinations at different load conditions are given in Table 4.5 (Appendix Table A10-A12).

Table 4.5: Peak pressure at different load in dual fuel mode with biodiesel as primary fuel

Fuel	Load (%)	Peak Pressure (bar)	Crank Angle (deg)
Biodiesel	0	48.75	362.95
	50	57.31	362.27
	100	61.12	362.11
Biodiesel + 10% Ethanol	0	47.50	365
	50	58.26	363
	100	61.21	363.53
Biodiesel + 20% Ethanol	0	45.36	365.67
	50	56.5	363.40
	100	61.04	363.31
Biodiesel + 30% Ethanol	0	43.51	366.92
	50	56.32	362.27
	100	60.51	363.31

Trend of peak pressure is similar to that of diesel except at 50% load where peak pressure for biodiesel with 10% ethanol is more than that of pure biodiesel.

The peak pressure for all combinations biodiesel with ethanol in dual fuel mode is slightly less than that of pure biodiesel in single fuel mode at no load condition as shown in Fig. 4.4 (a).

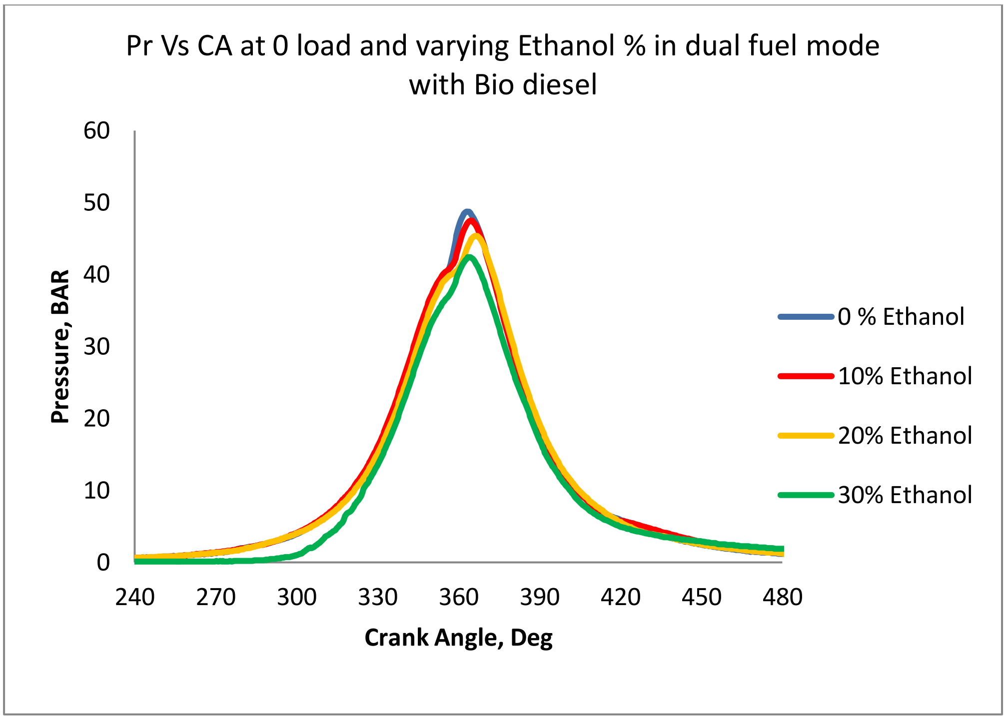


Figure 4.4(a): Pressure vs Crank angle at no load for biodiesel with different ethanol content.

The peak pressure for pure biodiesel in single fuel mode at no load is 48.75 bar that occurs at 363.64^o CA. A reducing trend of peak pressure is observed with increasing percentage of ethanol injection. In dual fuel mode with ethanol injection of 10%, 20% and 30%, the peak pressure is 47.50 bar, 45.36 bar and 42.41 bar that occurs respectively at 365^o, 365^o and 366^o CA.

At 50% load, the injection of ethanol with biodiesel in dual fuel mode results in very insignificant variation in the peak pressure as compared to single fuel mode for all percentage of ethanol as shown in Fig. 4.4(b).

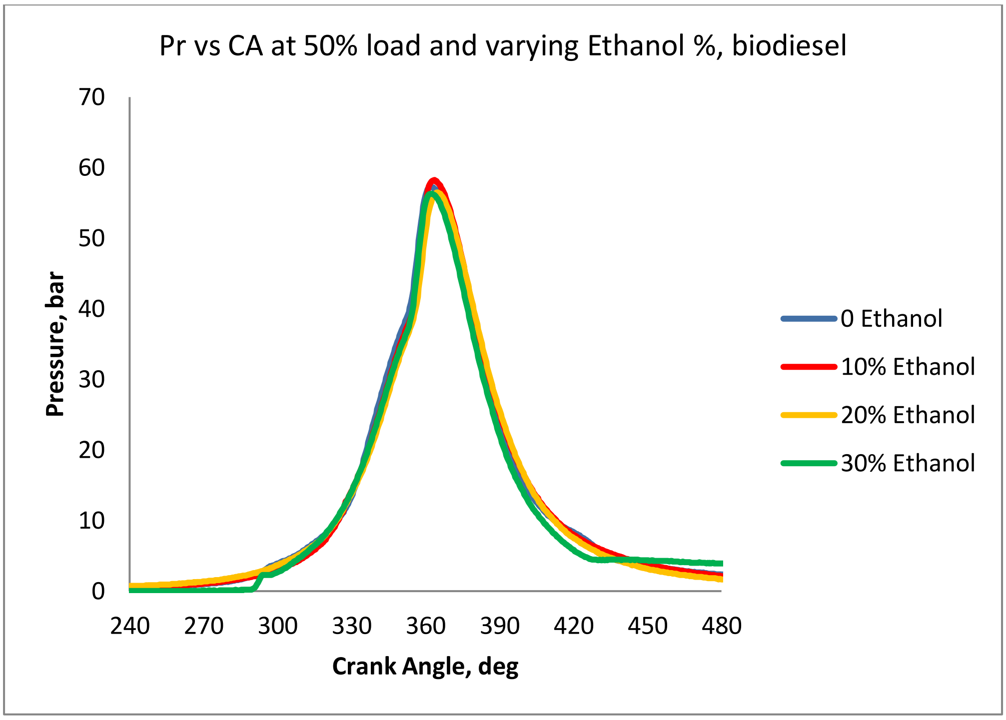


Figure 4.4(b): Pressure vs Crank angle at half load for biodiesel with different ethanol content.

A slight increase in peak pressure is observed with pure biodiesel with respect to dual fuel mode and a very slight decrease is noticed with increase in ethanol percentage at this load. In single fuel mode i.e. pure biodiesel, the peak pressure is 57.3 bar at 362.2^o CA and in dual fuel mode with 10%, 20% and 30% of ethanol, the peak pressures are 58.26 bar, 56.49 bar and 56.32 bar respectively at 362^o, 363^o, and 362^o CA.

The peak pressure for biodiesel with ethanol in dual fuel mode at 100% load is almost equal to that of pure biodiesel in single fuel mode as shown in Fig. 4.4(c). The peak pressure for pure biodiesel in single fuel mode at full load is 61.11 bar that occurs at 362.84^o CA.

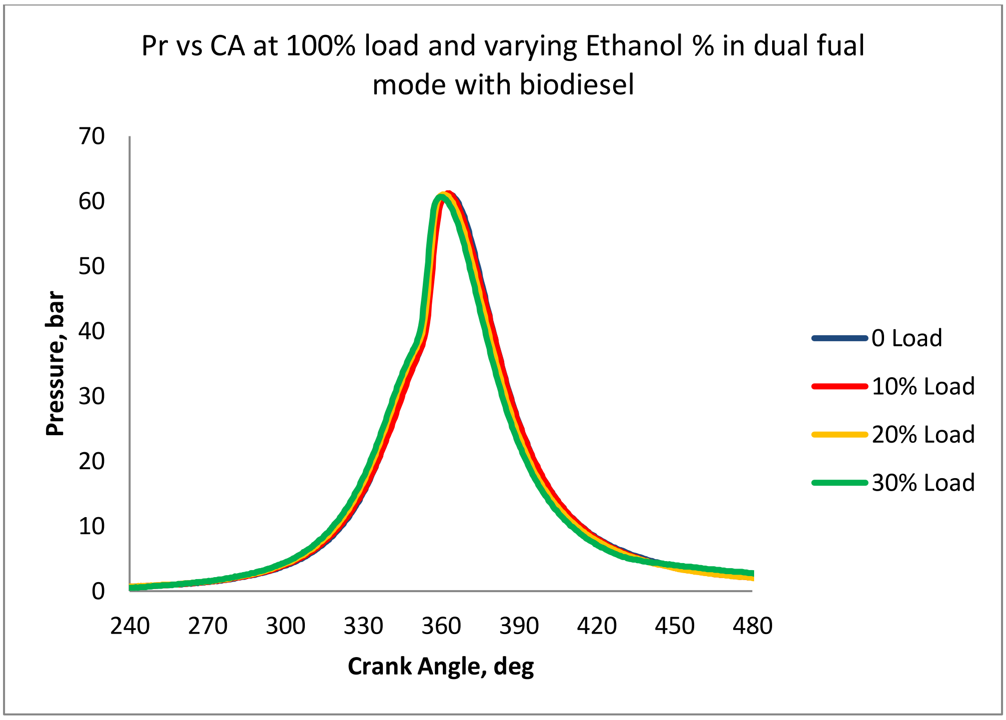


Figure 4.4(c): Pressure vs Crank angle at full load for biodiesel with different ethanol content.

A very insignificant decrease in peak pressure is observed with increasing percentage of ethanol injection. In dual fuel mode with ethanol injection of 10%, 20% and 30%, the peak pressures are 61.21 bar, 61.041 bar and 60.51 bar that occurs respectively at 364^o, 363.31^o and 363.32^o CA. The peak pressure with 10% alcohol is slightly higher than that with pure biodiesel.

Discussion

At all load conditions, the peak values of combustion pressure are slightly lower for biodiesel than that of diesel due to relatively shorter ignition delay. The increase in fuel viscosity particularly for petroleum-derived fuels, decreases cone angle and results in relatively longer ignition delay. As biodiesel is not derived from crude petroleum, it usually includes a small percentage of triglycerides having higher boiling points than diesel, opposite trend was observed.

The ignition ability of the fuel is also influenced by the chemical and physical properties, such as the structure of fuel composition, density, bulk moduli, cetane number, oxygen content, and aromatic content. The higher cetane number, the low stoichiometric air requirement, higher density and the large oxygen content of biodiesel play an important role in short ignition delays for biodiesel combustion [65].

The presence of ethanol in the charge affects the peak pressure at all engine loads as it is observed that the cylinder pressure under dual fuel operation deviates from the respective values under normal diesel operation.

As revealed from the results that all combinations of Polanga biodiesel with ethanol in dual fuel mode have less peak pressure than that of pure biodiesel in single fuel mode at all load conditions except for 10% ethanol combination where peak pressure is slightly higher at half and full load. Peak pressure with biodiesel occurred early as compared to diesel as the combustion in biodiesel initiated somewhat early as compared to that in diesel.

However, when compared to single-fuel combustion, the ignition delay was prolonged in dual fuel mode, but the peak combustion pressures for dual-fuel combustions were lowered. The lower peak pressure observed under dual fuel operation during the compression stroke is the result of the higher specific heat capacity and low cetane no of the ethanol than those of diesel/biodiesel.

At low loads, pilot fuel initiates the combustion followed by ethanol combustion due to its high self- ignition temperature and leads to advancement in the peak pressure by 1 to 2˚ CA.

The early peak characteristics warrant careful attention to ensure that, while running with diesel/ biodiesel and ethanol, the peak pressure takes place definitely after TDC for safe and efficient operation. Otherwise, a peak pressure occurring very close to TDC or before that causes severe engine knock, and thus affects engine durability. It is concluded from this discussion that both the oils in dual fuel mode give maximum peak cylinder pressure after the TDC which is encouraging. Also, the peak pressure is near to diesel and creates no danger to the engine structure.

4.2.3 Effect on Brake Thermal Efficiency (BTE)

The effect of ethanol injection on brake thermal efficiency has been studied. This enables one to compare BTE of the engine when fueled with different ratios of diesel/biodiesel and ethanol for constant speed operation under different loading conditions.

4.2.3.1 BTE of diesel and biodiesel at different loads

The brake thermal efficiency with biodiesel has improved slightly over that of diesel at lower loads and remains almost same at the higher loads as shown in Fig. 4.5(a).

The brake thermal efficiency for diesel in single fuel mode at 50%, 80% and 100% loads is measured as 22.45%, 24.12% and 28.83% respectively. For biodiesel, the brake thermal efficiency in single fuel mode at 50%, 80% and 100% loads is found to be 23.05%, 24.79% and 29.02% respectively.

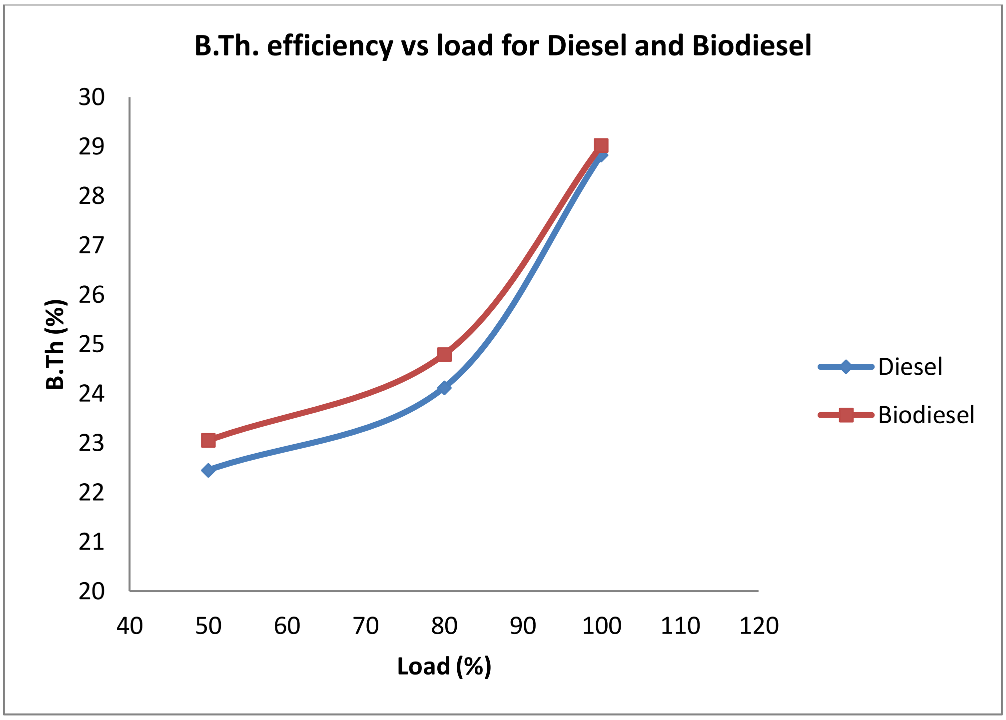


Figure 4.5(a): Brake Thermal Efficiency of diesel and biodiesel at different loads

This may be attributed to better combustion at lower loads and additional lubricity of biodiesel in comparison to diesel.

4.2.3.2 Brake thermal efficiency in dual fuel mode

In dual fuel mode, a slight increase in BTE is observed with increasing ethanol percentage as shown in Fig. 4.5(b).

Maximum BTE is observed for 30% ethanol and minimum BTE is observed for 0% ethanol at all loading conditions. Maximum/ minimum BTE at 50% load and 100% load, are measured to be 23.82%/22.5% and 30.69% / 28.83% respectively. BTE increases slightly with ethanol content at all loads thus, ethanol content has marginal effect on BTE at constant load.

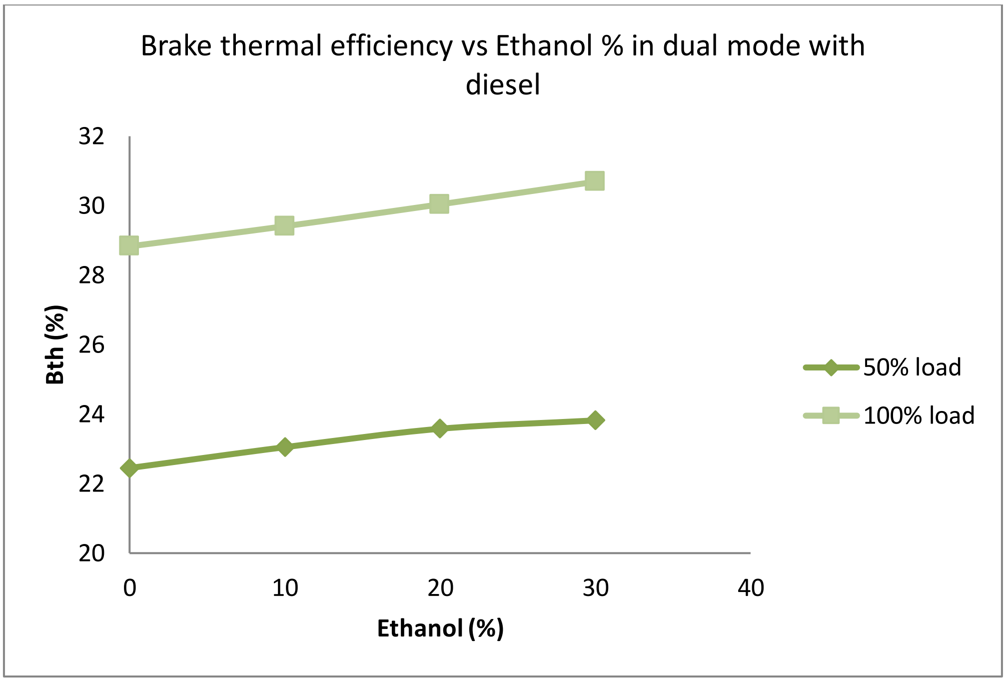


Figure 4.5(b): Brake Thermal Efficiency with diesel-ethanol combinations in dual fuel mode.

A slight improvement in the efficiency with increasing ethanol substitution at all loads can be seen for biodiesel in the Figs. 4.5 (c) and (d).

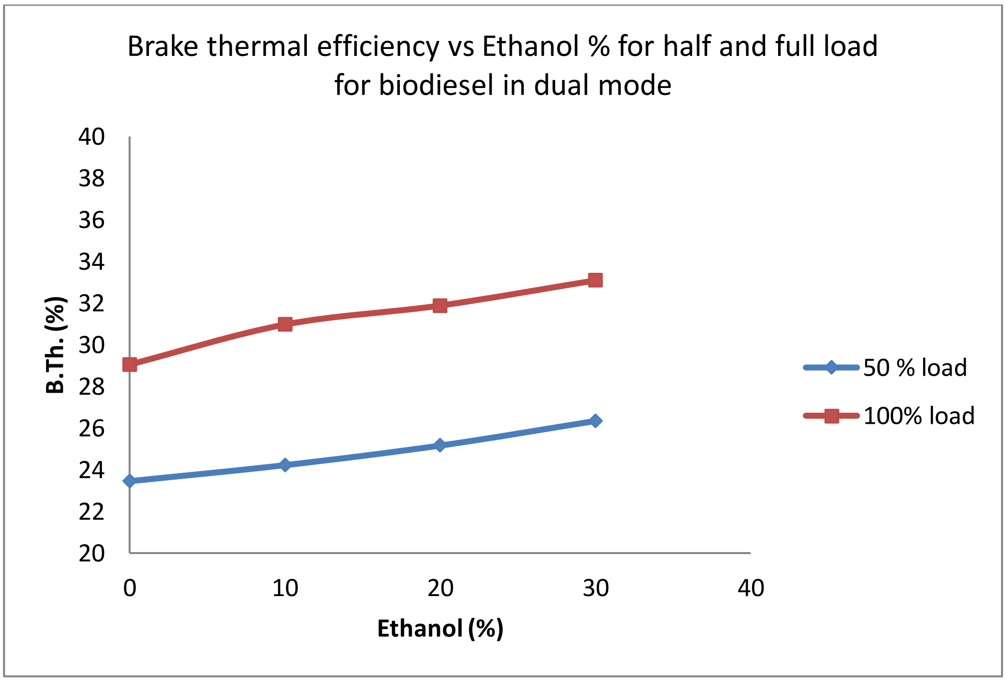


Figure 4.5(c): Brake Thermal Efficiency with biodiesel-ethanol combinations in dual fuel mode

Also, for the same ethanol content, biodiesel gives higher BTE than diesel under similar loading conditions. This improvement was approximately 1 to 3% over the entire load range for different amount of ethanol injection.

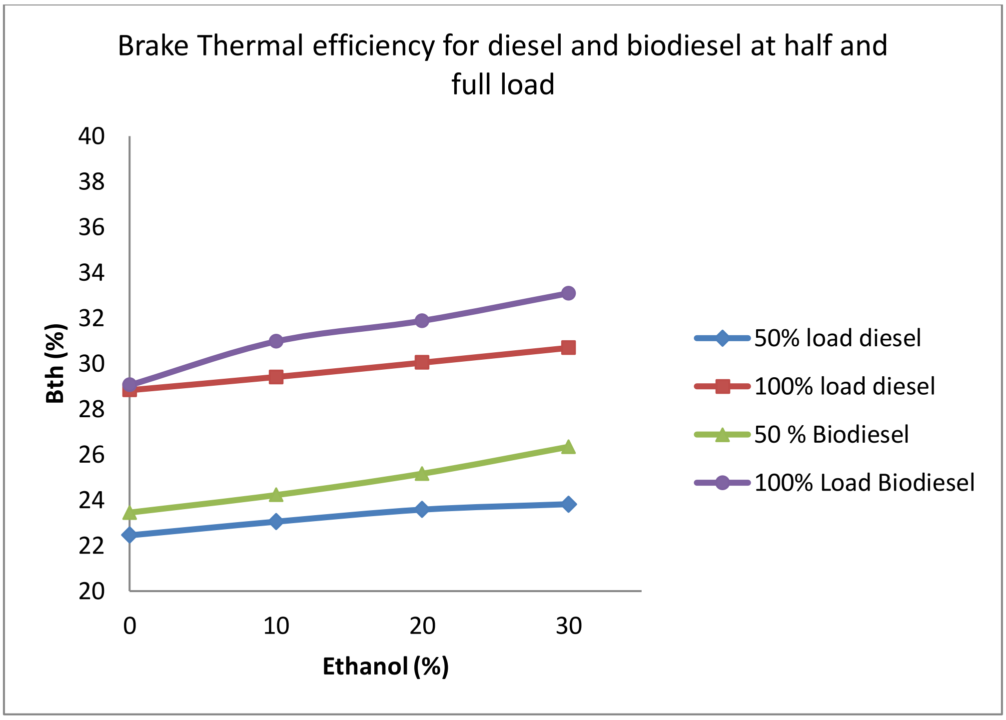


Figure 4.5(d): Variation in Brake Thermal Efficiency with ethanol content in diesel and biodiesel.

It is also observed that ethanol addition has almost similar effect on both diesel and biodiesel at all loads. The maximum improvement in the efficiency is with 30% ethanol combination at full load. The improvement in the thermal efficiency may be attributed to any possible combination of following factors related to the combustion process.

(1) Fast burning of homogeneous air-alcohol mixture results in more premixed combustion which in turn tends to increase the brake thermal efficiency.

(2) The increase in ignition delay due to lower cetane number of alcohol causes energy release in very short time. That results in reduction in the heat loss from the engine due to insufficient time for transferring heat through the cylinder wall to the coolant.

(3) Evaporation of ethanol in the intake air lowers the intake mixture temperature and increases its density. Thus, as more air is made available in the cylinder, greater power is generated.

(4) The slight gains in thermal efficiency with increased ethanol substitution may also be attributed to the increase in the heat release during controlled combustion.

4.2.4 Engine Emissions

Combustion of various fossil fuels leads to emission of several pollutants, which are categorized as regulated and unregulated pollutants. Regulated pollutants are the ones, whose limits have been prescribed by environmental legislations (such as USEPA, EURO and Bharat norms) whereas there are some pollutants for which no legislative limits have been prescribed. These are categorized as unregulated pollutants. Regulated pollutants include NOx, CO, HC, particulate matter (PM) and unregulated pollutants include formaldehyde, benzene, toluene, xylene (BTX), aldehydes, SO2, CO2, methane etc. [64–66].

4.2.4.1 CO Emissions

Emissions of CO depend on the air-fuel ratio relative to the stoichiometric proportion. Combustion of rich fuel mixture invariably produces CO.

CO emission for diesel and biodiesel in single fuel mode as well as with ethanol in dual fuel mode at different loads are shown respectively in Figs. 4.6 (a) and (b).

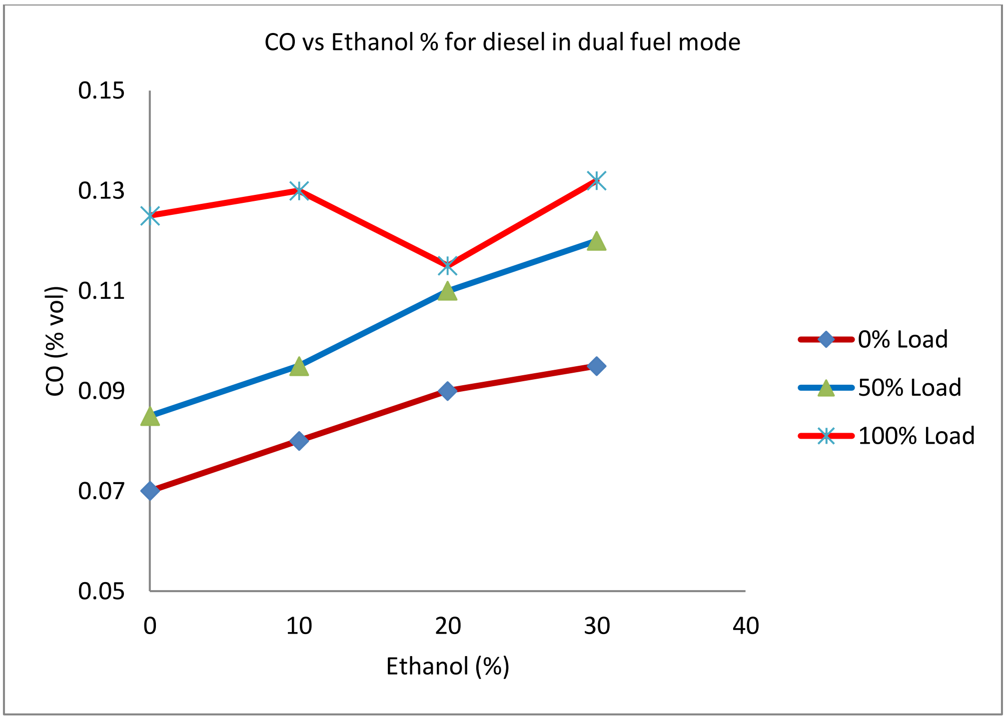


Figure 4.6(a): CO Emission (%) with pure diesel and diesel-ethanol in dual fuel mode.

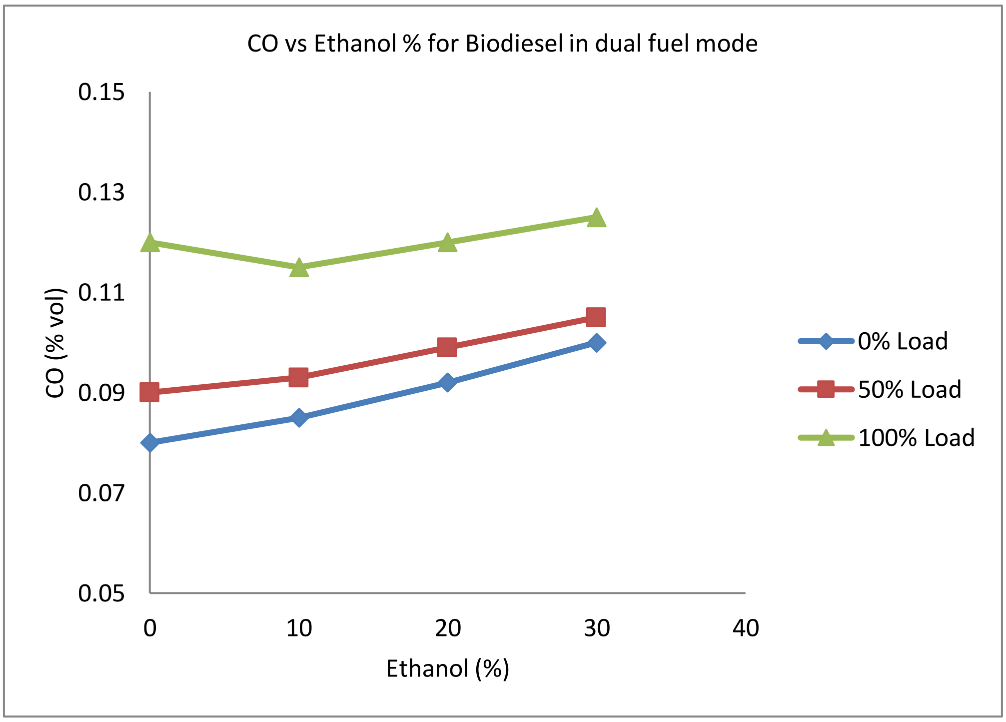


Figure 4.6 (b): CO Emission (%) with pure biodiesel and biodiesel-ethanol in dual fuel mode

CO emission increases steadily with increasing engine load in single fuel mode. This is due to the fact that as the load on the engine is increased, more amount of fuel is injected into the combustion chamber without any proportional increase in the amount of air. Since amount of air remains less than that required for increased fuel quantity, combustion remains incomplete and CO emission increases with load. However, in comparison between single and dual-fuel combustions, the concentrations of CO emissions for the dual-fuel mode with both pilot fuels are considerably higher than those of the single-fuel mode under all loading conditions with one exception for each pilot fuel.

For the single fuel mode, polanga biodiesel combustion emits somewhat less amount of CO at higher loads while it emits more amount of CO at lower loads as compared to diesel fuel combustion.

At no load and intermediate load (50%), CO emission increases with ethanol addition; maximum for 30% ethanol substitution. At higher load (100%) CO% decreases with 10% ethanol and increases thereafter to attain maximum with 30% ethanol substitution.

CO emissions for biodiesel are lower at higher load than that of diesel fuel in dual fuel combustion mode as given in Table 4.6. The reason for the lower concentrations of CO emissions is that biodiesel fuel contains about 11% oxygen by weight and requires less stoichiometric air-fuel ratio, which leads to a complete combustion. Formation of CO is the result of incomplete combustion. Also, if the temperature inside the cylinder during combustion process is not sufficient to support the complete combustion then transformation of CO to CO_2 does not occur. Thus, complete combustion of biodiesel suppresses the creation of incomplete combustion products like CO in the combustion chamber.

Table 4.6: CO emissions with diesel and biodiesel in dual fuel mode at different loads

Ethanol (%)	**Load (%)**	**CO (% Vol)**	
		Diesel	**Biodiesel**
0% Ethanol	0	0.07	0.08
	50	0.085	0.09
	100	0.125	0.12
10% Ethanol	0	0.08	0.085
	50	0.095	0.093
	100	0.13	0.115
20% Ethanol	0	0.09	0.092
	50	0.11	0.099
	100	0.115	0.12
30% Ethanol	0	0.095	0.1
	50	0.12	0.105
	100	0.135	0.125

It is relevant to mention that in diesel engine, rich mixture exists locally even if excess air is present in the combustion chamber and combustion may be poor due to low temperature conditions at no load resulting in higher CO emissions.

Rapid burning of vaporized alcohol, combustion quenching caused by high latent heats of vaporization and subsequent charge cooling decrease the inside cylinder temperature that might lead to incomplete oxidation of the CO to CO_2 during expansion stroke, resulting an increase in CO emission [69]. Alcohol addition increases CO emissions as compared to single fuel combustion [70 - 72].

4.2.4.2 CO_2 emissions

Carbon dioxide (CO_2) is the primary greenhouse gas emitted from diesel engine. Biodiesel and ethanol have the lowest life cycle greenhouse gas emissions (in grams) per kilometer traveled [73-75]. In fact, both emit larger quantities of CO_2 than conventional fuels, but as most of this is from renewable carbon stocks, that fraction is not counted towards the GHG emissions from the fuel.

Figures 4.7 (a) and (b) show CO_2 emissions respectively for diesel and biodiesel as primary fuels with different levels of ethanol as secondary fuel at different loads.

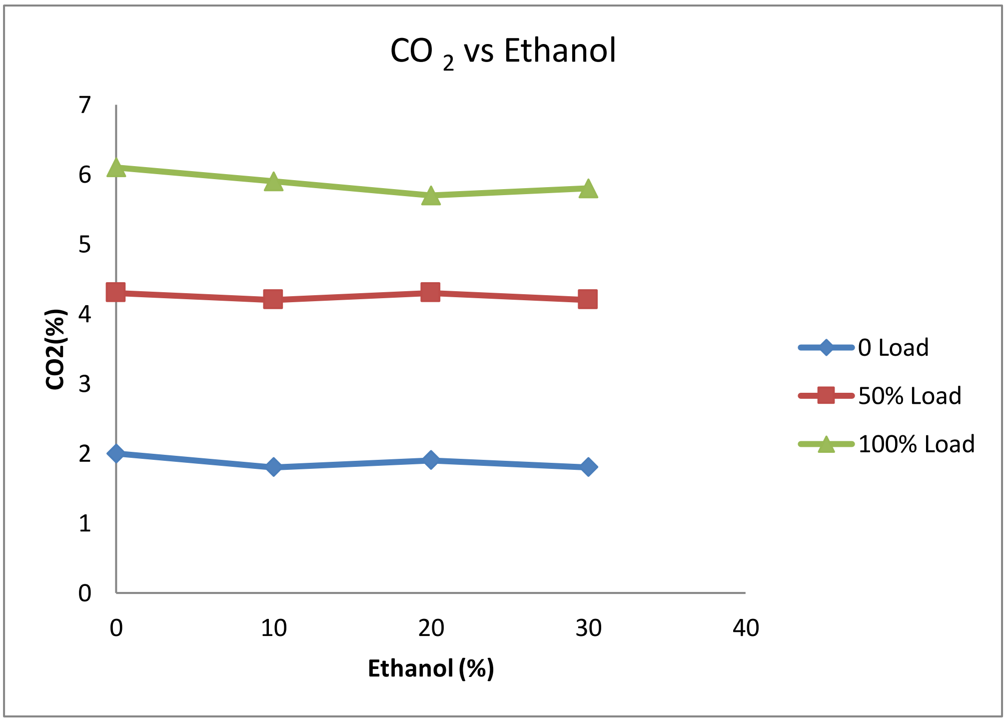


Figure 4.7(a): CO_2 Emission with diesel and diesel-ethanol combination in dual fuel mode

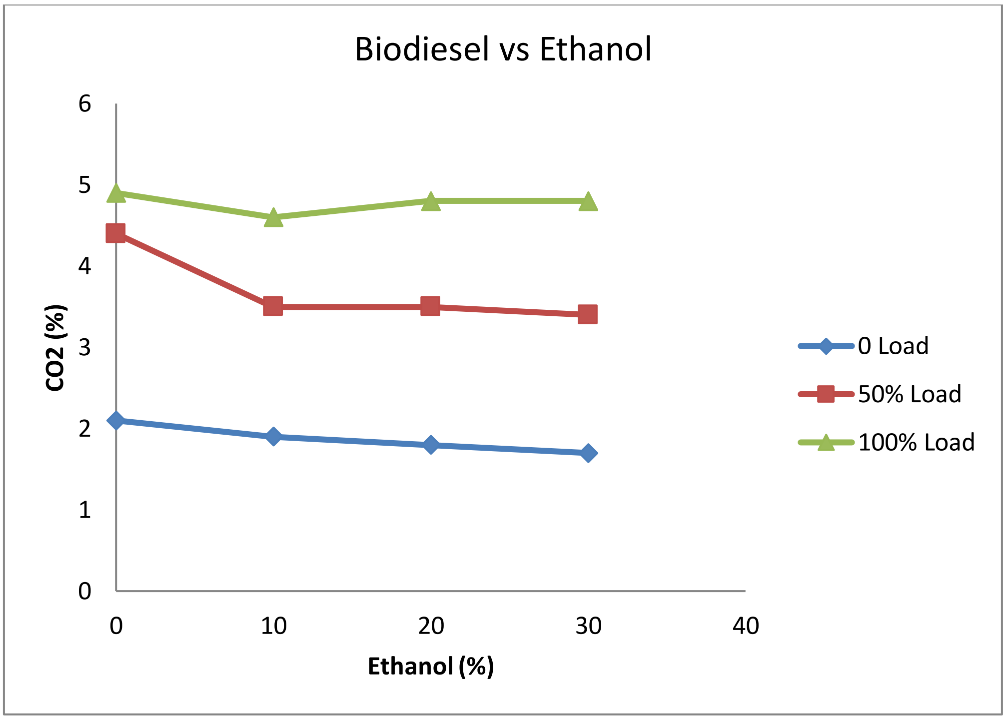


Figure 4.7 (b): CO_2 Emission with biodiesel and biodiesel-ethanol combination in dual fuel mode.

CO_2 occurs naturally in the atmosphere as a normal product of combustion. Ideally, combustion of a hydrocarbon fuel should produce only CO_2 and water (H_2O). As revealed from the results that at no load, CO_2 emission remains almost constant in both diesel and biodiesel. At 50% of load, it remains constant for diesel but decreases for biodiesel with increasing ethanol content. At 100% of load, CO_2 emission in dual fuel mode is less than that in single fuel mode but minima is attained at 20% of ethanol in case of diesel and at 10% of ethanol in case of biodiesel.

Formation of CO_2 during combustion process strongly depends on two things; Combustion temperature and oxygen availability.

The combustion process consists of two stages, in first stage, carbon monoxide is formed and in second stage, carbon monoxide reacts with excess oxygen to form carbon dioxide if inside cylinder temperature is sufficient and excess oxygen is available to support the complete combustion.

CO_2 emission greatly depends on the CO generation. In dual fuel mode, due to high heat of vaporization, alcohol reduces the inside cylinder temperature which leads to incomplete oxidation of the CO to CO_2 during expansion stroke. This results in an increase in CO emission and decrease in CO_2 emission. Based on the result obtained, it is clear that there is a significant decrease in CO_2 emission with alcohol injection as compared to pure diesel/biodiesel fuel.

4.2.4.3 NO_X emissions

The variation of NOx emissions with ethanol content under different loading conditions is shown in Figures 4.8 (a) & (b) respectively for diesel and biodiesel as primary fuels.

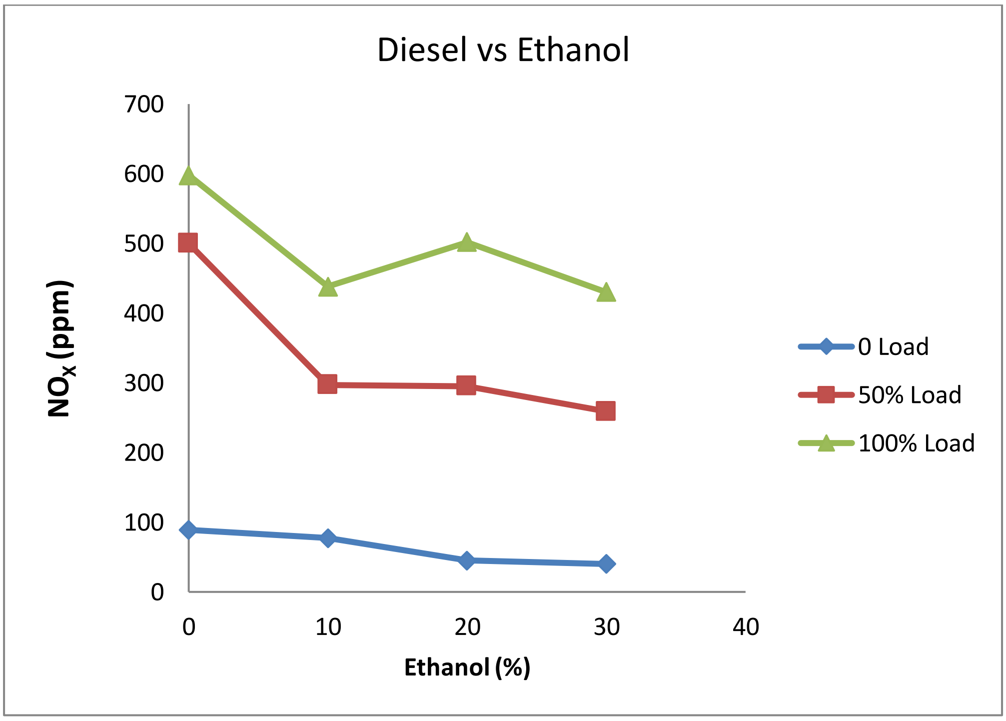


Figure 4.8(a): NOx Emission Vs ethanol content for diesel-ethanol combination

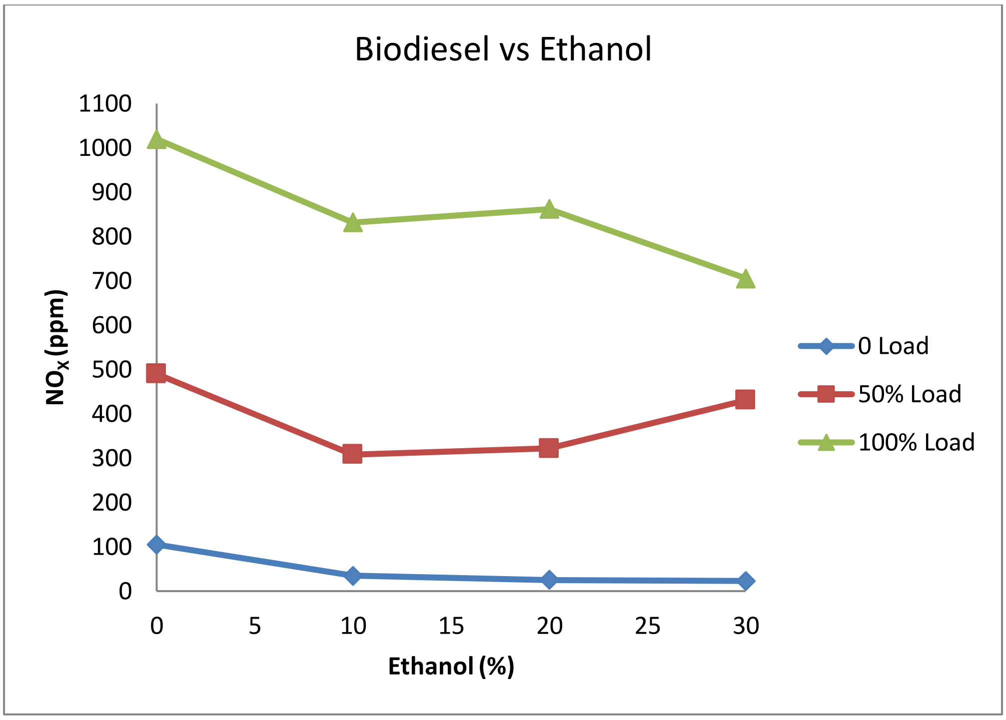


Figure 4.8 (b): NOx Emission Vs ethanol content for biodiesel-ethanol combination

The formation of NOx is highly affected by the combustion temperature inside the engine cylinder and the local stoichiometric ratio of the mixture. It can be seen that the NOx emissions increases with the engine load. At 100% load, NOx emission is minimum for 30% of ethanol addition and maximum for 0% ethanol. At all the loads, NO_x emissions show a fluctuating trend with alcohol substitution from 0% to 30%. Ethanol injection helps in decreasing the temperature due to atomization.

There is a reduction in NO_x emission with ethanol substitution with diesel as well as with biodiesel. At higher load (100%) fluctuating trend is observed for NO_x with minimum at 30% ethanol for both the fuels. At intermediate load (50%) minimum occurs at 30% ethanol in case of diesel and at 10% in case of biodiesel. At no load, the NO_x emissions seems to be unaffected of ethanol content for diesel but decreases slightly with increasing ethanol content for biodiesel.

A wide range of variation in results has been reported by different researchers [30, 33, and 44]. Some reported that NOx emission decreases with alcohol fumigation as alcohol has the cooling effect on combustion temperature. Simultaneously, other also reported that NOx emission increases due to high content of oxygen in alcohol [76-77].

For dual-fuel operations, the concentrations of NOx emissions were obviously lower at all engine loads; about 40% less than the levels measured in single combustion modes. The induction of alcohol increases the specific heat capacity of the working fluid which thereby caused the slowing of the flame propagation and finally reduces the combustion temperature during the combustion process. Concurrently, the production of NOx emissions is suppressed with the combined effects of these phenomena in the case of ethanol supplemented dual combustion. Alcohol having high latent heat of vaporization also releases less amount of heat during combustion process which reduces the combustion temperature, leading to the reduction of NOx formation especially under the lean conditions at lower engine loads [78-80]. At high engine loads, there is a reduction in the air/fuel ratio in the dual fuel mode hence diesel/ biodiesel fuel is burnt with such an air and alcohol mixture that might have a negative effect on the availability of oxygen required for NOx formation, thus resulting reduction in NOx emission [81-82].

In some cases, NOx emission increases with increasing level of ethanol injection. Alcohol contains higher oxygen than diesel/ biodiesel fuel hence supplementation of alcohol increases oxygen supply which might increase the NOx emission. The poor auto-ignition properties of injected alcohol leads to an increase of fuel burned in the premixed mode which increase the combustion temperature and hence increase the NOx emission [83].

4.2.4.4 Unburnt hydro carbon (UHC) emissions

The experiment shows an increase in UHC emission like CO emission. The reasons behind the formation of UHC during combustion are same as for CO formation. Alcohol injection affects the UHC emission in the same way as it affects the CO emission.

The variation of unburnt hydrocarbon (UHC) emissions for diesel and biodiesel with different level of ethanol substitution under different loading conditions is shown respectively in Figs. 4.9 (a) & (b).

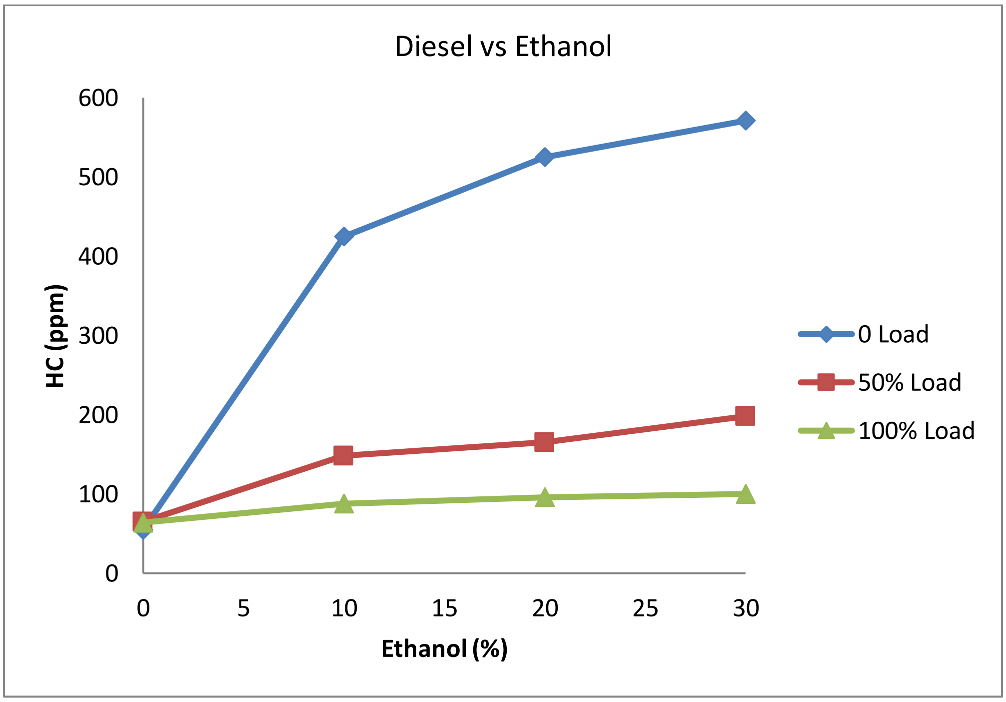


Figure 4.9 (a): UHC Emission with diesel-ethanol combination in dual fuel mode

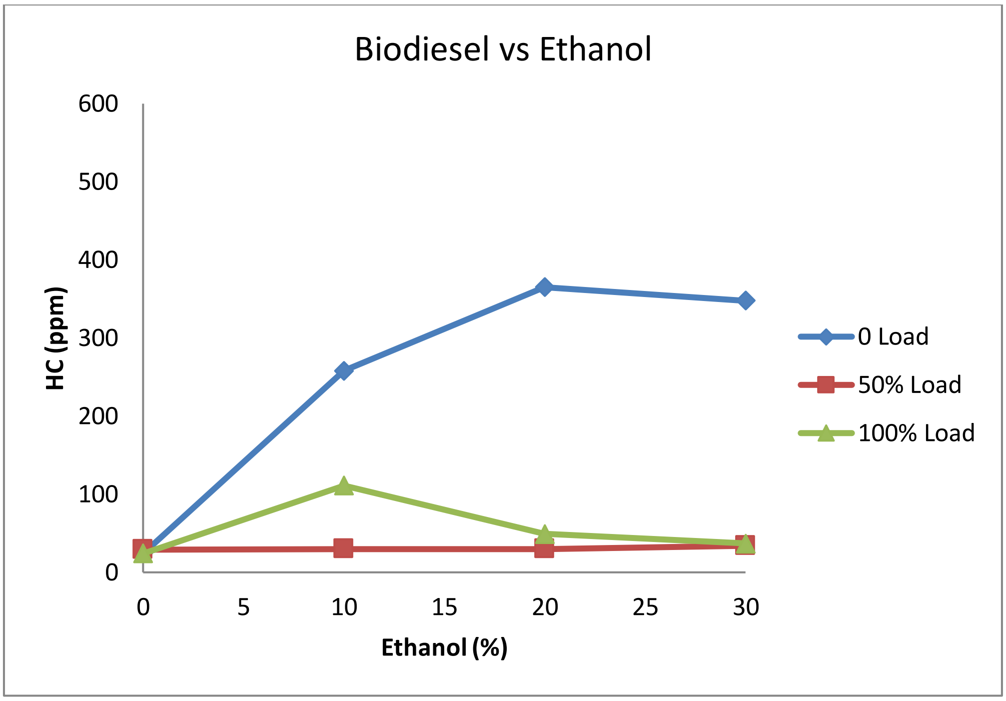


Figure 4.9 (b): UHC Emission with biodiesel-ethanol combination in dual fuel mode

At no and half load conditions, the unburnt HC emissions are higher than that at full load condition as the fuel is less apt to impinge on surfaces of cylinder. Consequently because of poor fuel distribution, large amounts of excess air and low exhaust temperature, lean fuel-air mixture regions may survive to escape into the exhaust resulting higher UHC emissions. With increasing ethanol substitution under no load condition, UHC increases substantially as temperatures are lower due to the higher heat of evaporation of ethanol resulting in poor combustion. It is found during experiment that under 50% and no load conditions, UHC slowly increases up to 10% ethanol substitution then remains nearly constant. At higher loads (100%), the UHC emission increases with increasing ethanol injection.

It is revealed from the results that pure biodiesel gives relatively lower UHC as compared to the pure diesel. This may be attributed to better combustion of biodiesel inside the combustion chamber due to higher amount of oxygen available in biodiesel. In dual fuel mode, emissions increases continuously with increasing ethanol injection at no load while remains constant at intermediate (50%) load. At full load (100%), UHC emissions vary randomly with maximum at 10% alcohol and minimum at 30% alcohol.

In dual fuel mode, quench layer of unburned fumigated alcohol may form inside the cylinder. Since alcohol has cooling effect on combustion process, as a result poor combustion temperature might not be able to ignite the unburned fumigated alcohol during expansion stroke which leads to an increase in UHC emission.

Another important phenomenon is wall-wetting. Fuel spray impinges on the surface of intake ports or valves and can build fuel films if the temperature is not high enough to cause surface boiling. Moreover, some fuel droplets that do not undergo complete vaporization and stay in the liquid phase can flow into the cylinder and adhere on the liner wall, resulting in increased UHC emissions[84].

4.2.4.5 Smoke opacity

Smoke opacity defined as darkness of smoke due to its carbon content which blocks the light. Diesel engines are the most remarkable sources of Particulate Matter (PM) emission. PM is the term used for a mixture of solid particles and liquid droplets suspended in the air as dust, dirt and smoke that vary in concentration, size, shape, surface area, chemical composition and solubility which are originated from a variety of anthropogenic and natural sources. These particles exist in different shapes and densities in the air which are especially relevance to inhalation and toxicity. PM is highly complex mixture of elemental carbon or soot, adsorbed hydrocarbons and inorganic compounds (sulfates and water etc.). Smoke opacity is an indirect indicator of soot content in the exhaust gases. Therefore, this parameter can be correlated with the fuel's tendency to form PM during engine operation. Soot particles are formed very early in the combustion process and most are oxidized at very high temperatures.

The variation of smoke opacity with ethanol content for diesel and biodiesel at different load conditions is shown respectively in Figs 4.10 (a) and (b).

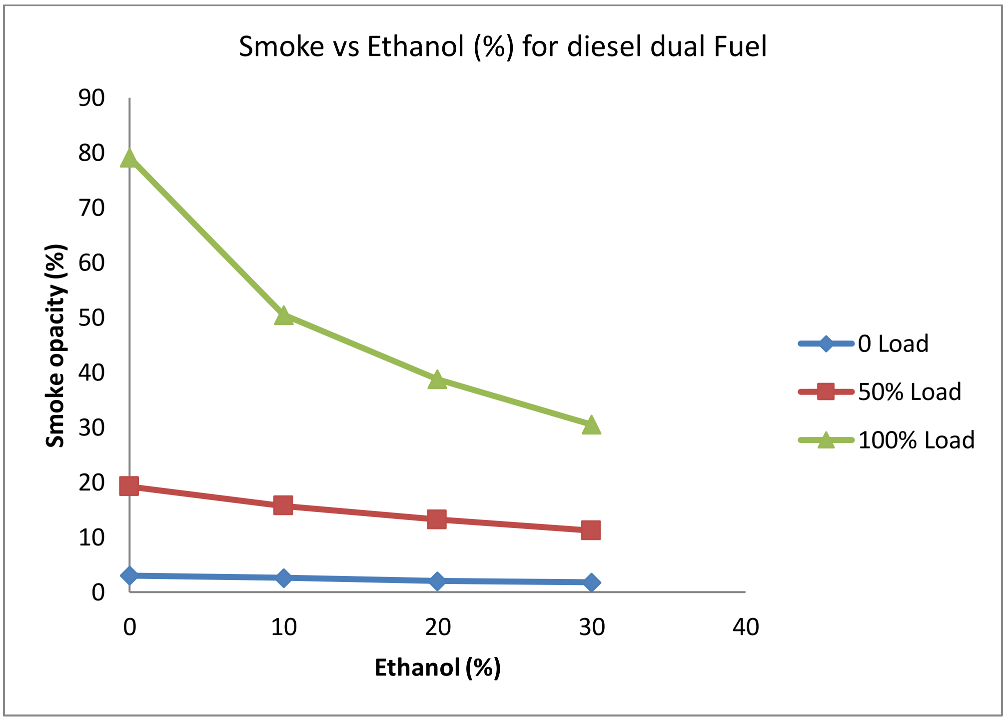


Figure 4.10(a): Variation of smoke opacity with diesel-ethanol combination

Smoke opacity increases with increasing load but decreases with increasing alcohol substitution for both the primary fuels. With diesel-ethanol combination and biodiesel-ethanol combination, smoke opacity decreases sharply up to 20% ethanol at 100% load. Both diesel and biodiesel with 20% ethanol injection gives maximum reduction of 42% in smoke opacity value at full load.

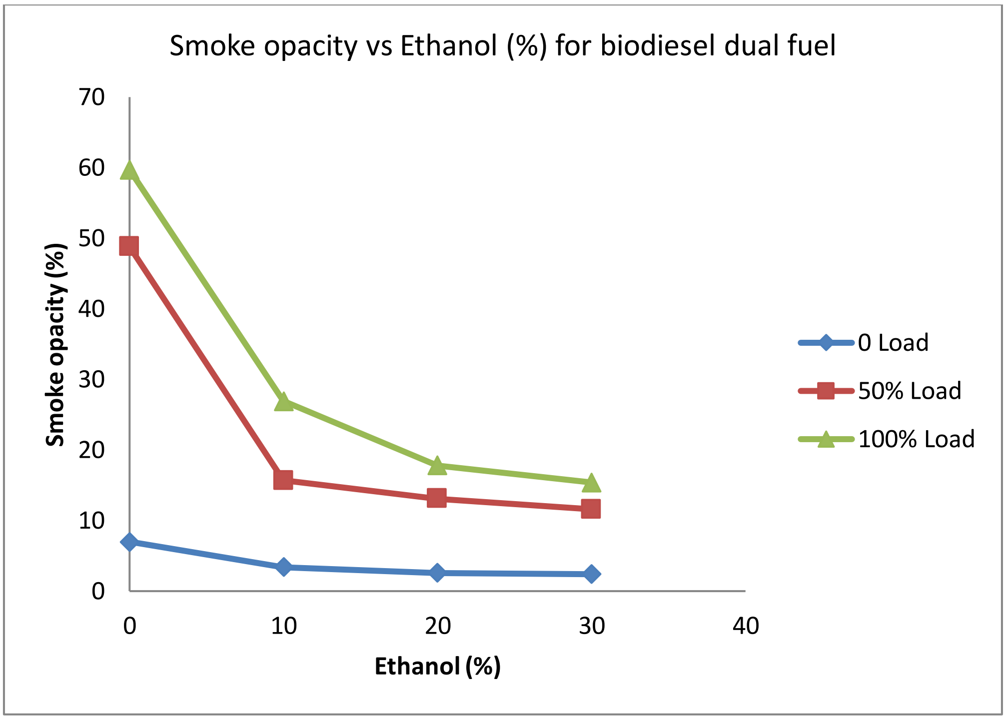


Figure 4.10 (b): Variation of smoke opacity with biodiesel-ethanol combination

Biodiesel-ethanol combination exhibits lower smoke opacity than diesel-ethanol combination under no load and high load conditions but exhibits higher smoke opacity under intermediate load condition. For all loads with diesel and biodiesel the smoke opacity decreases as ethanol percentage increases. Since alcohol has lower calorific values, so alcohol substitution significantly reduces smoke emission.

Smoke opacity increases as we move towards high loads in single fuel mode. At lower loads oxygenated excess air caused lower smoke opacity. At higher loads it increases due to improper mixing of air with diesel/ biodiesel fuel due to decrease in combustion time required for rich mixture.

Smoke opacity for biodiesel was lower than those of diesel fuel in both single and dual combustion modes under no load and high load conditions.

Restricted air filters, mismatch of injection timing, poorly maintained or malfunctioning engines are also sometimes the cause of excessive smoke. Alcohol fumigation significantly reduces the smoke opacity as compared to neat diesel/ biodiesel fuel. Reduction in smoke emission may be due to fact that less diesel/biodiesel fuel is consumed with increasing alcohol injection since a remarkable part of diesel fuel is replaced by alcohol. Therefore, less diesel fuel is burned in the diffusion mode and combusts together with the homogenous alcohol/ air mixture which helps in fast burning and with higher availability of oxygen, leading to a reduction in smoke emission.

Also, alcohol injection increases the ignition delay which enhances the mixing of diesel/biodiesel fuel with the alcohol–air mixture that improves air utilization and reduces smoke. Alcohol is free of aromatics, free of sulfur, has lower C/H ratio than diesel /biodiesel fuel and alcohol also increases the hydrogen content in the mixture, resulting in a reduction in smoke emission.

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

The present study was undertaken to handle the situation of fuel crisis arising with continuous depletion of petroleum based fossil fuels. This work mainly focuses on substitution of diesel with biodiesel supplemented with ethanol without any major modification in existing diesel engines. This study compares the performance and exhaust emissions of a DI diesel engine operated in dual fuel mode with diesel and with biodiesel as primary fuels both supplemented with ethanol as secondary fuel. This was achieved by producing the Polanga based methyl ester i.e. biodiesel and using a new simple injection technique for introducing the ethanol in the combustion chamber. The conclusions which may be drawn from this study are as follows:

1. The pretreatment reaction using acid based catalyst reaction reduced the acid value of the relatively cheaper but high FFA content Polanga feedstock to less than 2% in single step pretreatment process. Increasing the amount of the acid in the pretreatment process decreases the FFA content to the required level suitable for transesterification. Acid catalyzed pretreatment led the transesterification of polanga oil to produce methyl ester in less time with high yield. The amount of methanol used also got reduced as compared to the amount used by other researchers in their study.

2. The viscosity of polanga oil gets drastically reduced after transesterification. The calorific value of biodiesel was found to be slightly lower than mineral diesel. The physical characteristics like viscosity, flash point, and density of biodiesel are in very close agreement with those of mineral diesel making it a potential candidate for using as primary fuel in CI engines
3. The newly developed injection technique to introduce ethanol as secondary fuel in different percentage is effective and produces encouraging results. This is able to inject any required percentage of ethanol in the inlet manifold. The alcohol fuel injection system is separate from the diesel injection system. This flexibility enables diesel engines equipped with the secondary injection system to operate in single fuel mode also. The engine can switch from dual fuel to single fuel operation and vice-versa by disconnecting and connecting the alcohol injector.
4. Diesel engine can perform on biodiesel without any engine hardware modifications and for dual fuel injection alcohol injector is placed at the intake air manifold. Also, flow control of the fuel can be managed by a simplified device and fuel supply system.
5. Performance and emission characteristics of polanga oil based biodiesel are comparable to that of diesel. The cylinder peak pressure increases with load but decreases with ethanol content for both the primary fuels. The variation in peak pressure with load is vary drastic but just reasonable with alcohol content. For biodiesel as primary fuel, the variation with ethanol content is insignificant at half and full loads. Maximum and minimum peak pressures at full load are 63 and 61.33 bar for diesel respectively with 10% and 30% ethanol injection which are 4.5% and 7% less than the rated peak pressure.

Maximum and minimum peak pressures at full load are 61.21 and 60.51 for biodiesel respectively with 10% and 30% ethanol injection which are 7.2% and 8.2% less than the rated peak pressure. Dual fuel operation results in lower peak cylinder pressure (4 - 8% lower) as compared to that with diesel in single fuel operation, which eliminates any danger to the engine structure. The observed low peak pressure in dual fuel combustion is the result of high specific heat capacity and low cetane number of ethanol as compared to those of diesel/biodiesel.

6. Brake thermal efficiency was found to increase with increasing load and increasing alcohol addition for both the primary fuels. However, BTE for biodiesel is found to be 33.09% with 30% alcohol injection at full load. This is nearly 5% higher than the rated efficiency with diesel in single fuel mode and 2.5% higher than that of diesel with 30% alcohol at full load. It is attributed to more premixed combustion due to fast burning of homogeneous alcohol-air mixture, reduction in heat losses due to low cetane number of alcohol causing longer ignition delay, maximum air availability as a consequence of increase in density of intake mixture with alcohol addition and more heat release during controlled combustion.
7. CO emission increases with increasing load and alcohol content. CO emission at full load for diesel as primary fuel are minimum with 20% alcohol injection and for biodiesel as primary fuel are minimum with 10% alcohol injection. These emissions for both the primary fuels are even less than their corresponding CO emissions in single fuel mode. The reduction in CO emissions is 8% and 4% respectively for diesel and biodiesel as primary fuels. This may be attributed to rapid burning of vaporized alcohol

and decrease in inside cylinder temperature due to high latent heat of vaporization of alcohol.

8. CO_2 emissions follow the opposite trend to CO emissions i.e. decreases with increasing load and alcohol content. CO_2 emissions are minimum with 30% alcohol injection at full load and are less than corresponding emissions with primary fuels in single fuel mode however the reduction is not very significant. This may be attributed to high latent heat of vaporization of alcohol causing lowering of inside cylinder temperature which restricts the conversion of CO to CO_2.
9. NOx emissions follow a mixed trend i.e. decreases with increasing alcohol content but increases with increasing load with one exceptions for each of primary fuels. Maximum NOx emissions are observed with primary fuels in single fuel mode at full load. Addition of 30% alcohol as secondary fuel results in a drastic reduction in NOx emissions. This may also be attributed to high latent heat of vaporization of alcohol causing lowering of inside cylinder temperature which restricts the formation of NOx.
10. Unburnt Hydro Carbon (UHC) emissions follow the opposite trend to NOx emissions i.e. increases with increasing alcohol content but decreases with increasing load. Variation in UHC emissions with load is more significant than alcohol content. With 30% ethanol, the reduction in UHC emission is 83% for diesel as primary fuel while it is 89% for biodiesel under full load. The effect of alcohol content on UHC emission is insignificant at all loads. This may also be attributed to high latent heat of vaporization of alcohol causing lowering of inside cylinder temperature which leads to incomplete combustion of the fuel mixture.

11. Smoke opacity follows similar trend as exhibited by NOx emissions i.e. decreases with increasing alcohol content and increases with increasing load. Maximum smoke opacity is observed at full load for both the primary fuels however it decreases with increasing alcohol content under all loading conditions. Maximum reduction of 44% is achieved for both the primary fuels with 20% ethanol injection. Further increase in alcohol content affects the smoke opacity very marginally. The observed effect on smoke opacity may be attributed to replacement of aromatic primary fuels by alcohol and improved air utilization as a consequence of enhanced mixing of primary fuels with alcohol-air mixture due to increase in ignition delay.

Based on the above results, the optimum percentage of ethanol seems to be 20% for dual fuel operation. The use of 20% ethanol as a substitute can produce an increase of 2 % in the brake thermal efficiency. It also results in decrease of 10% CO emissions levels and 45% in NOx emissions levels. Also, this injection percentage produces a decrease of 55% in engine smoke.

This detailed experimental investigation confirms that biodiesel and ethanol can substitute mineral diesel without any modification in the engine. Hence, biodiesel and ethanol may be considered as diesel fuel substitutes. The use of biofuels as IC engine fuels can play a vital role in helping the developed and developing countries to reduce the environmental impact of fossil fuels.

However, further research and development on the additional fuel property measures, long-term run and wear analysis of dual fuel engine fueled with polanga biodiesel is also necessary along with injection timing and duration for better combustion.

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APPENDICES

Table A1: Heat Release at different crank angle for varying ethanol with diesel at no load

Diesel + 0% Ethanol		Diesel + 10% Ethanol		Diesel + 20% Ethanol		Diesel + 30% Ethanol	
Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)
320.354	0.777	321.168	-0.385	319.747	-0.211	320.760	-0.151
320.810	0.463	321.624	-0.636	320.202	0.007	321.217	-0.757
321.266	0.358	322.081	-1.133	320.657	-0.199	321.673	-0.905
321.722	-0.217	322.538	-0.620	321.112	-0.367	322.129	-0.798
322.177	-0.867	322.995	0.313	321.567	-0.502	322.586	-1.015
322.633	-0.973	323.452	-0.778	322.021	-0.469	323.042	-0.709
323.089	-0.538	323.909	-1.153	322.476	-0.409	323.498	-0.601
323.544	0.500	324.365	-0.385	322.931	-0.723	323.954	-1.131
324.000	-0.072	324.822	-0.101	323.386	-1.040	324.411	-0.990
324.456	-0.647	325.279	-0.270	323.841	-1.118	324.867	-0.508
324.911	-0.081	325.736	-0.623	324.296	-1.388	325.323	-0.430
325.367	0.432	326.193	-0.097	324.750	-1.719	325.779	-0.371
325.823	0.506	326.650	0.112	325.205	-1.674	326.236	-0.465
326.278	-0.564	327.107	-1.039	325.660	-1.302	326.692	-0.773
326.734	-0.603	327.563	-1.257	326.115	-0.663	327.148	-0.988
327.190	-0.118	328.020	-0.616	326.570	-0.087	327.605	-0.977
327.646	-0.450	328.477	-0.454	327.025	-1.117	328.061	-0.941
328.101	-0.659	328.934	-0.319	327.479	-1.984	328.517	-1.163
328.557	-0.599	329.391	-0.553	327.934	-1.413	328.973	-0.963
329.013	-0.331	329.848	-1.213	328.389	-1.340	329.430	-0.762
329.468	-0.424	330.305	-1.287	328.844	-0.976	329.886	-1.567
329.924	-0.558	330.761	-1.054	329.299	-0.717	330.342	-1.804
330.380	-0.558	331.218	-0.771	329.754	-1.588	330.798	-1.033
330.835	-0.890	331.675	-0.695	330.208	-2.001	331.255	-1.040
331.291	-0.833	332.132	-1.018	330.663	-1.351	331.711	-1.129
331.747	-0.335	332.589	-1.353	331.118	-1.073	332.167	-0.960
332.203	-0.696	333.046	-1.584	331.573	-1.226	332.624	-1.811
332.658	-1.117	333.503	-1.625	332.028	-1.249	333.080	-2.237
333.114	-1.540	333.959	-1.467	332.483	-1.188	333.536	-1.667
333.570	-1.948	334.416	-1.468	332.937	-1.469	333.992	-1.486
334.025	-1.086	334.873	-1.524	333.392	-1.425	334.449	-1.675
334.481	-0.726	335.330	-1.509	333.847	-1.000	334.905	-2.069
334.937	-1.363	335.787	-1.788	334.302	-1.641	335.361	-2.096
335.392	-1.526	336.244	-2.078	334.757	-1.909	335.817	-1.938
335.848	-1.136	336.701	-2.069	335.212	-1.226	336.274	-2.144
336.304	-1.043	337.157	-1.666	335.666	-1.036	336.730	-2.240
336.759	-1.726	337.614	-1.559	336.121	-1.729	337.186	-2.092
337.215	-1.741	338.071	-1.947	336.576	-1.860	337.643	-2.097
337.671	-1.179	338.528	-2.179	337.031	-1.417	338.099	-2.185
338.127	-1.753	338.985	-2.352	337.486	-1.301	338.555	-2.035
338.582	-2.320	339.442	-2.548	337.941	-1.624	339.011	-2.305
339.038	-2.275	339.898	-2.601	338.395	-1.815	339.468	-2.643
339.494	-2.394	340.355	-2.500	338.850	-1.489	339.924	-2.641
339.949	-2.217	340.812	-2.411	339.305	-1.921	340.380	-2.632
340.405	-2.116	341.269	-2.368	339.760	-2.419	340.837	-2.731

Table A1: Heat Release at different crank angle for varying ethanol with diesel at no load

340.861	-2.231	341.726	-2.513	340.215	-2.074	341.293	-2.921
341.316	-2.305	342.183	-2.531	340.670	-1.694	341.749	-2.937
341.772	-2.797	342.640	-2.570	341.124	-1.639	342.205	-2.967
342.228	-2.870	343.096	-2.794	341.579	-2.212	342.662	-2.953
342.684	-2.482	343.553	-2.858	342.034	-2.665	343.118	-2.886
343.139	-2.721	344.010	-3.009	342.489	-2.087	343.574	-3.213
343.595	-2.914	344.467	-2.879	342.944	-2.243	344.030	-3.332
344.051	-2.695	344.924	-2.632	343.399	-2.493	344.487	-2.789
344.506	-2.844	345.381	-2.913	343.853	-2.121	344.943	-3.063
344.962	-3.230	345.838	-3.151	344.308	-2.722	345.399	-3.688
345.418	-3.438	346.294	-3.001	344.763	-3.009	345.856	-3.342
345.873	-3.653	346.751	-2.789	345.218	-2.417	346.312	-3.132
346.329	-3.636	347.208	-2.949	345.673	-2.195	346.768	-3.388
346.785	-3.583	347.665	-3.471	346.128	-2.478	347.224	-3.604
347.241	-3.973	348.122	-3.684	346.582	-2.727	347.681	-3.783
347.696	-4.035	348.579	-3.449	347.037	-2.808	348.137	-3.818
348.152	-3.710	349.036	-3.203	347.492	-2.651	348.593	-3.751
348.608	-3.923	349.492	-3.256	347.947	-2.521	349.049	-3.764
349.063	-4.071	349.949	-3.359	348.402	-2.864	349.506	-3.868
349.519	-3.721	350.406	-3.323	348.857	-3.170	349.962	-4.120
349.975	-3.849	350.863	-3.372	349.311	-3.136	350.418	-4.156
350.430	-4.108	351.320	-3.682	349.766	-2.889	350.875	-3.937
350.886	-3.693	351.777	-3.694	350.221	-2.890	351.331	-4.038
351.342	-3.710	352.234	-3.357	350.676	-3.089	351.787	-3.938
351.797	-3.851	352.690	-2.646	351.131	-3.094	352.243	-3.753
352.253	-3.174	353.147	-2.272	351.586	-3.057	352.700	-3.738
352.709	-2.754	353.604	-3.416	352.040	-2.903	353.156	-3.706
353.165	-2.744	354.061	-4.085	352.495	-2.538	353.612	-3.992
353.620	-2.998	354.518	-3.517	352.950	-2.386	354.068	-4.021
354.076	-3.066	354.975	-3.119	353.405	-2.855	354.525	-3.840
354.532	-2.293	355.431	-2.856	353.860	-3.303	354.981	-3.717
354.987	-0.822	355.888	-2.364	354.315	-3.069	355.437	-3.337
355.443	0.781	356.345	-1.955	354.769	-2.873	355.894	-2.790
355.899	2.451	356.802	-1.810	355.224	-2.953	356.350	-2.259
356.354	4.589	357.259	-1.100	355.679	-2.402	356.806	-1.732
356.810	6.920	357.716	0.163	356.134	-1.526	357.262	-0.997
357.266	9.304	358.173	1.075	356.589	-1.361	357.719	-0.031
357.722	11.725	358.629	2.158	357.044	-1.495	358.175	1.235
358.177	13.836	359.086	3.745	357.498	-0.808	358.631	2.991
358.633	15.126	359.543	5.319	357.953	0.445	359.087	4.944
359.089	15.766	360.000	7.333	358.408	1.346	359.544	7.004
359.544	16.009	360.457	9.889	358.863	2.052	360.000	9.107
360.000	16.042	360.914	11.916	359.318	3.561	360.456	11.198
360.456	15.610	361.371	12.950	359.773	5.484	360.913	12.819
360.911	14.255	361.827	13.391	360.227	7.399	361.369	13.303
361.367	13.108	362.284	13.505	360.682	9.118	361.825	13.394
361.823	12.086	362.741	13.392	361.137	10.601	362.281	13.271
362.278	10.693	363.198	12.933	361.592	11.868	362.738	12.457
362.734	9.393	363.655	12.424	362.047	12.368	363.194	11.728
363.190	8.060	364.112	12.064	362.502	12.889	363.650	11.130
363.646	6.806	364.569	11.382	362.956	13.082	364.106	9.940
364.101	5.475	365.025	10.300	363.411	12.665	364.563	8.846

Table A1: Heat Release at different crank angle for varying ethanol with diesel at no load

364.557	4.409	365.482	9.092	363.866	12.427	365.019	8.046
365.013	3.865	365.939	8.139	364.321	12.183	365.475	7.134
365.468	3.722	366.396	7.609	364.776	11.816	365.932	6.444
365.924	3.562	366.853	7.098	365.231	11.102	366.388	5.626
366.380	3.005	367.310	6.030	365.685	9.952	366.844	4.801
366.835	3.128	367.766	5.409	366.140	8.922	367.300	4.583
367.291	3.358	368.223	5.414	366.595	8.135	367.757	4.171
367.747	2.955	368.680	4.978	367.050	7.297	368.213	3.733
368.203	3.051	369.137	4.840	367.505	6.377	368.669	3.723
368.658	3.410	369.594	4.757	367.960	5.434	369.125	3.578
369.114	3.414	370.051	4.205	368.414	5.024	369.582	3.351
369.570	3.294	370.508	4.037	368.869	5.361	370.038	3.330
370.025	3.355	370.964	4.148	369.324	5.418	370.494	3.481
370.481	3.312	371.421	4.110	369.779	5.030	370.951	3.455
370.937	3.249	371.878	3.914	370.234	4.687	371.407	3.440
371.392	3.178	372.335	3.965	370.689	4.553	371.863	3.426
371.848	3.056	372.792	3.986	371.143	4.340	372.319	3.534
372.304	3.248	373.249	3.626	371.598	3.940	372.776	3.694
372.759	3.128	373.706	3.501	372.053	3.588	373.232	3.462
373.215	2.995	374.162	3.538	372.508	3.307	373.688	3.189
373.671	3.028	374.619	3.746	372.963	3.160	374.144	2.915
374.127	2.859	375.076	3.594	373.418	3.019	374.601	2.814
374.582	2.746	375.533	3.376	373.872	2.646	375.057	2.987
375.038	2.877	375.990	3.616	374.327	2.198	375.513	3.174
375.494	3.147	376.447	3.252	374.782	1.973	375.970	3.122
375.949	3.166	376.904	2.919	375.237	2.091	376.426	3.105
376.405	3.113	377.360	3.174	375.692	2.231	376.882	3.408
376.861	3.135	377.817	3.201	376.147	2.432	377.338	3.471
377.316	3.101	378.274	3.017	376.601	2.714	377.795	3.124
377.772	2.970	378.731	2.670	377.056	2.479	378.251	2.726
378.228	2.554	379.188	2.315	377.511	2.276	378.707	2.494
378.684	2.370	379.645	2.624	377.966	2.141	379.163	2.500
379.139	2.413	380.102	2.801	378.421	2.029	379.620	2.488
379.595	2.472	380.558	2.291	378.876	1.808	380.076	2.569
380.051	2.852	381.015	1.973	379.330	1.927	380.532	2.594
380.506	2.913	381.472	1.953	379.785	2.307	380.989	2.252
380.962	2.944	381.929	1.626	380.240	2.396	381.445	1.948
381.418	3.246	382.386	1.592	380.695	2.554	381.901	1.956
381.873	3.413	382.843	2.102	381.150	2.113	382.357	1.952
382.329	3.627	383.299	1.879	381.605	1.766	382.814	1.666
382.785	3.470	383.756	1.371	382.059	1.950	383.270	1.678
383.241	3.677	384.213	1.236	382.514	1.946	383.726	1.925
383.696	4.133	384.670	1.708	382.969	1.431	384.183	2.029
384.152	3.985	385.127	2.113	383.424	1.307	384.639	1.715
384.608	3.948	385.584	1.570	383.879	1.950	385.095	1.400
385.063	3.755	386.041	1.854	384.334	2.045	385.551	1.370
385.519	3.686	386.497	2.315	384.788	2.216	386.008	1.048
385.975	3.621	386.954	1.766	385.243	2.010	386.464	1.099
386.430	3.723	387.411	1.639	385.698	1.415	386.920	1.596
386.886	4.169	387.868	1.780	386.153	1.817	387.376	1.715
387.342	3.556	388.325	1.594	386.608	1.720	387.833	1.831
387.797	2.413	388.782	1.408	387.063	1.477	388.289	1.814

Table A1: Heat Release at different crank angle for varying ethanol with diesel at no load

388.253	2.116	389.239	1.523	387.517	1.485	388.745	1.461
388.709	2.252	389.695	1.756	387.972	1.358	389.202	1.148
389.165	1.683	390.152	1.611	388.427	1.544	389.658	0.826
389.620	0.913	390.609	0.892	388.882	1.083	390.114	0.754
390.076	0.700	391.066	0.540	389.337	0.686	390.570	0.881
390.532	0.301	391.523	0.696	389.792	1.047	391.027	1.057
390.987	0.174	391.980	0.570	390.246	1.492	391.483	0.492
391.443	0.751	392.437	0.516	390.701	1.854	391.939	-0.215
391.899	0.203	392.893	0.874	391.156	0.927	392.395	0.084
392.354	-0.162	393.350	1.158	391.611	0.676	392.852	0.271
392.810	0.397	393.807	0.825	392.066	1.989	393.308	-0.050
393.266	0.531	394.264	0.496	392.521	1.349	393.764	-0.212
393.722	0.785	394.721	0.486	392.975	0.653	394.221	0.585
394.177	0.260	395.178	0.591	393.430	1.848	394.677	0.869
394.633	-0.075	395.635	0.812	393.885	2.150	395.133	0.197
395.089	0.982	396.091	0.703	394.340	1.854	395.589	0.535
395.544	1.053	396.548	0.791	394.795	1.936	396.046	0.626
396.000	0.799	397.005	1.022	395.250	1.625	396.502	0.088
396.456	0.974	397.462	0.807	395.704	2.437	396.958	0.431
396.911	-0.049	397.919	1.122	396.159	3.003	397.414	0.451
397.367	-0.348	398.376	1.098	396.614	2.291	397.871	-0.350
397.823	0.499	398.832	0.228	397.069	1.908	398.327	-0.420
398.278	1.414	399.289	0.146	397.524	2.591	398.783	0.229
398.734	1.757	399.746	0.404	397.979	3.245	399.240	1.078
399.190	1.219	400.203	1.265	398.433	3.210	399.696	0.820
399.646	0.504	400.660	1.449	398.888	3.482	400.152	-0.405
400.101	-0.026	401.117	-0.371	399.343	3.814	400.608	-0.381
400.557	0.235	401.574	-0.610	399.798	4.649	401.065	0.371
401.013	0.922	402.030	0.963	400.253	4.460	401.521	0.715
401.468	0.854	402.487	1.936	400.708	4.443	401.977	-0.019
401.924	0.264	402.944	1.529	401.162	5.503	402.433	-1.095
402.380	0.213	403.401	-0.106	401.617	5.749	402.890	-0.385
402.835	1.346	403.858	-0.443	402.072	6.753	403.346	0.908
403.291	1.758	404.315	0.582	402.527	7.207	403.802	0.624
403.747	-0.278	404.772	1.115	402.982	6.546	404.259	-0.458
404.203	-1.087	405.228	1.645	403.437	7.275	404.715	-0.240
404.658	-0.092	405.685	0.864	403.891	8.238	405.171	-0.087
405.114	-0.062	406.142	0.783	404.346	8.489	405.627	-0.735
405.570	0.574	406.599	1.809	404.801	8.894	406.084	-0.258
406.025	1.740	407.056	0.843	405.256	8.651	406.540	-0.163
406.481	1.231	407.513	1.126	405.711	8.472	406.996	-0.614
406.937	0.192	407.970	3.349	406.166	9.085	407.452	-0.792
407.392	-0.395	408.426	5.115	406.620	8.546	407.909	-0.554
407.848	0.119	408.883	5.565	407.075	7.920	408.365	-0.213
408.304	1.715	409.340	4.747	407.530	8.447	408.821	-0.092
408.759	3.077	409.797	5.191	407.985	8.380	409.278	0.244
409.215	3.352	410.254	7.616	408.440	6.678	409.734	-0.892
409.671	2.494	410.711	8.542	408.895	6.085	410.190	-1.485
410.127	2.698	411.168	8.013	409.349	7.639	410.646	-1.166
410.582	4.136	411.624	8.065	409.804	7.537	411.103	-1.571
411.038	4.258	412.081	8.572	410.259	6.945	411.559	-0.025
411.494	4.088	412.538	8.860	410.714	7.558	412.015	0.292

Table A1: Heat Release at different crank angle for varying ethanol with diesel at no load

411.949	4.857	412.995	9.002	411.169	7.254	412.471	-0.953
412.405	5.199	413.452	9.196	411.623	7.699	412.928	-0.941
412.861	4.177	413.909	8.811	412.078	8.233	413.384	-1.038
413.316	3.908	414.365	9.383	412.533	6.925	413.840	-0.354
413.772	5.611	414.822	9.149	412.988	6.105	414.297	0.703
414.228	5.026	415.279	7.480	413.443	5.405	414.753	0.358
414.684	4.069	415.736	6.230	413.898	5.541	415.209	-0.523
415.139	5.420	416.193	6.514	414.352	6.248	415.665	-0.258
415.595	5.890	416.650	8.170	414.807	4.870	416.122	-0.186
416.051	5.840	417.107	6.994	415.262	4.402	416.578	-0.208
416.506	5.077	417.563	5.060	415.717	6.309	417.034	-0.440
416.962	4.964	418.020	7.163	416.172	6.699	417.490	-0.516
417.418	5.910	418.477	8.422	416.627	4.789	417.947	-0.819
417.873	5.529	418.934	5.832	417.081	4.310	418.403	-2.157
418.329	4.420	419.391	5.485	417.536	5.930	418.859	-1.323
418.785	3.949	419.848	5.392	417.991	5.687	419.316	-1.182
419.241	5.146	420.305	3.979	418.446	3.889	419.772	-1.375
419.696	4.922	420.761	5.293	418.901	4.990	420.228	-0.582
420.152	5.032	421.218	5.061	419.356	4.776	420.684	-0.498
420.608	6.133	421.675	4.466	419.810	2.510	421.141	0.507

Table A2: Heat Release at different crank angle for varying ethanol with diesel at 50% load

Diesel + 0% Ethanol		Diesel + 10% Ethanol		Diesel + 20% Ethanol		Diesel + 30% Ethanol	
Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)
320.393	-1.074	321.778	-1.030	322.375	-0.584	321.429	1.119
320.836	-1.286	322.222	-0.787	322.820	-0.260	321.872	0.369
321.278	0.079	322.667	-0.605	323.265	0.033	322.315	0.288
321.721	-0.201	323.111	-0.436	323.711	-1.482	322.759	0.405
322.163	-0.367	323.556	-0.845	324.156	-1.522	323.202	-0.984
322.606	-0.534	324.000	-1.258	324.601	-0.057	323.645	-1.583
323.049	-0.770	324.444	-1.547	325.046	-0.948	324.089	-0.362
323.491	-0.046	324.889	-1.215	325.492	-1.512	324.532	-0.598
323.934	-0.407	325.333	-0.626	325.937	-0.940	324.975	-0.737
324.376	-0.478	325.778	-0.889	326.382	-0.899	325.419	0.792
324.819	-0.188	326.222	-0.406	326.827	-0.749	325.862	0.742
325.261	-0.458	326.667	-0.218	327.273	-0.755	326.305	-0.350
325.704	-0.184	327.111	-0.584	327.718	-0.862	326.749	-0.736
326.146	-0.355	327.556	-0.402	328.163	-0.548	327.192	-0.431
326.589	-0.217	328.000	-1.447	328.609	0.026	327.635	-0.308
327.031	-0.154	328.444	-1.825	329.054	0.239	328.079	-0.219
327.474	-0.909	328.889	-0.739	329.499	0.127	328.522	0.097
327.916	-1.491	329.333	-0.905	329.944	0.145	328.966	-0.192
328.359	-1.018	329.778	-1.051	330.390	0.107	329.409	-0.619
328.801	-0.241	330.222	-1.315	330.835	-0.094	329.852	-0.734
329.244	-0.372	330.667	-1.410	331.280	0.427	330.296	-0.407
329.687	-0.991	331.111	-1.007	331.725	1.210	330.739	-0.346
330.129	-1.488	331.556	-1.768	332.171	0.700	331.182	-0.468
330.572	-1.158	332.000	-1.396	332.616	-0.222	331.626	-0.474
331.014	-0.482	332.444	-0.466	333.061	-0.017	332.069	-0.910
331.457	-0.598	332.889	-0.988	333.506	1.022	332.512	-1.190
331.899	-1.765	333.333	-2.242	333.952	1.396	332.956	-1.050
332.342	-2.097	333.778	-2.150	334.397	0.696	333.399	-0.572
332.784	-1.093	334.222	-0.844	334.842	0.170	333.842	-0.773
333.227	-1.074	334.667	-0.812	335.288	0.499	334.286	-1.202
333.669	-1.422	335.111	-1.724	335.733	0.675	334.729	-0.730
334.112	-1.030	335.556	-2.549	336.178	0.403	335.172	-0.320
334.554	-1.283	336.000	-2.237	336.623	0.025	335.616	-0.244
334.997	-1.701	336.444	-1.618	337.069	0.118	336.059	-0.531
335.439	-1.524	336.889	-1.562	337.514	0.843	336.502	-1.227
335.882	-1.797	337.333	-2.020	337.959	0.364	336.946	-1.666
336.325	-2.242	337.778	-2.476	338.404	-0.285	337.389	-1.610
336.767	-1.893	338.222	-1.783	338.850	-0.259	337.833	-1.119
337.210	-1.426	338.667	-1.558	339.295	-0.797	338.276	-0.873
337.652	-1.685	339.111	-2.570	339.740	-1.347	338.719	-1.017
338.095	-2.643	339.556	-2.945	340.186	-1.512	339.163	-0.920
338.537	-2.772	340.000	-2.484	340.631	-1.092	339.606	-1.224
338.980	-2.095	340.444	-2.786	341.076	-0.756	340.049	-1.615
339.422	-2.163	340.889	-2.811	341.521	-1.182	340.493	-1.731
339.865	-2.364	341.333	-1.994	341.967	-1.483	340.936	-2.067
340.307	-2.213	341.778	-1.758	342.412	-1.379	341.379	-1.964

Table A2: Heat Release at different crank angle for varying ethanol with diesel at 50% load

340.750	-2.307	342.222	-2.239	342.857	-1.396	341.823	-1.209
341.192	-2.570	342.667	-2.841	343.302	-1.532	342.266	-1.095
341.635	-2.564	343.111	-2.759	343.748	-1.596	342.709	-1.793
342.077	-2.760	343.556	-2.599	344.193	-1.561	343.153	-1.860
342.520	-3.011	344.000	-2.540	344.638	-1.861	343.596	-1.772
342.963	-2.798	344.444	-2.424	345.083	-2.369	344.039	-2.085
343.405	-2.945	344.889	-3.268	345.529	-2.271	344.483	-2.020
343.848	-3.388	345.333	-3.652	345.974	-2.201	344.926	-1.730
344.290	-3.438	345.778	-3.064	346.419	-2.418	345.369	-1.875
344.733	-3.367	346.222	-3.046	346.865	-2.394	345.813	-2.290
345.175	-3.387	346.667	-2.785	347.310	-2.571	346.256	-2.482
345.618	-3.717	347.111	-2.951	347.755	-3.076	346.700	-2.582
346.060	-4.091	347.556	-3.599	348.200	-2.950	347.143	-2.309
346.503	-3.904	348.000	-3.784	348.646	-2.521	347.586	-2.253
346.945	-3.762	348.444	-3.759	349.091	-2.867	348.030	-2.529
347.388	-4.157	348.889	-3.165	349.536	-3.115	348.473	-2.468
347.830	-4.625	349.333	-3.522	349.981	-2.753	348.916	-2.847
348.273	-4.613	349.778	-4.111	350.427	-2.517	349.360	-3.077
348.715	-3.967	350.222	-3.564	350.872	-2.711	349.803	-2.580
349.158	-3.955	350.667	-3.373	351.317	-3.172	350.246	-2.259
349.600	-4.291	351.111	-3.331	351.763	-3.129	350.690	-2.283
350.043	-3.863	351.556	-3.227	352.208	-2.346	351.133	-2.268
350.486	-3.454	352.000	-3.158	352.653	-1.909	351.576	-1.963
350.928	-3.354	352.444	-2.524	353.098	-1.655	352.020	-1.301
351.371	-3.137	352.889	-2.141	353.544	-1.349	352.463	-0.614
351.813	-2.495	353.333	-1.953	353.989	-1.625	352.906	0.244
352.256	-1.286	353.778	-1.563	354.434	-1.578	353.350	1.934
352.698	0.408	354.222	-1.097	354.879	-0.317	353.793	4.159
353.141	2.735	354.667	0.485	355.325	1.515	354.236	6.876
353.583	5.761	355.111	2.998	355.770	3.573	354.680	10.360
354.026	8.920	355.556	5.689	356.215	6.493	355.123	14.647
354.468	13.452	356.000	9.419	356.660	10.334	355.567	19.183
354.911	19.659	356.444	13.800	357.106	14.254	356.010	23.234
355.353	24.590	356.889	17.754	357.551	17.694	356.453	26.644
355.796	28.087	357.333	21.376	357.996	20.864	356.897	28.690
356.238	31.082	357.778	24.721	358.442	24.191	357.340	29.459
356.681	31.869	358.222	27.245	358.887	26.707	357.783	29.034
357.124	31.925	358.667	28.720	359.332	27.693	358.227	27.154
357.566	31.464	359.111	29.799	359.777	28.621	358.670	24.430
358.009	28.468	359.556	30.389	360.223	29.456	359.113	21.097
358.451	24.953	360.000	29.466	360.668	29.126	359.557	18.052
358.894	20.597	360.444	27.132	361.113	27.643	360.000	15.647
359.336	15.730	360.889	23.999	361.558	25.232	360.443	13.305
359.779	11.650	361.333	19.812	362.004	22.273	360.887	11.651
360.221	8.338	361.778	15.673	362.449	19.076	361.330	10.616
360.664	6.854	362.222	12.210	362.894	16.068	361.773	9.743
361.106	6.253	362.667	9.172	363.340	13.206	362.217	9.000
361.549	5.994	363.111	7.409	363.785	10.635	362.660	8.122
361.991	6.163	363.556	6.832	364.230	8.837	363.103	7.977
362.434	5.852	364.000	6.921	364.675	7.771	363.547	8.278
362.876	5.818	364.444	7.050	365.121	7.259	363.990	8.140

Table A2: Heat Release at different crank angle for varying ethanol with diesel at 50% load

363.319	6.416	364.889	6.829	365.566	6.962	364.433	7.905
363.762	6.399	365.333	6.861	366.011	6.836	364.877	7.527
364.204	6.160	365.778	6.701	366.456	6.840	365.320	7.310
364.647	6.042	366.222	6.328	366.902	6.742	365.764	7.540
365.089	6.336	366.667	6.411	367.347	6.941	366.207	7.515
365.532	6.767	367.111	6.969	367.792	7.262	366.650	7.248
365.974	6.548	367.556	7.280	368.237	7.129	367.094	7.542
366.417	6.598	368.000	6.775	368.683	7.080	367.537	7.757
366.859	6.951	368.444	6.886	369.128	7.288	367.980	7.811
367.302	7.007	368.889	7.445	369.573	7.390	368.424	8.056
367.744	7.163	369.333	7.265	370.019	7.234	368.867	8.059
368.187	7.122	369.778	7.013	370.464	7.180	369.310	8.050
368.629	6.863	370.222	7.257	370.909	7.726	369.754	8.109
369.072	6.772	370.667	7.192	371.354	7.999	370.197	7.923
369.514	6.632	371.111	6.978	371.800	7.554	370.640	7.690
369.957	6.484	371.556	7.123	372.245	7.359	371.084	8.165
370.400	6.326	372.000	6.833	372.690	7.415	371.527	8.601
370.842	6.371	372.444	6.827	373.135	7.323	371.970	8.442
371.285	6.591	372.889	6.757	373.581	7.333	372.414	8.265
371.727	6.546	373.333	6.345	374.026	7.480	372.857	8.259
372.170	6.320	373.778	6.711	374.471	7.127	373.300	8.222
372.612	5.800	374.222	6.744	374.917	6.533	373.744	8.199
373.055	5.319	374.667	6.227	375.362	6.690	374.187	8.825
373.497	5.608	375.111	5.950	375.807	6.804	374.631	9.109
373.940	6.120	375.556	6.058	376.252	6.822	375.074	8.369
374.382	6.288	376.000	6.586	376.698	6.758	375.517	7.825
374.825	6.162	376.444	6.425	377.143	6.110	375.961	7.414
375.267	5.685	376.889	5.983	377.588	6.057	376.404	7.500
375.710	5.333	377.333	6.341	378.033	6.460	376.847	8.130
376.152	5.665	377.778	6.587	378.479	6.659	377.291	7.812
376.595	5.719	378.222	6.035	378.924	6.552	377.734	7.211
377.037	5.290	378.667	5.600	379.369	6.432	378.177	7.148
377.480	5.330	379.111	5.911	379.814	6.475	378.621	7.188
377.923	5.409	379.556	6.110	380.260	6.633	379.064	6.972
378.365	5.055	380.000	5.766	380.705	7.025	379.507	6.773
378.808	4.823	380.444	5.166	381.150	6.681	379.951	6.595
379.250	4.966	380.889	4.710	381.596	6.074	380.394	6.274
379.693	5.014	381.333	4.787	382.041	6.084	380.837	6.065
380.135	4.727	381.778	4.693	382.486	6.234	381.281	6.021
380.578	4.037	382.222	3.873	382.931	6.273	381.724	5.609
381.020	3.498	382.667	4.202	383.377	6.102	382.167	4.895
381.463	3.896	383.111	5.038	383.822	5.733	382.611	4.958
381.905	4.001	383.556	4.208	384.267	5.460	383.054	5.498
382.348	3.556	384.000	3.429	384.712	5.502	383.498	5.579
382.790	3.750	384.444	3.532	385.158	5.833	383.941	5.390
383.233	3.728	384.889	4.054	385.603	5.978	384.384	5.424
383.675	3.256	385.333	3.896	386.048	6.040	384.828	5.428
384.118	3.226	385.778	3.470	386.494	6.513	385.271	5.089
384.561	3.668	386.222	4.608	386.939	6.952	385.714	4.940
385.003	3.462	386.667	4.947	387.384	6.812	386.158	4.975
385.446	2.577	387.111	3.701	387.829	6.789	386.601	4.916

Table A2: Heat Release at different crank angle for varying ethanol with diesel at 50% load

385.888	2.836	387.556	3.440	388.275	6.969	387.044	4.908
386.331	3.436	388.000	3.897	388.720	6.612	387.488	4.768
386.773	3.312	388.444	2.978	389.165	6.448	387.931	4.191
387.216	3.081	388.889	2.284	389.610	6.320	388.374	3.601
387.658	2.954	389.333	3.318	390.056	5.146	388.818	4.358
388.101	3.042	389.778	3.614	390.501	5.644	389.261	5.238
388.543	3.195	390.222	2.615	390.946	6.816	389.704	4.693
388.986	2.795	390.667	3.054	391.391	5.498	390.148	4.293
389.428	2.807	391.111	4.353	391.837	5.185	390.591	3.644
389.871	2.882	391.556	3.179	392.282	6.095	391.034	2.971
390.313	1.748	392.000	2.556	392.727	6.087	391.478	3.483
390.756	1.579	392.444	4.003	393.173	5.933	391.921	3.705
391.199	2.255	392.889	4.047	393.618	5.874	392.365	4.006
391.641	2.371	393.333	3.655	394.063	5.179	392.808	3.820
392.084	2.892	393.778	2.450	394.508	4.788	393.251	3.249
392.526	3.271	394.222	-0.046	394.954	4.982	393.695	3.704
392.969	1.903	394.667	-0.419	395.399	4.003	394.138	3.981
393.411	0.415	395.111	1.103	395.844	2.945	394.581	4.127
393.854	0.752	395.556	2.041	396.289	3.494	395.025	3.439
394.296	1.810	396.000	1.254	396.735	4.276	395.468	2.126
394.739	2.177	396.444	1.877	397.180	3.217	395.911	1.933
395.181	2.066	396.889	3.126	397.625	2.732	396.355	2.273
395.624	2.248	397.333	0.847	398.071	3.216	396.798	2.237
396.066	1.715	397.778	0.140	398.516	2.824	397.241	2.073
396.509	0.647	398.222	1.943	398.961	1.792	397.685	2.293
396.951	0.274	398.667	1.783	399.406	0.378	398.128	2.451
397.394	-0.304	399.111	0.671	399.852	1.157	398.571	2.405
397.837	0.011	399.556	1.091	400.297	2.667	399.015	2.406
398.279	1.209	400.000	1.009	400.742	3.131	399.458	2.870
398.722	1.467	400.444	-0.426	401.187	3.366	399.901	3.064
399.164	1.525	400.889	0.531	401.633	2.775	400.345	2.262
399.607	0.405	401.333	2.038	402.078	2.751	400.788	1.823
400.049	-0.168	401.778	2.852	402.523	3.285	401.232	1.785
400.492	0.987	402.222	2.411	402.968	2.471	401.675	2.114
400.934	1.494	402.667	0.370	403.414	2.167	402.118	2.188
401.377	1.752	403.111	0.910	403.859	2.646	402.562	1.322
401.819	1.765	403.556	1.599	404.304	2.009	403.005	0.840
402.262	1.274	404.000	0.583	404.750	2.035	403.448	1.298
402.704	1.224	404.444	0.938	405.195	1.895	403.892	2.102
403.147	1.168	404.889	1.048	405.640	0.825	404.335	1.355
403.589	0.398	405.333	0.150	406.085	1.044	404.778	0.252
404.032	0.737	405.778	0.149	406.531	1.506	405.222	0.529
404.474	1.203	406.222	-0.358	406.976	1.010	405.665	0.724
404.917	0.299	406.667	-0.184	407.421	1.797	406.108	0.705
405.360	-0.919	407.111	0.873	407.866	1.646	406.552	0.241
405.802	-1.288	407.556	0.311	408.312	-0.636	406.995	-0.060
406.245	-0.091	408.000	0.596	408.757	0.133	407.438	0.339
406.687	0.901	408.444	1.121	409.202	1.241	407.882	1.239
407.130	0.744	408.889	0.433	409.647	0.023	408.325	1.434
407.572	0.291	409.333	1.297	410.093	-0.627	408.768	0.454
408.015	0.879	409.778	1.341	410.538	0.147	409.212	0.201

Table A2: Heat Release at different crank angle for varying ethanol with diesel at 50% load

408.457	1.101	410.222	0.352	410.983	0.769	409.655	0.149
408.900	0.577	410.667	0.590	411.429	1.116	410.099	1.287
409.342	0.841	411.111	0.561	411.874	2.046	410.542	2.041
409.785	0.071	411.556	0.667	412.319	1.327	410.985	-0.005
410.227	-0.180	412.000	-0.451	412.764	-0.199	411.429	0.143
410.670	0.647	412.444	-0.849	413.210	-0.055	411.872	1.328
411.112	0.681	412.889	-0.365	413.655	1.779	412.315	-0.436
411.555	0.730	413.333	0.189	414.100	1.527	412.759	-0.801
411.998	0.845	413.778	1.405	414.545	0.356	413.202	0.147
412.440	1.036	414.222	-1.374	414.991	-0.335	413.645	-1.629
412.883	0.520	414.667	-3.103	415.436	-1.325	414.089	-2.556
413.325	-0.952	415.111	0.235	415.881	1.034	414.532	1.038
413.768	-0.571	415.556	1.453	416.327	1.352	414.975	2.331
414.210	0.587	416.000	0.035	416.772	-0.686	415.419	0.103
414.653	-0.237	416.444	0.061	417.217	0.208	415.862	0.291
415.095	-0.554	416.889	1.254	417.662	0.180	416.305	1.037
415.538	-0.270	417.333	1.564	418.108	0.074	416.749	0.070
415.980	-1.435	417.778	0.706	418.553	-0.416	417.192	-1.840
416.423	-3.206	418.222	0.441	418.998	-1.897	417.635	-2.929
416.865	-2.588	418.667	0.978	419.443	-1.145	418.079	-2.308
417.308	-0.123	419.111	0.708	419.889	-0.102	418.522	-1.739
417.750	-0.183	419.556	-0.879	420.334	0.009	418.966	-2.650
418.193	-1.070	420.000	-3.070	420.779	-1.307	419.409	-0.546
418.636	-0.081	420.444	-2.748	421.224	-1.099	419.852	2.467
419.078	0.518	420.889	1.223	421.670	-0.650	420.296	0.226
419.521	0.607	421.333	1.438	422.115	-1.007	420.739	-1.738
419.963	0.054	421.778	-2.573	422.560	0.692	421.182	-1.273
420.406	-1.347	422.222	-3.521	423.006	0.325	421.626	-0.114
420.848	-0.981	422.667	-0.940	423.451	-0.982	422.069	-0.046

Table A3: Heat Release at different crank angle for varying ethanol with diesel at 100% load

Diesel + 0% Ethanol		Diesel + 10% Ethanol		Diesel + 20% Ethanol		Diesel + 30% Ethanol	
Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)
320.293	0.514	322.454	-0.048	321.468	-0.768	322.059	-0.368
320.731	0.205	322.896	-0.537	321.908	-0.592	322.500	-0.788
321.170	-0.335	323.337	0.006	322.349	-0.258	322.941	-1.258
321.609	-0.808	323.779	0.237	322.789	-0.865	323.382	-0.820
322.048	-1.173	324.221	-1.389	323.229	-0.380	323.824	-0.605
322.486	-0.823	324.663	-1.230	323.670	0.111	324.265	-0.838
322.925	-0.759	325.104	-0.394	324.110	-0.607	324.706	-0.945
323.364	-1.028	325.546	-0.269	324.550	-0.886	325.147	-0.514
323.803	-0.920	325.988	0.194	324.991	-1.392	325.588	-0.502
324.241	-1.469	326.429	-0.964	325.431	-1.722	326.029	-1.009
324.680	-1.802	326.871	-1.360	325.872	-0.665	326.471	-0.775
325.119	-0.768	327.313	0.304	326.312	-0.317	326.912	-0.600
325.558	-0.370	327.755	0.187	326.752	-0.687	327.353	-1.099
325.996	-0.768	328.196	-1.055	327.193	-0.886	327.794	-0.843
326.435	-0.456	328.638	-1.203	327.633	-1.350	328.235	-0.493
326.874	-0.061	329.080	-0.731	328.073	-0.782	328.676	-0.719
327.313	-0.700	329.521	-0.505	328.514	-0.408	329.118	-0.854
327.751	-1.050	329.963	-0.780	328.954	-1.638	329.559	-1.258
328.190	-0.792	330.405	-1.264	329.394	-1.936	330.000	-1.549
328.629	-1.259	330.847	-1.575	329.835	-1.251	330.441	-1.200
329.068	-1.261	331.288	-0.995	330.275	-1.194	330.882	-0.989
329.506	-1.048	331.730	-0.447	330.716	-1.388	331.324	-1.388
329.945	-1.090	332.172	-0.982	331.156	-1.248	331.765	-1.113
330.384	-0.677	332.613	-1.315	331.596	-1.186	332.206	-0.947
330.823	-0.959	333.055	-1.334	332.037	-1.220	332.647	-1.522
331.261	-1.359	333.497	-1.111	332.477	-1.104	333.088	-1.453
331.700	-0.780	333.939	-1.408	332.917	-1.830	333.529	-1.076
332.139	-0.514	334.380	-2.109	333.358	-2.154	333.971	-1.090
332.578	-1.184	334.822	-1.480	333.798	-1.506	334.412	-1.496
333.016	-1.289	335.264	-1.116	334.239	-1.555	334.853	-1.866
333.455	-1.036	335.706	-1.833	334.679	-2.156	335.294	-1.865
333.894	-1.321	336.147	-2.013	335.119	-2.444	335.735	-1.731
334.333	-1.081	336.589	-1.996	335.560	-2.191	336.176	-1.565
334.771	-0.721	337.031	-1.811	336.000	-2.028	336.618	-1.630
335.210	-1.145	337.472	-1.196	336.440	-2.300	337.059	-1.947
335.649	-1.536	337.914	-1.596	336.881	-2.276	337.500	-1.724
336.088	-1.790	338.356	-2.334	337.321	-1.592	337.941	-1.631
336.527	-2.079	338.798	-1.982	337.761	-1.745	338.382	-2.237
336.965	-1.877	339.239	-1.923	338.202	-2.705	338.824	-1.976
337.404	-1.229	339.681	-2.829	338.642	-2.949	339.265	-1.276
337.843	-1.025	340.123	-3.015	339.083	-2.573	339.706	-1.419
338.282	-1.123	340.564	-2.350	339.523	-2.409	340.147	-1.703
338.720	-1.242	341.006	-2.290	339.963	-2.863	340.588	-2.067
339.159	-2.077	341.448	-2.727	340.404	-2.952	341.029	-2.184
339.598	-2.823	341.890	-2.361	340.844	-2.527	341.471	-2.146
340.037	-2.900	342.331	-2.261	341.284	-2.501	341.912	-2.247

Table A3: Heat Release at different crank angle for varying ethanol with diesel at 100% load

340.475	-2.420	342.773	-2.864	341.725	-2.784	342.353	-1.838
340.914	-1.374	343.215	-2.631	342.165	-2.990	342.794	-1.459
341.353	-1.344	343.656	-2.615	342.606	-3.036	343.235	-1.813
341.792	-2.258	344.098	-3.004	343.046	-3.111	343.676	-2.309
342.230	-2.226	344.540	-2.844	343.486	-3.089	344.118	-2.171
342.669	-2.156	344.982	-2.821	343.927	-2.868	344.559	-1.915
343.108	-2.216	345.423	-3.015	344.367	-2.844	345.000	-2.307
343.547	-2.220	345.865	-3.596	344.807	-3.087	345.441	-2.356
343.985	-2.626	346.307	-4.201	345.248	-3.347	345.882	-2.028
344.424	-2.533	346.748	-3.925	345.688	-3.677	346.324	-2.370
344.863	-3.050	347.190	-3.695	346.128	-4.361	346.765	-2.802
345.302	-3.557	347.632	-3.721	346.569	-4.557	347.206	-2.851
345.740	-3.244	348.074	-3.995	347.009	-4.072	347.647	-2.613
346.179	-3.751	348.515	-4.315	347.450	-4.158	348.088	-2.441
346.618	-4.056	348.957	-4.033	347.890	-4.572	348.529	-2.659
347.057	-3.249	349.399	-3.730	348.330	-4.501	348.971	-3.041
347.495	-3.264	349.840	-3.901	348.771	-4.330	349.412	-3.121
347.934	-3.969	350.282	-3.766	349.211	-4.115	349.853	-2.611
348.373	-4.101	350.724	-3.103	349.651	-3.807	350.294	-2.163
348.812	-4.072	351.166	-3.053	350.092	-3.702	350.735	-2.508
349.250	-3.495	351.607	-2.743	350.532	-3.641	351.176	-2.574
349.689	-2.761	352.049	-1.856	350.972	-3.500	351.618	-2.034
350.128	-2.672	352.491	-1.380	351.413	-3.008	352.059	-1.602
350.567	-2.737	352.933	-0.360	351.853	-2.341	352.500	-1.142
351.005	-2.161	353.374	1.888	352.294	-1.733	352.941	-0.158
351.444	-1.116	353.816	4.849	352.734	-1.061	353.382	1.078
351.883	0.158	354.258	8.754	353.174	0.562	353.824	2.448
352.322	2.490	354.699	13.346	353.615	3.857	354.265	4.960
352.761	6.653	355.141	18.193	354.055	7.522	354.706	8.273
353.199	13.147	355.583	23.024	354.495	12.000	355.147	12.215
353.638	20.446	356.025	27.311	354.936	18.141	355.588	16.645
354.077	25.884	356.466	31.398	355.376	24.786	356.029	20.587
354.516	31.211	356.908	35.395	355.817	30.794	356.471	24.455
354.954	38.987	357.350	38.718	356.257	35.073	356.912	28.551
355.393	42.474	357.791	43.143	356.697	39.177	357.353	32.141
355.832	45.452	358.233	39.187	357.138	42.347	357.794	34.617
356.271	43.633	358.675	34.673	357.578	42.378	358.235	39.914
356.709	41.819	359.117	27.618	358.018	42.092	358.676	35.668
357.148	31.178	359.558	21.385	358.459	36.758	359.118	33.404
357.587	21.240	360.000	16.010	358.899	29.008	359.559	29.937
358.026	14.782	360.442	12.936	359.339	22.441	360.000	26.243
358.464	12.109	360.883	11.109	359.780	17.207	360.441	22.596
358.903	11.066	361.325	9.834	360.220	13.027	360.882	19.458
359.342	8.450	361.767	10.268	360.661	10.677	361.324	16.851
359.781	8.499	362.209	9.989	361.101	9.838	361.765	14.766
360.219	8.731	362.650	10.274	361.541	9.505	362.206	13.332
360.658	8.929	363.092	9.965	361.982	8.939	362.647	12.637
361.097	9.109	363.534	9.436	362.422	9.315	363.088	12.596
361.536	9.356	363.975	10.211	362.862	9.834	363.529	12.372
361.974	10.558	364.417	10.016	363.303	9.954	363.971	12.163
362.413	9.810	364.859	10.343	363.743	10.070	364.412	11.946

Table A3: Heat Release at different crank angle for varying ethanol with diesel at 100% load

362.852	10.001	365.301	10.522	364.183	9.922	364.853	11.932
363.291	9.546	365.742	10.274	364.624	10.379	365.294	11.743
363.729	9.058	366.184	10.174	365.064	10.597	365.735	11.088
364.168	9.955	366.626	10.196	365.505	10.301	366.176	11.366
364.607	9.890	367.067	10.656	365.945	10.178	366.618	11.701
365.046	10.163	367.509	10.562	366.385	10.859	367.059	11.562
365.484	9.895	367.951	10.736	366.826	11.172	367.500	11.639
365.923	10.110	368.393	10.663	367.266	10.726	367.941	11.442
366.362	10.324	368.834	9.954	367.706	10.855	368.382	11.064
366.801	10.331	369.276	9.727	368.147	10.630	368.824	10.767
367.239	10.383	369.718	9.930	368.587	10.608	369.265	11.075
367.678	9.894	370.160	9.824	369.028	10.546	369.706	11.332
368.117	10.058	370.601	9.186	369.468	10.111	370.147	10.747
368.556	9.474	371.043	9.306	369.908	10.107	370.588	10.586
368.995	9.527	371.485	9.187	370.349	9.998	371.029	10.551
369.433	9.672	371.926	8.227	370.789	9.999	371.471	10.157
369.872	9.441	372.368	8.017	371.229	9.613	371.912	9.695
370.311	9.169	372.810	8.020	371.670	9.005	372.353	9.437
370.750	8.171	373.252	8.342	372.110	8.327	372.794	9.395
371.188	8.232	373.693	8.072	372.550	7.961	373.235	9.293
371.627	8.220	374.135	7.337	372.991	8.297	373.676	9.451
372.066	7.935	374.577	7.851	373.431	8.061	374.118	9.449
372.505	7.743	375.018	7.456	373.872	7.757	374.559	9.213
372.943	7.527	375.460	6.983	374.312	7.710	375.000	9.109
373.382	7.793	375.902	7.497	374.752	7.406	375.441	9.135
373.821	7.347	376.344	7.332	375.193	7.513	375.882	9.366
374.260	7.162	376.785	7.156	375.633	7.344	376.324	9.103
374.698	7.251	377.227	7.038	376.073	6.849	376.765	8.685
375.137	6.859	377.669	6.950	376.514	6.897	377.206	8.715
375.576	7.334	378.110	6.915	376.954	6.741	377.647	8.394
376.015	7.576	378.552	6.744	377.394	6.580	378.088	8.137
376.453	7.538	378.994	6.536	377.835	6.879	378.529	8.016
376.892	7.293	379.436	6.360	378.275	6.816	378.971	8.291
377.331	6.004	379.877	6.087	378.716	6.388	379.412	8.470
377.770	5.900	380.319	6.019	379.156	6.150	379.853	7.564
378.208	6.135	380.761	6.104	379.596	6.521	380.294	6.912
378.647	5.986	381.202	5.525	380.037	6.545	380.735	7.027
379.086	6.459	381.644	5.526	380.477	5.789	381.176	7.362
379.525	6.087	382.086	5.303	380.917	5.612	381.618	6.763
379.963	6.179	382.528	4.270	381.358	5.498	382.059	5.956
380.402	6.504	382.969	4.601	381.798	5.407	382.500	6.033
380.841	5.401	383.411	5.230	382.239	5.706	382.941	5.893
381.280	4.693	383.853	4.713	382.679	5.131	383.382	5.754
381.718	4.847	384.294	4.254	383.119	4.455	383.824	5.729
382.157	4.820	384.736	4.041	383.560	4.344	384.265	5.733
382.596	4.429	385.178	3.826	384.000	4.107	384.706	5.235
383.035	4.084	385.620	4.021	384.440	4.342	385.147	4.565
383.473	4.437	386.061	4.068	384.881	4.668	385.588	5.298
383.912	4.666	386.503	4.161	385.321	4.128	386.029	5.324
384.351	3.864	386.945	4.090	385.761	3.857	386.471	5.100
384.790	3.549	387.387	3.584	386.202	3.960	386.912	5.269

Table A3: Heat Release at different crank angle for varying ethanol with diesel at 100% load

385.229	4.186	387.828	3.599	386.642	3.903	387.353	4.353
385.667	4.246	388.270	3.801	387.083	3.974	387.794	4.003
386.106	3.873	388.712	3.437	387.523	3.921	388.235	4.416
386.545	3.579	389.153	3.449	387.963	3.351	388.676	3.985
386.984	3.894	389.595	3.939	388.404	3.223	389.118	3.253
387.422	4.610	390.037	4.179	388.844	4.031	389.559	3.552
387.861	3.621	390.479	4.232	389.284	2.807	390.000	3.708
388.300	2.833	390.920	4.028	389.725	2.195	390.441	3.640
388.739	3.573	391.362	3.952	390.165	3.786	390.882	4.203
389.177	3.814	391.804	3.591	390.606	4.068	391.324	4.522
389.616	3.656	392.245	2.343	391.046	4.379	391.765	3.844
390.055	3.706	392.687	1.706	391.486	4.058	392.206	2.844
390.494	3.551	393.129	2.268	391.927	3.310	392.647	2.703
390.932	3.073	393.571	3.033	392.367	3.141	393.088	3.009
391.371	3.018	394.012	3.173	392.807	2.337	393.529	2.746
391.810	3.687	394.454	2.457	393.248	2.775	393.971	2.296
392.249	4.071	394.896	2.289	393.688	3.298	394.412	1.966
392.687	3.494	395.337	2.667	394.128	2.815	394.853	2.130
393.126	2.580	395.779	1.642	394.569	3.285	395.294	2.616
393.565	1.697	396.221	0.951	395.009	3.768	395.735	3.044
394.004	1.914	396.663	2.645	395.450	2.413	396.176	2.695
394.442	2.672	397.104	2.858	395.890	0.828	396.618	1.336
394.881	2.517	397.546	1.458	396.330	1.136	397.059	1.360
395.320	2.311	397.988	1.452	396.771	1.667	397.500	1.886
395.759	2.824	398.429	1.359	397.211	0.898	397.941	0.933
396.197	2.957	398.871	1.904	397.651	0.476	398.382	0.718
396.636	1.493	399.313	2.484	398.092	1.698	398.824	2.143
397.075	0.644	399.755	0.313	398.532	1.861	399.265	1.574
397.514	1.722	400.196	0.438	398.972	1.346	399.706	0.498
397.952	2.578	400.638	2.064	399.413	1.885	400.147	1.701
398.391	2.170	401.080	0.900	399.853	2.011	400.588	4.442
398.830	1.775	401.521	1.673	400.294	1.963	401.029	4.893
399.269	2.009	401.963	2.015	400.734	1.918	401.471	0.925
399.707	2.184	402.405	1.950	401.174	2.197	401.912	-0.537
400.146	3.687	402.847	3.081	401.615	2.266	402.353	0.372
400.585	4.036	403.288	2.116	402.055	1.756	402.794	0.974
401.024	2.218	403.730	0.961	402.495	1.141	403.235	1.361
401.463	2.192	404.172	0.169	402.936	1.022	403.676	1.492
401.901	3.194	404.613	1.083	403.376	1.626	404.118	1.239
402.340	4.089	405.055	2.377	403.817	1.197	404.559	-0.308
402.779	3.121	405.497	0.755	404.257	0.700	405.000	-0.699
403.218	2.142	405.939	0.058	404.697	0.838	405.441	0.092
403.656	2.838	406.380	1.284	405.138	1.394	405.882	1.135
404.095	1.839	406.822	0.755	405.578	2.312	406.324	0.621
404.534	1.091	407.264	0.672	406.018	2.495	406.765	-0.352
404.973	2.506	407.706	1.481	406.459	1.399	407.206	0.354
405.411	3.242	408.147	1.204	406.899	0.038	407.647	0.627
405.850	2.518	408.589	1.146	407.339	0.736	408.088	0.525
406.289	2.184	409.031	0.762	407.780	1.852	408.529	0.903
406.728	1.164	409.472	-0.977	408.220	0.566	408.971	0.927
407.166	-0.935	409.914	-1.370	408.661	-0.669	409.412	-0.336

Table A3: Heat Release at different crank angle for varying ethanol with diesel at 100% load

407.605	-1.231	410.356	0.308	409.101	0.029	409.853	-1.172
408.044	-0.091	410.798	-0.035	409.541	-0.845	410.294	-0.944
408.483	0.206	411.239	-2.158	409.982	-1.735	410.735	-0.631
408.921	0.169	411.681	-1.806	410.422	-0.622	411.176	0.160
409.360	0.684	412.123	0.335	410.862	-0.076	411.618	0.758
409.799	1.337	412.564	1.276	411.303	1.618	412.059	-0.302
410.238	0.118	413.006	-0.058	411.743	2.643	412.500	-1.358
410.676	-1.145	413.448	-1.395	412.183	0.004	412.941	-0.494
411.115	-0.883	413.890	0.574	412.624	-1.557	413.382	-0.029
411.554	-0.067	414.331	2.703	413.064	-0.213	413.824	0.005
411.993	1.718	414.773	3.272	413.505	0.937	414.265	0.593
412.431	1.430	415.215	2.849	413.945	0.864	414.706	1.406
412.870	0.603	415.656	1.739	414.385	1.064	415.147	1.297
413.309	0.315	416.098	1.429	414.826	1.448	415.588	0.133
413.748	0.368	416.540	1.237	415.266	1.618	416.029	0.490
414.186	1.453	416.982	1.718	415.706	1.987	416.471	1.557
414.625	0.709	417.423	1.125	416.147	0.749	416.912	0.697
415.064	-0.080	417.865	-0.176	416.587	0.239	417.353	-0.354
415.503	-0.022	418.307	-0.383	417.028	1.397	417.794	-0.310
415.941	0.517	418.748	-0.862	417.468	1.539	418.235	0.226
416.380	1.261	419.190	-0.856	417.908	1.506	418.676	0.500
416.819	-0.140	419.632	-0.360	418.349	1.056	419.118	-1.218
417.258	-1.748	420.074	-0.478	418.789	-1.192	419.559	-2.533
417.697	-0.374	420.515	-2.457	419.229	-1.939	420.000	-1.998
418.135	1.565	420.957	-2.420	419.670	-0.991	420.441	-2.160
418.574	1.251	421.399	0.271	420.110	-1.630	420.882	-1.129
419.013	0.189	421.840	0.402	420.550	-0.812	421.324	1.074
419.452	0.152	422.282	0.065	420.991	0.280	421.765	0.334
419.890	-0.181	422.724	0.296	421.431	-0.529	422.206	0.377
420.329	-0.059	423.166	-0.050	421.872	-0.687	422.647	2.029
420.768	1.064	423.607	0.057	422.312	0.349	423.088	0.480

Table A4: Heat Release at different crank angle for varying ethanol with Biodiesel at no load

Biodiesel + 0% Ethanol		Biodiesel + 10% Ethanol		Biodiesel + 20% Ethanol		Biodiesel + 30% Ethanol	
Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)
320.252	-0.813	320.455	-0.534	319.849	-0.550	314.498	-0.247
320.707	0.408	320.909	-0.620	320.302	-0.998	314.944	0.507
321.161	0.177	321.364	0.283	320.756	-0.767	315.390	0.758
321.615	-0.351	321.818	0.389	321.210	0.029	315.836	-0.172
322.069	-0.578	322.273	0.111	321.664	0.151	316.283	-0.168
322.524	-0.773	322.727	-0.274	322.117	-0.364	316.729	0.118
322.978	-0.081	323.182	-1.291	322.571	-0.572	317.175	-0.460
323.432	0.079	323.636	-1.400	323.025	0.024	317.621	-0.535
323.886	-0.777	324.091	-0.666	323.478	-0.439	318.067	-0.644
324.341	-0.340	324.545	-0.040	323.932	-1.127	318.513	-0.650
324.795	-0.329	325.000	0.264	324.386	-0.501	318.959	-0.078
325.249	-0.682	325.455	-0.094	324.839	-0.369	319.405	0.801
325.703	-0.007	325.909	-0.490	325.293	-0.129	319.851	0.450
326.158	-0.314	326.364	-0.773	325.747	0.565	320.297	-0.415
326.612	-0.707	326.818	-1.376	326.200	0.204	320.743	-0.318
327.066	-0.434	327.273	-1.450	326.654	-1.382	321.190	-0.622
327.521	-0.471	327.727	-0.874	327.108	-2.346	321.636	-0.936
327.975	-0.684	328.182	-0.142	327.561	-0.913	322.082	-0.986
328.429	-0.681	328.636	0.194	328.015	0.538	322.528	-0.677
328.883	-0.756	329.091	-0.828	328.469	-0.167	322.974	-0.306
329.338	-1.371	329.545	-1.762	328.922	-1.037	323.420	-1.062
329.792	-1.378	330.000	-0.885	329.376	-1.292	323.866	-1.262
330.246	-0.881	330.455	-0.358	329.830	-1.419	324.312	-0.781
330.700	-0.853	330.909	-1.117	330.284	-1.081	324.758	-1.572
331.155	-1.133	331.364	-1.485	330.737	-0.911	325.204	-1.434
331.609	-1.433	331.818	-1.533	331.191	-1.112	325.651	-0.490
332.063	-1.530	332.273	-1.593	331.645	-1.574	326.097	-0.592
332.517	-1.462	332.727	-1.003	332.098	-1.766	326.543	-0.703
332.972	-1.514	333.182	-0.841	332.552	-1.214	326.989	-0.870
333.426	-1.486	333.636	-1.240	333.006	-0.825	327.435	-1.385
333.880	-0.967	334.091	-1.411	333.459	-1.354	327.881	-1.774
334.334	-1.146	334.545	-1.430	333.913	-1.878	328.327	-1.533
334.789	-1.652	335.000	-1.611	334.367	-1.597	328.773	-1.461
335.243	-1.859	335.455	-1.883	334.820	-1.537	329.219	-1.473
335.697	-2.067	335.909	-1.822	335.274	-1.775	329.665	-1.107
336.151	-1.563	336.364	-1.885	335.728	-1.848	330.112	-1.132
336.606	-1.170	336.818	-1.970	336.181	-2.002	330.558	-1.531
337.060	-1.722	337.273	-2.316	336.635	-2.148	331.004	-1.916
337.514	-2.548	337.727	-2.464	337.089	-2.204	331.450	-1.866
337.968	-2.769	338.182	-2.428	337.543	-2.350	331.896	-1.397
338.423	-2.657	338.636	-2.496	337.996	-2.225	332.342	-1.125
338.877	-2.533	339.091	-2.289	338.450	-2.273	332.788	-1.373
339.331	-2.440	339.545	-2.231	338.904	-2.520	333.234	-1.900
339.785	-2.263	340.000	-2.209	339.357	-2.372	333.680	-1.835
340.240	-2.042	340.455	-2.452	339.811	-2.277	334.126	-1.264
340.694	-2.469	340.909	-2.875	340.265	-2.111	334.572	-1.476

Table A4: Heat Release at different crank angle for varying ethanol with Biodiesel at no load

341.148	-2.439	341.364	-3.020	340.718	-2.285	335.019	-2.073
341.603	-2.431	341.818	-3.191	341.172	-2.474	335.465	-1.566
342.057	-3.200	342.273	-3.213	341.626	-2.290	335.911	-1.433
342.511	-2.874	342.727	-3.160	342.079	-2.451	336.357	-2.173
342.965	-2.514	343.182	-3.273	342.533	-3.068	336.803	-2.135
343.420	-3.147	343.636	-3.237	342.987	-3.389	337.249	-1.920
343.874	-3.375	344.091	-3.163	343.440	-2.984	337.695	-1.668
344.328	-3.113	344.545	-3.226	343.894	-2.650	338.141	-1.721
344.782	-3.143	345.000	-3.280	344.348	-2.964	338.587	-2.322
345.237	-3.471	345.455	-3.130	344.802	-2.999	339.033	-2.640
345.691	-3.364	345.909	-3.131	345.255	-2.824	339.480	-2.305
346.145	-3.310	346.364	-3.775	345.709	-3.220	339.926	-1.927
346.599	-3.775	346.818	-4.091	346.163	-3.072	340.372	-2.111
347.054	-3.856	347.273	-3.826	346.616	-2.854	340.818	-2.297
347.508	-3.851	347.727	-3.934	347.070	-3.384	341.264	-2.081
347.962	-4.034	348.182	-4.043	347.524	-3.479	341.710	-1.872
348.416	-4.107	348.636	-4.244	347.977	-3.222	342.156	-2.389
348.871	-4.324	349.091	-4.537	348.431	-3.657	342.602	-2.537
349.325	-4.239	349.545	-4.253	348.885	-3.939	343.048	-2.326
349.779	-4.077	350.000	-4.175	349.338	-3.605	343.494	-2.684
350.233	-4.263	350.455	-4.366	349.792	-3.607	343.941	-2.854
350.688	-4.323	350.909	-4.271	350.246	-3.705	344.387	-2.521
351.142	-4.054	351.364	-4.121	350.699	-3.749	344.833	-2.070
351.596	-3.709	351.818	-3.733	351.153	-3.830	345.279	-2.000
352.050	-3.586	352.273	-3.720	351.607	-3.685	345.725	-2.278
352.505	-3.254	352.727	-4.100	352.060	-3.463	346.171	-2.552
352.959	-3.205	353.182	-4.142	352.514	-3.318	346.617	-2.583
353.413	-3.766	353.636	-4.349	352.968	-3.237	347.063	-2.540
353.868	-3.605	354.091	-4.313	353.422	-3.240	347.509	-2.758
354.322	-2.793	354.545	-3.715	353.875	-3.634	347.955	-3.181
354.776	-2.060	355.000	-3.384	354.329	-3.878	348.401	-3.230
355.230	-1.066	355.455	-3.246	354.783	-3.484	348.848	-2.717
355.685	0.355	355.909	-2.732	355.236	-3.230	349.294	-2.543
356.139	1.946	356.364	-2.087	355.690	-3.050	349.740	-2.853
356.593	3.944	356.818	-1.496	356.144	-2.757	350.186	-3.255
357.047	6.767	357.273	-0.492	356.597	-2.668	350.632	-2.998
357.502	9.583	357.727	0.614	357.051	-2.175	351.078	-2.469
357.956	11.767	358.182	2.174	357.505	-1.364	351.524	-2.724
358.410	13.571	358.636	4.560	357.958	-0.691	351.970	-2.642
358.864	14.161	359.091	6.719	358.412	0.069	352.416	-2.101
359.319	13.398	359.545	8.953	358.866	0.800	352.862	-1.865
359.773	12.538	360.000	11.221	359.319	2.022	353.309	-1.934
360.227	11.874	360.455	12.781	359.773	4.002	353.755	-2.363
360.681	11.219	360.909	13.667	360.227	5.934	354.201	-2.387
361.136	10.363	361.364	13.491	360.681	7.968	354.647	-1.800
361.590	9.685	361.818	12.987	361.134	10.011	355.093	-1.322
362.044	9.174	362.273	12.659	361.588	11.579	355.539	-0.394
362.498	8.262	362.727	12.131	362.042	12.838	355.985	1.157
362.953	7.287	363.182	11.625	362.495	13.163	356.431	2.576
363.407	6.324	363.636	11.111	362.949	12.715	356.877	4.035
363.861	5.604	364.091	10.421	363.403	12.721	357.323	6.012

Table A4: Heat Release at different crank angle for varying ethanol with Biodiesel at no load

364.315	5.086	364.545	9.421	363.856	12.737	357.770	8.254
364.770	4.497	365.000	8.576	364.310	12.119	358.216	10.328
365.224	3.906	365.455	7.686	364.764	11.587	358.662	11.927
365.678	3.655	365.909	6.434	365.217	11.497	359.108	12.551
366.132	3.655	366.364	5.897	365.671	11.171	359.554	12.686
366.587	3.310	366.818	5.692	366.125	10.282	360.000	12.499
367.041	2.910	367.273	4.899	366.578	9.455	360.446	12.132
367.495	2.935	367.727	4.384	367.032	8.730	360.892	12.028
367.950	3.185	368.182	4.343	367.486	7.877	361.338	11.894
368.404	2.886	368.636	4.002	367.940	6.910	361.784	11.675
368.858	2.604	369.091	3.517	368.393	6.123	362.230	11.022
369.312	2.857	369.545	3.575	368.847	5.844	362.677	10.418
369.767	2.923	370.000	3.725	369.301	5.387	363.123	9.715
370.221	2.899	370.455	3.518	369.754	5.195	363.569	8.400
370.675	2.902	370.909	3.497	370.208	5.326	364.015	7.242
371.129	3.178	371.364	3.666	370.662	4.706	364.461	6.629
371.584	3.221	371.818	3.564	371.115	4.344	364.907	6.106
372.038	2.687	372.273	3.366	371.569	4.594	365.353	4.968
372.492	2.381	372.727	3.163	372.023	4.698	365.799	3.886
372.946	2.328	373.182	2.888	372.476	4.573	366.245	3.539
373.401	2.506	373.636	3.008	372.930	4.256	366.691	3.542
373.855	2.443	374.091	3.025	373.384	3.762	367.138	3.536
374.309	2.132	374.545	2.450	373.837	3.714	367.584	3.590
374.763	2.297	375.000	2.172	374.291	3.969	368.030	3.908
375.218	2.751	375.455	2.750	374.745	3.453	368.476	3.959
375.672	2.551	375.909	3.006	375.198	3.135	368.922	3.744
376.126	2.044	376.364	2.840	375.652	3.071	369.368	3.365
376.580	2.196	376.818	2.879	376.106	3.063	369.814	3.112
377.035	2.088	377.273	2.538	376.560	3.418	370.260	3.718
377.489	1.739	377.727	2.373	377.013	2.965	370.706	3.897
377.943	2.043	378.182	2.684	377.467	2.657	371.152	3.802
378.397	2.314	378.636	2.540	377.921	2.928	371.599	3.845
378.852	1.642	379.091	2.235	378.374	2.735	372.045	3.496
379.306	1.505	379.545	2.279	378.828	2.389	372.491	3.640
379.760	2.174	380.000	2.332	379.282	2.298	372.937	3.773
380.215	1.836	380.455	2.196	379.735	2.498	373.383	3.555
380.669	1.928	380.909	1.490	380.189	2.592	373.829	3.404
381.123	2.574	381.364	0.922	380.643	2.567	374.275	3.331
381.577	2.448	381.818	1.295	381.096	2.090	374.721	3.472
382.032	2.123	382.273	1.997	381.550	1.537	375.167	3.623
382.486	1.707	382.727	2.317	382.004	1.659	375.613	3.600
382.940	1.602	383.182	2.241	382.457	1.468	376.059	3.130
383.394	1.449	383.636	2.229	382.911	1.619	376.506	2.713
383.849	0.730	384.091	2.070	383.365	2.172	376.952	2.855
384.303	0.606	384.545	1.512	383.819	1.830	377.398	2.922
384.757	0.925	385.000	1.528	384.272	1.813	377.844	2.737
385.211	0.572	385.455	2.179	384.726	2.218	378.290	2.448
385.666	-0.247	385.909	1.730	385.180	2.250	378.736	2.479
386.120	-0.206	386.364	0.846	385.633	2.336	379.182	2.285
386.574	0.266	386.818	0.868	386.087	2.576	379.628	2.351
387.028	-0.063	387.273	1.040	386.541	2.882	380.074	3.109

Table A4: Heat Release at different crank angle for varying ethanol with Biodiesel at no load

387.483	0.294	387.727	0.997	386.994	2.329	380.520	3.159
387.937	1.308	388.182	1.204	387.448	1.335	380.967	1.960
388.391	1.259	388.636	1.226	387.902	0.647	381.413	-0.208
388.845	1.050	389.091	1.026	388.355	0.339	381.859	-1.144
389.300	1.124	389.545	1.039	388.809	0.196	382.305	-0.116
389.754	1.306	390.000	1.121	389.263	-0.046	382.751	0.456
390.208	1.668	390.455	1.213	389.716	0.615	383.197	-0.413
390.662	0.677	390.909	0.460	390.170	0.685	383.643	-0.751
391.117	0.017	391.364	0.188	390.624	0.290	384.089	-0.085
391.571	0.582	391.818	0.262	391.078	0.510	384.535	0.214
392.025	1.044	392.273	0.012	391.531	0.638	384.981	-0.380
392.479	0.687	392.727	0.532	391.985	0.689	385.428	-0.709
392.934	0.007	393.182	1.017	392.439	0.696	385.874	-0.124
393.388	1.192	393.636	1.486	392.892	0.487	386.320	-0.222
393.842	1.975	394.091	1.516	393.346	0.289	386.766	-0.575
394.297	0.563	394.545	0.876	393.800	0.080	387.212	-0.510
394.751	-0.281	395.000	0.998	394.253	0.218	387.658	-0.511
395.205	0.697	395.455	1.668	394.707	0.759	388.104	0.017
395.659	1.328	395.909	1.224	395.161	0.142	388.550	0.202
396.114	0.759	396.364	0.946	395.614	-0.288	388.996	-0.156
396.568	0.468	396.818	1.133	396.068	0.050	389.442	0.184
397.022	0.962	397.273	0.402	396.522	0.430	389.888	0.448
397.476	1.331	397.727	-0.044	396.975	0.352	390.335	-0.402
397.931	0.953	398.182	-0.562	397.429	0.087	390.781	-0.932
398.385	0.923	398.636	-0.335	397.883	0.555	391.227	-0.047
398.839	0.566	399.091	0.570	398.336	0.247	391.673	0.132
399.293	-0.199	399.545	0.486	398.790	-0.420	392.119	-0.253
399.748	0.753	400.000	0.741	399.244	-0.261	392.565	-0.127
400.202	1.275	400.455	1.162	399.698	0.669	393.011	-0.174
400.656	0.777	400.909	1.298	400.151	1.315	393.457	0.386
401.110	1.038	401.364	1.192	400.605	0.506	393.903	0.962
401.565	1.018	401.818	0.720	401.059	0.318	394.349	0.410
402.019	0.035	402.273	0.797	401.512	0.807	394.796	-0.074
402.473	-0.795	402.727	0.343	401.966	0.965	395.242	0.216
402.927	0.137	403.182	-0.265	402.420	1.349	395.688	0.667
403.382	0.861	403.636	0.207	402.873	0.437	396.134	0.721
403.836	0.631	404.091	-0.027	403.327	-0.242	396.580	0.652
404.290	0.894	404.545	-0.462	403.781	0.141	397.026	0.322
404.744	0.660	405.000	-0.321	404.234	0.014	397.472	-0.414
405.199	0.729	405.455	-0.158	404.688	0.549	397.918	-0.833
405.653	0.636	405.909	-0.609	405.142	0.668	398.364	-0.725
406.107	0.923	406.364	-1.339	405.595	0.169	398.810	0.065
406.562	1.677	406.818	0.022	406.049	0.464	399.257	0.449
407.016	0.212	407.273	1.102	406.503	0.922	399.703	0.200
407.470	-0.968	407.727	-0.189	406.957	0.515	400.149	0.809
407.924	-0.809	408.182	-1.000	407.410	0.174	400.595	-0.029
408.379	-0.886	408.636	-1.085	407.864	0.566	401.041	-1.250
408.833	-0.797	409.091	-0.418	408.318	0.781	401.487	-0.383
409.287	-0.649	409.545	-0.438	408.771	0.544	401.933	0.698
409.741	-1.555	410.000	-1.481	409.225	-0.373	402.379	0.831
410.196	-1.430	410.455	-1.208	409.679	0.031	402.825	-0.655

Table A4: Heat Release at different crank angle for varying ethanol with Biodiesel at no load

410.650	1.076	410.909	-0.936	410.132	-0.024	403.271	-0.854
411.104	0.840	411.364	-0.622	410.586	-1.442	403.717	-0.202
411.558	-0.263	411.818	-0.479	411.040	-0.312	404.164	-0.260
412.013	0.982	412.273	-1.731	411.493	1.044	404.610	0.002
412.467	0.031	412.727	-2.488	411.947	0.744	405.056	-0.043
412.921	-0.477	413.182	-1.179	412.401	0.555	405.502	-0.029
413.375	1.053	413.636	0.877	412.854	-0.283	405.948	-0.403
413.830	0.935	414.091	1.709	413.308	-0.651	406.394	-1.266
414.284	1.030	414.545	1.266	413.762	-0.883	406.840	-0.797
414.738	2.998	415.000	0.636	414.216	-1.630	407.286	0.122
415.192	4.164	415.455	-0.517	414.669	-1.252	407.732	0.082
415.647	3.541	415.909	-1.185	415.123	-0.123	408.178	0.471
416.101	2.844	416.364	-0.184	415.577	1.052	408.625	0.497
416.555	3.588	416.818	0.913	416.030	-0.375	409.071	-0.675
417.009	5.564	417.273	3.178	416.484	-1.977	409.517	-0.902
417.464	5.193	417.727	4.240	416.938	-1.364	409.963	0.979
417.918	3.023	418.182	3.289	417.391	-0.851	410.409	2.308
418.372	3.967	418.636	4.305	417.845	-0.506	410.855	1.825
418.826	5.155	419.091	6.212	418.299	-1.077	411.301	1.511
419.281	3.304	419.545	7.102	418.752	-1.437	411.747	3.019
419.735	2.237	420.000	5.750	419.206	-0.123	412.193	4.909
420.189	2.698	420.455	4.671	419.660	-0.083	412.639	5.664
420.644	3.181	420.909	5.279	420.113	-1.800	413.086	7.296

Table A5: Heat Release at different crank angle for varying ethanol with Biodiesel at 50% load

Biodiesel + 0% Ethanol		Biodiesel + 10% Ethanol		Biodiesel + 20% Ethanol		Biodiesel + 30% Ethanol	
Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)
320.354	-1.230	319.142	5.307	318.941	1.607	319.949	0.586
320.810	-1.415	319.596	3.699	319.395	0.912	320.405	-0.176
321.266	-1.915	320.050	3.017	319.849	0.734	320.860	0.172
321.722	-0.768	320.504	2.394	320.302	0.337	321.315	0.917
322.177	-0.897	320.958	1.264	320.756	0.263	321.770	1.823
322.633	-1.660	321.412	1.198	321.210	0.513	322.225	1.704
323.089	-1.302	321.866	2.230	321.664	0.427	322.680	0.619
323.544	-1.427	322.320	3.587	322.117	0.396	323.135	0.459
324.000	-1.087	322.774	3.997	322.571	0.168	323.590	0.869
324.456	-0.594	323.228	3.506	323.025	0.512	324.046	0.830
324.911	-0.030	323.682	4.230	323.478	1.574	324.501	0.682
325.367	0.007	324.136	4.797	323.932	1.451	324.956	0.810
325.823	-0.597	324.590	1.645	324.386	0.886	325.411	0.867
326.278	-0.493	325.044	0.361	324.839	1.428	325.866	0.695
326.734	-0.222	325.498	6.495	325.293	1.775	326.321	0.899
327.190	-0.004	325.952	13.744	325.747	1.078	326.776	0.667
327.646	0.056	326.406	11.049	326.200	0.928	327.231	-0.154
328.101	0.450	326.860	1.481	326.654	0.887	327.686	0.255
328.557	0.487	327.314	-2.370	327.108	-0.148	328.142	1.160
329.013	0.557	327.768	-1.339	327.561	-0.845	328.597	0.356
329.468	1.504	328.222	-0.074	328.015	-0.638	329.052	-0.644
329.924	1.853	328.676	0.538	328.469	-0.739	329.507	-0.163
330.380	2.276	329.130	0.255	328.922	-1.021	329.962	0.606
330.835	2.911	329.584	-0.096	329.376	-0.997	330.417	0.517
331.291	3.048	330.038	-0.469	329.830	-0.777	330.872	-0.143
331.747	3.330	330.492	-0.224	330.284	-0.998	331.327	-0.336
332.203	3.125	330.946	0.091	330.737	-1.288	331.783	-0.464
332.658	3.123	331.400	-0.627	331.191	-1.229	332.238	-0.252
333.114	4.390	331.854	-1.075	331.645	-1.477	332.693	-0.172
333.570	4.521	332.308	-0.722	332.098	-1.130	333.148	-0.427
334.025	4.029	332.762	-1.111	332.552	-0.990	333.603	-0.300
334.481	4.490	333.216	-1.283	333.006	-1.469	334.058	-0.866
334.937	4.095	333.670	-0.882	333.459	-1.488	334.513	-0.935
335.392	3.176	334.124	-0.827	333.913	-1.107	334.968	-0.283
335.848	3.503	334.578	-1.210	334.367	-1.045	335.424	-0.393
336.304	3.979	335.032	-1.465	334.820	-1.374	335.879	-0.576
336.759	3.347	335.485	-1.062	335.274	-1.430	336.334	-0.698
337.215	2.631	335.939	-0.516	335.728	-1.418	336.789	-1.180
337.671	1.985	336.393	1.769	336.181	-1.227	337.244	-1.348
338.127	0.986	336.847	3.932	336.635	-1.377	337.699	-1.029
338.582	0.502	337.301	1.620	337.089	-1.718	338.154	-1.100
339.038	0.379	337.755	-1.799	337.543	-1.676	338.609	-1.274
339.494	-0.225	338.209	-2.351	337.996	-1.312	339.064	-1.366
339.949	-0.431	338.663	-1.929	338.450	-1.362	339.520	-1.816
340.405	-0.628	339.117	-2.067	338.904	-2.114	339.975	-2.010
340.861	-1.377	339.571	-2.217	339.357	-2.149	340.430	-1.651

Table A5: Heat Release at different crank angle for varying ethanol with Biodiesel at 50% load

341.316	-1.383	340.025	-2.115	339.811	-2.115	340.885	-1.432
341.772	-1.387	340.479	-2.336	340.265	-2.150	341.340	-1.781
342.228	-2.442	340.933	-2.636	340.718	-1.827	341.795	-2.076
342.684	-2.945	341.387	-2.477	341.172	-2.060	342.250	-2.315
343.139	-2.424	341.841	-2.308	341.626	-2.351	342.705	-2.456
343.595	-2.515	342.295	-2.612	342.079	-2.240	343.161	-2.246
344.051	-2.868	342.749	-3.009	342.533	-2.183	343.616	-2.464
344.506	-3.167	343.203	-2.871	342.987	-2.215	344.071	-2.792
344.962	-3.680	343.657	-2.664	343.440	-2.258	344.526	-2.740
345.418	-3.583	344.111	-2.718	343.894	-2.562	344.981	-2.861
345.873	-3.333	344.565	-2.885	344.348	-2.732	345.436	-3.197
346.329	-3.395	345.019	-3.279	344.802	-2.681	345.891	-3.189
346.785	-3.568	345.473	-3.562	345.255	-2.586	346.346	-3.146
347.241	-4.015	345.927	-3.495	345.709	-2.599	346.802	-3.343
347.696	-3.979	346.381	-3.501	346.163	-2.986	347.257	-3.433
348.152	-3.461	346.835	-3.812	346.616	-3.048	347.712	-3.449
348.608	-3.946	347.289	-4.086	347.070	-3.026	348.167	-3.722
349.063	-4.273	347.743	-4.011	347.524	-3.210	348.622	-3.949
349.519	-3.740	348.197	-3.863	347.977	-3.108	349.077	-3.530
349.975	-3.758	348.651	-3.911	348.431	-3.072	349.532	-3.392
350.430	-3.936	349.105	-4.090	348.885	-3.122	349.987	-3.480
350.886	-3.840	349.559	-4.193	349.338	-2.937	350.442	-3.460
351.342	-3.374	350.013	-3.827	349.792	-2.976	350.898	-3.354
351.797	-2.771	350.467	-3.163	350.246	-3.096	351.353	-2.782
352.253	-2.074	350.921	-3.235	350.699	-3.033	351.808	-2.297
352.709	-1.211	351.375	-3.583	351.153	-2.879	352.263	-1.440
353.165	0.050	351.828	-3.149	351.607	-2.444	352.718	0.202
353.620	2.259	352.282	-2.165	352.060	-1.763	353.173	2.055
354.076	5.074	352.736	-0.903	352.514	-1.120	353.628	4.467
354.532	8.723	353.190	0.357	352.968	-0.256	354.083	8.033
354.987	12.795	353.644	2.130	353.422	1.457	354.539	12.343
355.443	16.633	354.098	5.534	353.875	3.621	354.994	16.638
355.899	19.654	354.552	10.091	354.329	6.121	355.449	20.106
356.354	20.950	355.006	14.625	354.783	9.288	355.904	22.222
356.810	21.790	355.460	18.597	355.236	12.958	356.359	23.561
357.266	22.042	355.914	21.888	355.690	16.459	356.814	24.110
357.722	21.171	356.368	24.158	356.144	18.880	357.269	23.762
358.177	20.665	356.822	25.108	356.597	20.177	357.724	23.096
358.633	19.540	357.276	25.535	357.051	21.090	358.180	21.665
359.089	17.548	357.730	25.394	357.505	21.560	358.635	19.568
359.544	15.655	358.184	24.292	357.958	21.210	359.090	16.942
360.000	13.480	358.638	22.256	358.412	20.495	359.545	13.748
360.456	10.925	359.092	19.040	358.866	19.248	360.000	10.493
360.911	8.438	359.546	15.713	359.319	17.390	360.455	7.634
361.367	6.757	360.000	12.495	359.773	15.695	360.910	5.944
361.823	5.806	360.454	9.286	360.227	13.904	361.365	4.926
362.278	4.958	360.908	7.010	360.681	12.064	361.820	4.307
362.734	4.746	361.362	5.420	361.134	10.785	362.276	4.178
363.190	4.800	361.816	5.143	361.588	9.725	362.731	4.071
363.646	4.792	362.270	4.809	362.042	8.975	363.186	4.006
364.101	4.804	362.724	4.179	362.495	8.348	363.641	4.067

Table A5: Heat Release at different crank angle for varying ethanol with Biodiesel at 50% load

364.557	4.683	363.178	4.652	362.949	7.734	364.096	4.426
365.013	5.079	363.632	4.520	363.403	7.343	364.551	4.563
365.468	5.296	364.086	4.705	363.856	6.818	365.006	4.477
365.924	5.156	364.540	5.040	364.310	6.414	365.461	4.417
366.380	5.182	364.994	4.887	364.764	6.300	365.917	4.053
366.835	5.323	365.448	5.199	365.217	6.244	366.372	4.239
367.291	5.333	365.902	5.226	365.671	5.885	366.827	4.586
367.747	5.278	366.356	5.325	366.125	5.618	367.282	4.478
368.203	5.214	366.810	5.196	366.578	5.833	367.737	4.494
368.658	5.639	367.264	4.875	367.032	5.776	368.192	4.249
369.114	5.699	367.718	5.214	367.486	5.563	368.647	4.204
369.570	5.167	368.172	5.418	367.940	5.634	369.102	4.444
370.025	5.478	368.625	5.374	368.393	5.728	369.558	4.514
370.481	5.800	369.079	5.264	368.847	5.742	370.013	4.509
370.937	5.795	369.533	5.193	369.301	5.836	370.468	4.418
371.392	5.341	369.987	5.406	369.754	5.857	370.923	4.393
371.848	4.613	370.441	5.392	370.208	5.881	371.378	4.603
372.304	4.833	370.895	5.148	370.662	6.044	371.833	4.590
372.759	5.213	371.349	4.933	371.115	6.021	372.288	4.426
373.215	5.242	371.803	4.874	371.569	5.867	372.743	4.247
373.671	5.304	372.257	5.357	372.023	5.979	373.198	3.794
374.127	4.850	372.711	5.713	372.476	6.214	373.654	3.946
374.582	4.085	373.165	5.338	372.930	5.844	374.109	4.095
375.038	4.174	373.619	4.687	373.384	5.573	374.564	3.957
375.494	4.714	374.073	4.240	373.837	5.774	375.019	3.715
375.949	4.745	374.527	4.726	374.291	5.885	375.474	3.595
376.405	5.156	374.981	5.442	374.745	6.097	375.929	3.865
376.861	4.863	375.435	5.008	375.198	5.927	376.384	3.757
377.316	4.034	375.889	4.491	375.652	5.782	376.839	3.465
377.772	4.114	376.343	4.802	376.106	5.891	377.295	3.328
378.228	4.243	376.797	4.896	376.560	5.313	377.750	3.412
378.684	4.250	377.251	4.641	377.013	4.996	378.205	3.418
379.139	3.966	377.705	4.545	377.467	5.466	378.660	3.033
379.595	4.348	378.159	4.529	377.921	5.636	379.115	2.691
380.051	4.517	378.613	4.660	378.374	5.222	379.570	2.561
380.506	3.307	379.067	4.445	378.828	4.925	380.025	2.428
380.962	3.283	379.521	4.061	379.282	4.891	380.480	2.560
381.418	3.967	379.975	4.325	379.735	4.818	380.936	2.389
381.873	3.705	380.429	4.251	380.189	4.806	381.391	1.907
382.329	3.433	380.883	3.836	380.643	4.550	381.846	2.254
382.785	3.193	381.337	3.750	381.096	3.863	382.301	2.527
383.241	3.124	381.791	3.649	381.550	3.744	382.756	1.999
383.696	3.260	382.245	3.492	382.004	3.840	383.211	2.140
384.152	3.154	382.699	3.763	382.457	3.516	383.666	2.436
384.608	2.596	383.153	3.756	382.911	2.874	384.121	2.241
385.063	2.213	383.607	3.272	383.365	1.822	384.576	2.194
385.519	2.520	384.061	3.328	383.819	2.159	385.032	2.049
385.975	2.943	384.515	3.256	384.272	3.114	385.487	2.244
386.430	3.295	384.968	3.125	384.726	2.991	385.942	2.164
386.886	2.953	385.422	3.316	385.180	2.800	386.397	1.126
387.342	2.362	385.876	3.148	385.633	3.232	386.852	0.121

Table A5: Heat Release at different crank angle for varying ethanol with Biodiesel at 50% load

387.797	2.524	386.330	2.710	386.087	3.901	387.307	-0.294
388.253	2.877	386.784	2.839	386.541	4.109	387.762	-0.390
388.709	2.606	387.238	2.934	386.994	3.620	388.217	-0.186
389.165	1.843	387.692	2.982	387.448	3.439	388.673	-0.107
389.620	1.360	388.146	3.398	387.902	4.162	389.128	0.311
390.076	1.653	388.600	2.588	388.355	3.807	389.583	0.479
390.532	2.191	389.054	1.728	388.809	3.131	390.038	-0.416
390.987	2.005	389.508	2.288	389.263	3.650	390.493	-0.204
391.443	1.688	389.962	3.019	389.716	3.340	390.948	0.193
391.899	1.412	390.416	3.078	390.170	2.192	391.403	-0.241
392.354	0.427	390.870	2.781	390.624	1.835	391.858	-0.079
392.810	0.336	391.324	2.202	391.078	2.136	392.314	0.183
393.266	1.623	391.778	1.277	391.531	1.731	392.769	0.201
393.722	2.367	392.232	1.717	391.985	1.502	393.224	0.616
394.177	1.163	392.686	2.015	392.439	2.367	393.679	0.073
394.633	0.799	393.140	1.110	392.892	1.912	394.134	-0.769
395.089	2.235	393.594	1.501	393.346	1.014	394.589	0.042
395.544	1.997	394.048	1.853	393.800	1.592	395.044	0.404
396.000	1.457	394.502	2.076	394.253	1.325	395.499	-0.305
396.456	2.585	394.956	2.699	394.707	0.326	395.954	0.161
396.911	2.997	395.410	2.867	395.161	0.612	396.410	1.127
397.367	1.974	395.864	2.806	395.614	1.357	396.865	0.722
397.823	2.342	396.318	1.831	396.068	1.596	397.320	0.190
398.278	2.761	396.772	1.824	396.522	1.655	397.775	0.257
398.734	2.378	397.226	1.660	396.975	0.884	398.230	-0.038
399.190	3.101	397.680	1.151	397.429	0.193	398.685	-0.401
399.646	3.140	398.134	1.456	397.883	0.957	399.140	-0.582
400.101	2.505	398.588	1.191	398.336	0.454	399.595	-0.675
400.557	2.652	399.042	1.281	398.790	-0.814	400.051	-0.482
401.013	2.225	399.496	1.374	399.244	-0.904	400.506	-1.786
401.468	1.946	399.950	1.016	399.698	-0.229	400.961	-2.293
401.924	2.526	400.404	0.327	400.151	0.517	401.416	-0.662
402.380	2.676	400.858	0.790	400.605	-0.358	401.871	-0.337
402.835	3.072	401.311	1.409	401.059	-1.347	402.326	-0.856
403.291	2.902	401.765	1.176	401.512	-0.540	402.781	-0.779
403.747	1.641	402.219	1.364	401.966	-0.307	403.236	0.460
404.203	1.018	402.673	1.045	402.420	-0.568	403.692	0.298
404.658	1.608	403.127	0.832	402.873	0.072	404.147	-1.479
405.114	2.737	403.581	2.087	403.327	0.216	404.602	-0.517
405.570	3.024	404.035	1.467	403.781	0.038	405.057	0.995
406.025	2.733	404.489	-1.029	404.234	-0.283	405.512	0.116
406.481	2.578	404.943	0.009	404.688	-0.499	405.967	-1.153
406.937	2.577	405.397	2.208	405.142	0.264	406.422	-1.601
407.392	3.682	405.851	2.160	405.595	0.677	406.877	-0.734
407.848	3.090	406.305	1.900	406.049	0.323	407.332	-0.597
408.304	1.684	406.759	2.117	406.503	0.896	407.788	-1.510
408.759	2.362	407.213	1.903	406.957	1.480	408.243	-1.594
409.215	1.905	407.667	1.500	407.410	1.522	408.698	-0.897
409.671	2.181	408.121	1.544	407.864	1.362	409.153	-0.438
410.127	3.979	408.575	1.542	408.318	0.911	409.608	-1.155
410.582	4.459	409.029	1.664	408.771	0.705	410.063	-1.608

Table A5: Heat Release at different crank angle for varying ethanol with Biodiesel at 50% load

411.038	4.208	409.483	1.361	409.225	-0.350	410.518	-1.381
411.494	3.789	409.937	1.134	409.679	-0.875	410.973	-1.741
411.949	3.644	410.391	1.756	410.132	0.013	411.429	-2.203
412.405	4.756	410.845	0.586	410.586	0.951	411.884	-1.606
412.861	5.370	411.299	0.775	411.040	0.711	412.339	-1.395
413.316	3.640	411.753	2.422	411.493	-0.395	412.794	-2.184
413.772	3.423	412.207	1.667	411.947	-0.007	413.249	-2.347
414.228	4.639	412.661	1.494	412.401	-0.147	413.704	-3.061
414.684	3.196	413.115	1.871	412.854	-1.753	414.159	-3.821
415.139	3.167	413.569	1.283	413.308	-1.528	414.614	-2.316
415.595	4.678	414.023	-0.459	413.762	0.524	415.070	-1.451
416.051	4.026	414.477	-0.835	414.216	0.908	415.525	-2.238
416.506	4.394	414.931	0.997	414.669	-0.406	415.980	-1.664
416.962	4.670	415.385	1.668	415.123	-1.026	416.435	-0.391
417.418	4.032	415.839	1.207	415.577	-0.674	416.890	-1.883
417.873	5.264	416.293	0.928	416.030	-0.691	417.345	-3.234
418.329	7.519	416.747	1.734	416.484	-0.421	417.800	-1.331
418.785	5.418	417.201	0.733	416.938	0.485	418.255	-1.237
419.241	4.037	417.654	-0.360	417.391	0.137	418.710	-3.146
419.696	6.261	418.108	1.640	417.845	0.070	419.166	-3.776
420.152	4.366	418.562	3.370	418.299	1.317	419.621	-4.024
420.608	2.758	419.016	4.583	418.752	2.476	420.076	-3.781

Table A6: Heat Release at different crank angle for varying ethanol with Biodiesel at 100% load

Biodiesel + 0% Ethanol		Biodiesel + 10% Ethanol		Biodiesel + 20% Ethanol		Biodiesel + 30% Ethanol	
Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)	Crank Angle (deg)	Heat Release (J/deg)
320.244	0.598	321.224	0.286	321.815	-0.242	322.210	-0.554
320.683	0.090	321.665	-0.416	322.256	-0.102	322.652	-0.441
321.123	-0.127	322.105	-1.057	322.698	-0.161	323.094	-0.526
321.562	-0.214	322.546	-0.817	323.139	-0.053	323.536	-1.103
322.001	-0.917	322.987	-0.804	323.581	0.041	323.978	-0.806
322.441	-0.460	323.427	-0.669	324.022	-0.368	324.420	-0.575
322.880	-0.024	323.868	-1.296	324.464	-1.165	324.862	-0.390
323.319	-0.667	324.308	-1.610	324.905	-1.109	325.304	-0.168
323.758	-0.719	324.749	-0.664	325.346	-0.509	325.746	-0.692
324.198	-0.504	325.190	-0.650	325.788	-0.171	326.188	-0.842
324.637	-0.024	325.630	-1.538	326.229	0.290	326.630	-1.183
325.076	-0.162	326.071	-1.631	326.671	0.398	327.072	-1.247
325.516	-0.338	326.512	-0.863	327.112	-0.460	327.514	0.123
325.955	0.711	326.952	-0.639	327.554	-1.013	327.956	0.189
326.394	0.354	327.393	-0.515	327.995	-1.008	328.398	-0.963
326.833	-0.912	327.834	-0.073	328.437	-0.938	328.840	-0.375
327.273	-0.493	328.274	-0.398	328.878	-0.321	329.282	-0.348
327.712	-0.242	328.715	-1.038	329.319	-0.220	329.724	-1.957
328.151	-0.955	329.155	-1.372	329.761	-0.188	330.166	-1.765
328.591	-0.469	329.596	-1.506	330.202	-0.373	330.608	-0.475
329.030	-0.085	330.037	-1.424	330.644	-1.310	331.050	-0.620
329.469	-0.635	330.477	-1.633	331.085	-1.414	331.492	-1.218
329.908	-0.280	330.918	-2.258	331.527	-1.222	331.934	-2.020
330.348	-0.371	331.359	-2.256	331.968	-1.157	332.376	-1.990
330.787	-0.890	331.799	-1.692	332.410	-1.165	332.818	-0.968
331.226	-0.959	332.240	-1.240	332.851	-1.095	333.260	-1.393
331.666	-1.115	332.681	-0.864	333.292	-0.972	333.702	-2.021
332.105	-1.286	333.121	-1.126	333.734	-1.194	334.144	-1.778
332.544	-1.653	333.562	-1.906	334.175	-1.521	334.586	-1.571
332.984	-1.178	334.002	-2.487	334.617	-2.323	335.028	-1.708
333.423	-0.701	334.443	-1.806	335.058	-2.337	335.470	-1.593
333.862	-0.996	334.884	-1.319	335.500	-1.621	335.912	-1.676
334.301	-1.095	335.324	-1.818	335.941	-1.637	336.354	-2.259
334.741	-1.078	335.765	-1.555	336.383	-1.745	336.796	-1.803
335.180	-1.194	336.206	-1.939	336.824	-1.534	337.238	-1.680
335.619	-1.677	336.646	-2.529	337.265	-1.690	337.680	-2.474
336.059	-1.827	337.087	-2.363	337.707	-2.250	338.122	-2.766
336.498	-1.554	337.528	-1.971	338.148	-2.074	338.564	-2.781
336.937	-1.422	337.968	-1.799	338.590	-1.955	339.006	-2.807
337.376	-1.579	338.409	-2.426	339.031	-2.354	339.448	-2.530
337.816	-1.755	338.849	-2.245	339.473	-2.626	339.890	-2.266
338.255	-1.754	339.290	-2.180	339.914	-2.679	340.331	-2.686
338.694	-2.020	339.731	-2.670	340.356	-2.494	340.773	-2.803
339.134	-2.143	340.171	-2.724	340.797	-2.877	341.215	-2.776
339.573	-2.148	340.612	-3.201	341.239	-3.075	341.657	-3.099

Table A6: Heat Release at different crank angle for varying ethanol with Biodiesel at 100% load

340.012	-2.610	341.053	-3.266	341.680	-2.660	342.099	-3.050
340.451	-2.797	341.493	-3.103	342.121	-2.577	342.541	-2.848
340.891	-2.451	341.934	-2.850	342.563	-2.710	342.983	-3.036
341.330	-2.669	342.375	-2.294	343.004	-2.754	343.425	-3.517
341.769	-2.903	342.815	-2.404	343.446	-2.843	343.867	-3.844
342.209	-2.500	343.256	-2.445	343.887	-2.707	344.309	-3.974
342.648	-2.468	343.696	-2.066	344.329	-2.735	344.751	-3.874
343.087	-2.635	344.137	-2.071	344.770	-3.596	345.193	-3.965
343.527	-2.527	344.578	-2.286	345.212	-3.902	345.635	-4.389
343.966	-2.836	345.018	-2.501	345.653	-3.630	346.077	-4.471
344.405	-3.585	345.459	-2.278	346.094	-3.819	346.519	-4.427
344.844	-3.657	345.900	-1.877	346.536	-3.833	346.961	-4.307
345.284	-3.667	346.340	-2.282	346.977	-3.870	347.403	-4.545
345.723	-3.841	346.781	-2.836	347.419	-4.305	347.845	-4.978
346.162	-3.746	347.222	-2.913	347.860	-4.358	348.287	-4.807
346.602	-3.932	347.662	-2.615	348.302	-4.186	348.729	-4.818
347.041	-4.234	348.103	-2.424	348.743	-4.264	349.171	-4.825
347.480	-4.528	348.543	-2.350	349.185	-4.421	349.613	-4.820
347.919	-4.214	348.984	-2.245	349.626	-4.301	350.055	-4.757
348.359	-3.827	349.425	-2.571	350.067	-3.868	350.497	-4.153
348.798	-3.972	349.865	-2.797	350.509	-3.581	350.939	-3.985
349.237	-4.167	350.306	-2.523	350.950	-3.582	351.381	-3.951
349.677	-3.974	350.747	-2.147	351.392	-3.688	351.823	-3.130
350.116	-3.359	351.187	-2.005	351.833	-3.478	352.265	-2.311
350.555	-3.111	351.628	-1.974	352.275	-3.021	352.707	-1.533
350.995	-2.944	352.069	-1.810	352.716	-2.398	353.149	-0.044
351.434	-2.394	352.509	-1.224	353.158	-1.355	353.591	2.275
351.873	-1.388	352.950	-0.287	353.599	0.260	354.033	5.679
352.312	0.310	353.390	0.464	354.040	1.997	354.475	10.187
352.752	3.586	353.831	1.411	354.482	4.221	354.917	15.717
353.191	8.094	354.272	3.198	354.923	8.601	355.359	21.191
353.630	12.971	354.712	6.145	355.365	14.342	355.801	25.680
354.070	18.780	355.153	10.789	355.806	20.685	356.243	29.382
354.509	24.065	355.594	16.518	356.248	26.641	356.685	31.031
354.948	28.059	356.034	21.615	356.689	30.546	357.127	31.155
355.387	31.059	356.475	25.846	357.131	32.912	357.569	31.911
355.827	33.142	356.916	29.589	357.572	34.104	358.011	31.445
356.266	34.281	357.356	32.205	358.013	34.808	358.453	29.033
356.705	33.531	357.797	33.725	358.455	34.097	358.895	25.377
357.145	31.030	358.237	34.108	358.896	31.553	359.337	20.354
357.584	26.769	358.678	32.983	359.338	28.248	359.779	15.723
358.023	21.091	359.119	30.471	359.779	23.592	360.221	11.318
358.462	15.532	359.559	27.044	360.221	18.087	360.663	8.406
358.902	10.879	360.000	23.111	360.662	13.129	361.105	6.813
359.341	7.830	360.441	19.269	361.104	9.682	361.547	5.351
359.780	6.414	360.881	16.445	361.545	7.700	361.989	5.269
360.220	6.034	361.322	14.296	361.987	6.917	362.431	5.187
360.659	6.192	361.763	12.407	362.428	6.552	362.873	5.246
361.098	6.257	362.203	11.031	362.869	6.402	363.315	5.421
361.538	6.423	362.644	10.277	363.311	6.785	363.757	5.496
361.977	6.588	363.084	9.936	363.752	6.648	364.199	5.799

Table A6: Heat Release at different crank angle for varying ethanol with Biodiesel at 100% load

362.416	6.925	363.525	9.337	364.194	6.840	364.641	5.751
362.855	6.964	363.966	8.935	364.635	7.206	365.083	5.868
363.295	6.946	364.406	8.873	365.077	7.121	365.525	5.926
363.734	7.109	364.847	8.609	365.518	7.130	365.967	6.259
364.173	7.170	365.288	8.428	365.960	7.149	366.409	6.528
364.613	7.359	365.728	8.055	366.401	7.544	366.851	6.186
365.052	7.150	366.169	8.016	366.842	7.558	367.293	6.227
365.491	7.779	366.610	7.996	367.284	7.450	367.735	6.343
365.930	8.175	367.050	8.031	367.725	7.630	368.177	6.566
366.370	7.874	367.491	8.191	368.167	7.542	368.619	6.713
366.809	7.827	367.931	8.174	368.608	7.675	369.061	6.662
367.248	7.569	368.372	8.175	369.050	7.846	369.503	6.800
367.688	8.034	368.813	8.110	369.491	8.000	369.945	6.433
368.127	7.983	369.253	8.639	369.933	8.077	370.387	6.267
368.566	7.588	369.694	8.346	370.374	7.750	370.829	6.359
369.005	7.816	370.135	7.837	370.815	7.379	371.271	6.299
369.445	7.533	370.575	8.202	371.257	6.960	371.713	6.183
369.884	7.510	371.016	7.903	371.698	7.204	372.155	5.775
370.323	7.452	371.457	7.852	372.140	7.247	372.597	5.479
370.763	6.912	371.897	8.008	372.581	6.835	373.039	5.330
371.202	6.953	372.338	7.530	373.023	6.890	373.481	5.784
371.641	7.045	372.778	7.528	373.464	6.514	373.923	5.851
372.081	6.762	373.219	7.725	373.906	6.372	374.365	5.262
372.520	6.422	373.660	7.767	374.347	6.346	374.807	5.651
372.959	5.991	374.100	7.799	374.788	5.992	375.249	5.706
373.398	6.070	374.541	7.594	375.230	5.956	375.691	5.062
373.838	6.342	374.982	7.721	375.671	6.037	376.133	5.252
374.277	6.161	375.422	7.977	376.113	6.071	376.575	5.419
374.716	6.175	375.863	7.990	376.554	5.568	377.017	5.145
375.156	6.039	376.304	8.185	376.996	5.378	377.459	5.199
375.595	6.193	376.744	8.224	377.437	5.885	377.901	5.109
376.034	6.313	377.185	7.819	377.879	5.771	378.343	5.100
376.473	5.546	377.625	7.764	378.320	5.916	378.785	5.210
376.913	5.616	378.066	8.408	378.761	5.859	379.227	5.019
377.352	5.719	378.507	9.093	379.203	4.939	379.669	4.718
377.791	5.513	378.947	9.698	379.644	5.100	380.110	4.634
378.231	6.157	379.388	9.767	380.086	5.585	380.552	4.541
378.670	5.999	379.829	8.799	380.527	4.977	380.994	3.952
379.109	5.011	380.269	7.400	380.969	4.594	381.436	3.543
379.549	4.734	380.710	6.602	381.410	4.714	381.878	3.900
379.988	4.755	381.151	6.621	381.852	4.616	382.320	4.299
380.427	5.105	381.591	6.750	382.293	4.507	382.762	3.820
380.866	5.398	382.032	6.702	382.735	4.656	383.204	3.259
381.306	4.505	382.472	5.742	383.176	4.660	383.646	3.609
381.745	4.566	382.913	4.340	383.617	4.040	384.088	3.838
382.184	4.828	383.354	3.909	384.059	3.488	384.530	3.400
382.624	3.605	383.794	3.805	384.500	3.691	384.972	3.335
383.063	3.260	384.235	3.270	384.942	3.864	385.414	3.099
383.502	3.626	384.676	2.687	385.383	3.413	385.856	3.003
383.941	3.356	385.116	2.615	385.825	2.973	386.298	2.902
384.381	3.372	385.557	2.778	386.266	2.633	386.740	2.435

Table A6: Heat Release at different crank angle for varying ethanol with Biodiesel at 100% load

384.820	3.858	385.998	2.242	386.708	2.545	387.182	2.788
385.259	3.501	386.438	2.173	387.149	2.899	387.624	2.959
385.699	2.850	386.879	3.232	387.590	3.574	388.066	3.117
386.138	3.053	387.319	3.544	388.032	3.817	388.508	3.379
386.577	3.597	387.760	3.614	388.473	3.012	388.950	2.970
387.016	3.886	388.201	3.782	388.915	2.242	389.392	2.409
387.456	3.633	388.641	3.365	389.356	2.232	389.834	2.325
387.895	3.055	389.082	3.855	389.798	2.778	390.276	3.155
388.334	3.151	389.523	3.935	390.239	2.907	390.718	3.477
388.774	3.236	389.963	3.251	390.681	2.957	391.160	3.124
389.213	2.229	390.404	3.209	391.122	3.123	391.602	3.001
389.652	1.989	390.845	3.418	391.563	3.231	392.044	3.520
390.092	3.161	391.285	4.045	392.005	3.565	392.486	3.179
390.531	3.308	391.726	3.857	392.446	2.512	392.928	2.003
390.970	3.059	392.166	3.261	392.888	1.593	393.370	2.649
391.409	3.151	392.607	3.043	393.329	2.216	393.812	2.284
391.849	2.704	393.048	3.066	393.771	2.610	394.254	1.203
392.288	2.925	393.488	3.252	394.212	1.988	394.696	2.046
392.727	3.600	393.929	2.724	394.654	1.161	395.138	1.938
393.167	3.169	394.370	1.747	395.095	1.244	395.580	1.424
393.606	2.116	394.810	1.540	395.536	1.363	396.022	1.952
394.045	1.835	395.251	2.376	395.978	1.739	396.464	1.560
394.484	2.018	395.692	2.791	396.419	1.604	396.906	0.857
394.924	2.087	396.132	2.166	396.861	0.584	397.348	1.176
395.363	1.313	396.573	2.057	397.302	1.227	397.790	1.665
395.802	0.580	397.013	2.416	397.744	1.522	398.232	1.535
396.242	0.974	397.454	2.056	398.185	0.888	398.674	1.505
396.681	2.030	397.895	2.597	398.627	1.958	399.116	1.874
397.120	2.798	398.335	2.781	399.068	3.021	399.558	2.031
397.559	1.753	398.776	2.043	399.510	3.245	400.000	2.255
397.999	1.100	399.217	1.504	399.951	3.279	400.442	2.076
398.438	1.407	399.657	0.721	400.392	2.372	400.884	1.239
398.877	1.681	400.098	1.118	400.834	1.582	401.326	0.851
399.317	2.211	400.539	1.598	401.275	1.130	401.768	0.879
399.756	2.125	400.979	1.763	401.717	1.427	402.210	1.014
400.195	1.769	401.420	1.147	402.158	2.069	402.652	1.252
400.635	1.617	401.860	0.562	402.600	1.610	403.094	0.604
401.074	2.243	402.301	1.569	403.041	1.747	403.536	0.244
401.513	1.709	402.742	1.726	403.483	1.317	403.978	0.687
401.952	0.471	403.182	0.655	403.924	0.320	404.420	1.172
402.392	1.486	403.623	-0.075	404.365	1.253	404.862	1.923
402.831	2.114	404.064	0.667	404.807	1.872	405.304	1.065
403.270	1.728	404.504	1.186	405.248	1.406	405.746	-0.165
403.710	1.974	404.945	0.863	405.690	1.810	406.188	0.323
404.149	1.149	405.386	0.724	406.131	1.925	406.630	1.739
404.588	-0.381	405.826	0.596	406.573	1.731	407.072	1.937
405.027	-0.429	406.267	1.174	407.014	2.494	407.514	0.646
405.467	0.783	406.707	0.858	407.456	1.527	407.956	0.411
405.906	1.705	407.148	-0.136	407.897	-0.720	408.398	1.104
406.345	1.183	407.589	0.694	408.338	0.431	408.840	0.655
406.785	1.239	408.029	1.539	408.780	2.318	409.282	-0.042

Table A6: Heat Release at different crank angle for varying ethanol with Biodiesel at 100% load

407.224	1.989	408.470	0.381	409.221	2.010	409.724	0.431
407.663	0.658	408.911	-0.678	409.663	2.152	410.166	0.590
408.103	-0.839	409.351	0.279	410.104	1.671	410.608	0.220
408.542	-0.436	409.792	1.648	410.546	-0.021	411.050	-0.672
408.981	0.246	410.233	0.411	410.987	0.107	411.492	-0.127
409.420	1.367	410.673	-0.693	411.429	1.187	411.934	0.510
409.860	2.298	411.114	0.115	411.870	0.878	412.376	0.113
410.299	1.281	411.554	-0.245	412.311	0.529	412.818	2.260
410.738	1.625	411.995	0.183	412.753	1.412	413.260	2.820
411.178	2.562	412.436	0.649	413.194	2.386	413.702	0.438
411.617	1.376	412.876	0.350	413.636	1.828	414.144	-0.923
412.056	1.346	413.317	0.633	414.077	0.482	414.586	-0.783
412.495	1.576	413.758	0.822	414.519	1.024	415.028	-0.014
412.935	0.715	414.198	0.836	414.960	2.628	415.470	0.284
413.374	1.104	414.639	0.493	415.402	1.565	415.912	0.030
413.813	1.491	415.080	1.163	415.843	-1.543	416.354	-1.464
414.253	0.678	415.520	1.134	416.284	-2.016	416.796	-2.051
414.692	0.039	415.961	-0.208	416.726	0.674	417.238	-1.364
415.131	0.778	416.401	-0.943	417.167	0.318	417.680	-0.761
415.570	0.108	416.842	-1.438	417.609	-1.567	418.122	-0.345
416.010	-2.082	417.283	-1.338	418.050	0.050	418.564	-0.646
416.449	-0.144	417.723	-0.696	418.492	0.111	419.006	-0.044
416.888	0.721	418.164	-0.363	418.933	-0.019	419.448	-0.139
417.328	-1.897	418.605	-0.694	419.375	1.121	419.890	-0.545
417.767	-1.425	419.045	-2.558	419.816	0.497	420.331	1.022
418.206	0.255	419.486	-1.976	420.258	0.370	420.773	2.126
418.646	2.031	419.927	1.117	420.699	0.515	421.215	0.517
419.085	2.024	420.367	0.458	421.140	1.419	421.657	-1.697
419.524	0.534	420.808	-0.075	421.582	1.737	422.099	-0.861
419.963	1.545	421.248	1.150	422.023	1.220	422.541	0.714
420.403	1.701	421.689	0.443	422.465	0.441	422.983	-0.210
420.842	0.089	422.130	0.191	422.906	-0.557	423.425	-0.748

Table A7: Pressure at different Crank angle at no load for diesel with varying ethanol content

Diesel + 0% Ethanol		Diesel + 10% Ethanol		Diesel + 20% Ethanol		Diesel + 30% Ethanol	
Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)
320.354	9.517	321.168	9.643	319.747	8.986	320.964	6.987
320.810	9.716	321.624	9.887	320.202	9.188	321.420	7.030
321.266	9.947	322.081	10.058	320.657	9.376	321.877	7.206
321.722	10.166	322.538	10.267	321.112	9.583	322.334	7.465
322.177	10.360	322.995	10.536	321.567	9.776	322.790	7.741
322.633	10.594	323.452	10.739	322.021	9.990	323.247	8.021
323.089	10.787	323.909	10.956	322.476	10.201	323.703	8.217
323.544	11.079	324.365	11.210	322.931	10.425	324.160	8.438
324.000	11.320	324.822	11.461	323.386	10.626	324.616	8.652
324.456	11.547	325.279	11.730	323.841	10.860	325.073	8.944
324.911	11.839	325.736	11.982	324.296	11.069	325.529	9.213
325.367	12.088	326.193	12.251	324.750	11.298	325.986	9.648
325.823	12.430	326.650	12.578	325.205	11.509	326.443	10.211
326.278	12.666	327.107	12.819	325.660	11.763	326.899	10.556
326.734	12.963	327.563	13.106	326.115	12.005	327.356	10.785
327.190	13.275	328.020	13.400	326.570	12.309	327.812	10.978
327.646	13.569	328.477	13.722	327.025	12.578	328.269	11.265
328.101	13.888	328.934	14.029	327.479	12.794	328.725	11.544
328.557	14.190	329.391	14.386	327.934	13.106	329.182	11.796
329.013	14.542	329.848	14.671	328.389	13.358	329.639	12.085
329.468	14.872	330.305	15.023	328.844	13.670	330.095	12.397
329.924	15.224	330.761	15.340	329.299	13.986	330.552	12.694
330.380	15.579	331.218	15.717	329.754	14.288	331.008	13.048
330.835	15.943	331.675	16.074	330.208	14.565	331.465	13.353
331.291	16.290	332.132	16.456	330.663	14.899	331.921	13.737
331.747	16.708	332.589	16.813	331.118	15.239	332.378	14.032
332.203	17.093	333.046	17.198	331.573	15.571	332.834	14.401
332.658	17.475	333.503	17.565	332.028	15.933	333.291	14.774
333.114	17.892	333.959	17.973	332.483	16.275	333.748	15.141
333.570	18.234	334.416	18.373	332.937	16.670	334.204	15.478
334.025	18.687	334.873	18.785	333.392	16.984	334.661	15.868
334.481	19.130	335.330	19.213	333.847	17.450	335.117	16.273
334.937	19.562	335.787	19.638	334.302	17.777	335.574	16.642
335.392	19.995	336.244	20.058	334.757	18.194	336.030	17.080
335.848	20.460	336.701	20.493	335.212	18.577	336.487	17.475
336.304	20.948	337.157	20.941	335.666	19.054	336.944	17.920
336.759	21.411	337.614	21.436	336.121	19.437	337.400	18.335
337.215	21.859	338.071	21.874	336.576	19.869	337.857	18.755
337.671	22.402	338.528	22.367	337.031	20.319	338.313	19.208
338.127	22.880	338.985	22.812	337.486	20.775	338.770	19.678
338.582	23.358	339.442	23.307	337.941	21.255	339.226	20.148
339.038	23.866	339.898	23.755	338.395	21.675	339.683	20.591
339.494	24.354	340.355	24.271	338.850	22.203	340.140	21.066
339.949	24.869	340.812	24.741	339.305	22.653	340.596	21.547
340.405	25.408	341.269	25.274	339.760	23.126	341.053	22.035
340.861	25.918	341.726	25.760	340.215	23.597	341.509	22.508

Table A7: Pressure at different Crank angle at no load for diesel with varying ethanol content

341.316	26.476	342.183	26.280	340.670	24.127	341.966	22.983
341.772	26.984	342.640	26.798	341.124	24.623	342.422	23.478
342.228	27.498	343.096	27.299	341.579	25.166	342.879	24.022
342.684	28.063	343.553	27.819	342.034	25.591	343.335	24.490
343.139	28.597	344.010	28.320	342.489	26.162	343.792	24.990
343.595	29.122	344.467	28.826	342.944	26.668	344.249	25.503
344.051	29.681	344.924	29.369	343.399	27.150	344.705	26.016
344.506	30.226	345.381	29.874	343.853	27.724	345.162	26.532
344.962	30.747	345.838	30.370	344.308	28.209	345.618	27.032
345.418	31.270	346.294	30.878	344.763	28.692	346.075	27.515
345.873	31.776	346.751	31.386	345.218	29.228	346.531	28.046
346.329	32.269	347.208	31.904	345.673	29.759	346.988	28.509
346.785	32.794	347.665	32.354	346.128	30.282	347.445	29.012
347.241	33.257	348.122	32.812	346.582	30.772	347.901	29.490
347.696	33.720	348.579	33.252	347.037	31.283	348.358	29.970
348.152	34.205	349.036	33.725	347.492	31.756	348.814	30.438
348.608	34.668	349.492	34.153	347.947	32.291	349.271	30.878
349.063	35.073	349.949	34.580	348.402	32.737	349.727	31.361
349.519	35.543	350.406	34.980	348.857	33.207	350.184	31.771
349.975	35.953	350.863	35.382	349.311	33.624	350.640	32.218
350.430	36.336	351.320	35.732	349.766	34.085	351.097	32.616
350.886	36.720	351.777	36.051	350.221	34.510	351.554	33.053
351.342	37.138	352.234	36.404	350.676	34.907	352.010	33.438
351.797	37.407	352.690	36.703	351.131	35.297	352.467	33.818
352.253	37.832	353.147	37.130	351.586	35.662	352.923	34.135
352.709	38.141	353.604	37.337	352.040	36.019	353.380	34.462
353.165	38.519	354.061	37.525	352.495	36.368	353.836	34.779
353.620	38.783	354.518	37.729	352.950	36.730	354.293	35.086
354.076	39.052	354.975	37.925	353.405	37.017	354.750	35.362
354.532	39.303	355.431	38.089	353.860	37.254	355.206	35.616
354.987	39.633	355.888	38.262	354.315	37.475	355.663	35.823
355.443	40.015	356.345	38.431	354.769	37.719	356.119	36.069
355.899	40.433	356.802	38.561	355.224	37.862	356.576	36.298
356.354	40.961	357.259	38.677	355.679	38.053	357.032	36.527
356.810	41.565	357.716	38.883	356.134	38.247	357.489	36.728
357.266	42.279	358.173	39.062	356.589	38.451	357.945	36.952
357.722	43.079	358.629	39.268	357.044	38.544	358.402	37.161
358.177	43.984	359.086	39.545	357.498	38.695	358.859	37.420
358.633	44.910	359.543	39.857	357.953	38.858	359.315	37.787
359.089	45.825	360.000	40.226	358.408	39.075	359.772	38.164
359.544	46.731	360.457	40.735	358.863	39.233	360.228	38.549
360.000	47.563	360.914	41.308	359.318	39.472	360.685	38.961
360.456	48.396	361.371	41.894	359.773	39.794	361.141	39.379
360.911	49.039	361.827	42.455	360.227	40.141	361.598	39.894
361.367	49.598	362.284	42.988	360.682	40.621	362.055	40.249
361.823	50.093	362.741	43.463	361.137	41.031	362.511	40.714
362.278	50.403	363.198	43.893	361.592	41.615	362.968	41.059
362.734	50.672	363.655	44.210	362.047	42.037	363.424	41.421
363.190	50.755	364.112	44.527	362.502	42.558	363.881	41.736
363.646	50.795	364.569	44.718	362.956	42.993	364.337	41.990
364.101	50.674	365.025	44.859	363.411	43.380	364.794	42.148

Table A7: Pressure at different Crank angle at no load for diesel with varying ethanol content

364.557	50.478	365.482	44.849	363.866	43.700	365.250	42.389
365.013	50.216	365.939	44.796	364.321	43.992	365.707	42.410
365.468	49.900	366.396	44.645	364.776	44.195	366.164	42.420
365.924	49.585	366.853	44.492	365.231	44.369	366.620	42.347
366.380	49.153	367.310	44.213	365.685	44.391	367.077	42.259
366.835	48.715	367.766	43.861	366.140	44.366	367.533	42.025
367.291	48.307	368.223	43.549	366.595	44.241	367.990	41.813
367.747	47.777	368.680	43.129	367.050	44.075	368.446	41.484
368.203	47.279	369.137	42.709	367.505	43.800	368.903	41.170
368.658	46.758	369.594	42.284	367.960	43.489	369.360	40.820
369.114	46.227	370.051	41.776	368.414	43.074	369.816	40.408
369.570	45.657	370.508	41.268	368.869	42.726	370.273	40.003
370.025	45.078	370.964	40.750	369.324	42.319	370.729	39.507
370.481	44.497	371.421	40.216	369.779	41.891	371.186	39.127
370.937	43.861	371.878	39.668	370.234	41.416	371.642	38.619
371.392	43.272	372.335	39.090	370.689	40.926	372.099	38.184
371.848	42.586	372.792	38.559	371.143	40.428	372.555	37.679
372.304	41.987	373.249	37.938	371.598	39.869	373.012	37.201
372.759	41.310	373.706	37.367	372.053	39.324	373.469	36.693
373.215	40.657	374.162	36.748	372.508	38.715	373.925	36.185
373.671	39.993	374.619	36.170	372.963	38.141	374.382	35.659
374.127	39.319	375.076	35.584	373.418	37.513	374.838	35.101
374.582	38.639	375.533	34.947	373.872	36.919	375.295	34.575
375.038	37.960	375.990	34.386	374.327	36.240	375.751	34.042
375.494	37.309	376.447	33.768	374.782	35.621	376.208	33.461
375.949	36.650	376.904	33.146	375.237	34.935	376.665	32.918
376.405	35.991	377.360	32.553	375.692	34.349	377.121	32.369
376.861	35.345	377.817	31.962	376.147	33.662	377.578	31.859
377.316	34.693	378.274	31.363	376.601	33.119	378.034	31.268
377.772	34.054	378.731	30.775	377.056	32.447	378.491	30.740
378.228	33.400	379.188	30.154	377.511	31.874	378.947	30.161
378.684	32.734	379.645	29.570	377.966	31.225	379.404	29.613
379.139	32.113	380.102	29.017	378.421	30.636	379.860	29.077
379.595	31.454	380.558	28.423	378.876	30.015	380.317	28.584
380.051	30.868	381.015	27.850	379.330	29.401	380.774	28.089
380.506	30.259	381.472	27.274	379.785	28.853	381.230	27.515
380.962	29.668	381.929	26.720	380.240	28.252	381.687	27.012
381.418	29.105	382.386	26.127	380.695	27.736	382.143	26.449
381.873	28.544	382.843	25.629	381.150	27.158	382.600	25.978
382.329	28.008	383.299	25.083	381.605	26.602	383.056	25.503
382.785	27.482	383.756	24.555	382.059	26.059	383.513	25.081
383.241	26.932	384.213	24.024	382.514	25.531	383.970	24.603
383.696	26.481	384.670	23.511	382.969	25.000	384.426	24.170
384.152	25.946	385.127	23.061	383.424	24.442	384.883	23.753
384.608	25.501	385.584	22.555	383.879	23.969	385.339	23.300
385.063	24.993	386.041	22.083	384.334	23.468	385.796	22.875
385.519	24.537	386.497	21.670	384.788	22.991	386.252	22.447
385.975	24.069	386.954	21.195	385.243	22.553	386.709	22.042
386.430	23.607	387.411	20.770	385.698	22.032	387.166	21.587
386.886	23.194	387.868	20.335	386.153	21.615	387.622	21.190
387.342	22.759	388.325	19.925	386.608	21.157	388.079	20.729

Table A7: Pressure at different Crank angle at no load for diesel with varying ethanol content

387.797	22.296	388.782	19.497	387.063	20.709	388.535	20.312
388.253	21.839	389.239	19.102	387.517	20.297	388.992	19.867
388.709	21.411	389.695	18.710	387.972	19.847	389.448	19.406
389.165	20.973	390.152	18.340	388.427	19.464	389.905	18.974
389.620	20.516	390.609	17.948	388.882	19.042	390.361	18.501
390.076	20.081	391.066	17.553	389.337	18.629	390.818	18.081
390.532	19.645	391.523	17.193	389.792	18.239	391.275	17.638
390.987	19.198	391.980	16.818	390.246	17.867	391.731	17.218
391.443	18.808	392.437	16.466	390.701	17.515	392.188	16.796
391.899	18.408	392.893	16.117	391.156	17.173	392.644	16.426
392.354	17.968	393.350	15.805	391.611	16.748	393.101	15.976
392.810	17.628	393.807	15.473	392.066	16.491	393.557	15.636
393.266	17.216	394.264	15.151	392.521	16.127	394.014	15.254
393.722	16.899	394.721	14.837	392.975	15.792	394.471	14.917
394.177	16.522	395.178	14.530	393.430	15.480	394.927	14.560
394.633	16.167	395.635	14.240	393.885	15.221	395.384	14.311
395.089	15.838	396.091	13.956	394.340	14.889	395.840	13.961
395.544	15.551	396.548	13.667	394.795	14.655	396.297	13.687
396.000	15.194	397.005	13.418	395.250	14.334	396.753	13.390
396.456	14.947	397.462	13.139	395.704	14.095	397.210	13.169
396.911	14.595	397.919	12.892	396.159	13.863	397.666	12.900
397.367	14.303	398.376	12.658	396.614	13.602	398.123	12.656
397.823	14.007	398.832	12.392	397.069	13.365	398.580	12.377
398.278	13.750	399.289	12.145	397.524	13.106	399.036	12.148
398.734	13.509	399.746	11.912	397.979	12.938	399.493	11.876
399.190	13.247	400.203	11.675	398.433	12.679	399.949	11.640
399.646	13.001	400.660	11.509	398.888	12.528	400.406	11.381
400.101	12.724	401.117	11.240	399.343	12.289	400.862	11.175
400.557	12.485	401.574	11.016	399.798	12.158	401.319	10.931
401.013	12.243	402.030	10.812	400.253	11.969	401.776	10.704
401.468	12.037	402.487	10.641	400.708	11.793	402.232	10.470
401.924	11.783	402.944	10.463	401.162	11.663	402.689	10.292
402.380	11.577	403.401	10.262	401.617	11.509	403.145	10.078
402.835	11.343	403.858	10.038	402.072	11.383	403.602	9.869
403.291	11.205	404.315	9.882	402.527	11.295	404.058	9.660
403.747	10.948	404.772	9.691	402.982	11.142	404.515	9.447
404.203	10.737	405.228	9.550	403.437	11.051	404.971	9.248
404.658	10.528	405.685	9.389	403.891	10.951	405.428	9.024
405.114	10.347	406.142	9.193	404.346	10.870	405.885	8.856
405.570	10.131	406.599	9.097	404.801	10.780	406.341	8.652
406.025	10.010	407.056	8.906	405.256	10.717	406.798	8.456
406.481	9.814	407.513	8.770	405.711	10.601	407.254	8.280
406.937	9.663	407.970	8.647	406.166	10.558	407.711	8.136
407.392	9.459	408.426	8.569	406.620	10.460	408.167	7.965
407.848	9.303	408.883	8.486	407.075	10.377	408.624	7.845
408.304	9.147	409.340	8.398	407.530	10.292	409.081	7.694
408.759	9.039	409.797	8.292	407.985	10.229	409.537	7.540
409.215	8.916	410.254	8.255	408.440	10.126	409.994	7.415
409.671	8.800	410.711	8.219	408.895	10.003	410.450	7.294
410.127	8.654	411.168	8.159	409.349	9.937	410.907	7.140
410.582	8.582	411.624	8.124	409.804	9.859	411.363	7.045

Table A7: Pressure at different Crank angle at no load for diesel with varying ethanol content

411.038	8.471	412.081	8.068	410.259	9.751	411.820	6.917
411.494	8.378	412.538	8.053	410.714	9.693	412.276	6.818
411.949	8.287	412.995	7.993	411.169	9.600	412.733	6.675
412.405	8.217	413.452	7.990	411.623	9.520	413.190	6.605
412.861	8.126	413.909	7.928	412.078	9.474	413.646	6.459
413.316	8.018	414.365	7.912	412.533	9.376	414.103	6.351
413.772	7.960	414.822	7.887	412.988	9.296	414.559	6.298
414.228	7.900	415.279	7.827	413.443	9.203	415.016	6.197
414.684	7.777	415.736	7.779	413.898	9.095	415.472	6.092
415.139	7.746	416.193	7.694	414.352	9.042	415.929	6.024
415.595	7.656	416.650	7.686	414.807	8.931	416.386	5.910
416.051	7.618	417.107	7.631	415.262	8.831	416.842	5.853
416.506	7.538	417.563	7.550	415.717	8.755	417.299	5.817
416.962	7.465	418.020	7.495	416.172	8.705	417.755	5.699
417.418	7.420	418.477	7.500	416.627	8.602	418.212	5.594
417.873	7.354	418.934	7.412	417.081	8.509	418.668	5.518
418.329	7.291	419.391	7.354	417.536	8.436	419.125	5.425
418.785	7.206	419.848	7.319	417.991	8.383	419.581	5.367
419.241	7.150	420.305	7.211	418.446	8.267	420.038	5.307
419.696	7.108	420.761	7.178	418.901	8.194	420.495	5.224
420.152	7.007	421.218	7.120	419.356	8.146	420.951	5.181
420.608	7.017	421.675	7.035	419.810	8.006	421.408	5.093

Table A8: Pressure at different Crank angle at 50% load for diesel with varying ethanol content

Diesel + 0% Ethanol		Diesel + 10% Ethanol		Diesel + 20% Ethanol		Diesel + 30% Ethanol	
Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)
320.393	9.663	321.778	9.897	322.375	9.283	320.985	8.720
320.836	9.821	322.222	10.106	322.820	9.469	321.429	8.941
321.278	10.070	322.667	10.304	323.265	9.706	321.872	9.130
321.721	10.259	323.111	10.536	323.711	9.884	322.315	9.326
322.163	10.480	323.556	10.747	324.156	10.035	322.759	9.557
322.606	10.709	324.000	10.958	324.601	10.319	323.202	9.741
323.049	10.900	324.444	11.182	325.046	10.498	323.645	9.904
323.491	11.167	324.889	11.381	325.492	10.707	324.089	10.133
323.934	11.398	325.333	11.668	325.937	10.941	324.532	10.365
324.376	11.622	325.778	11.874	326.382	11.162	324.975	10.528
324.819	11.919	326.222	12.158	326.827	11.411	325.419	10.840
325.261	12.125	326.667	12.435	327.273	11.655	325.862	11.069
325.704	12.447	327.111	12.691	327.718	11.906	326.305	11.338
326.146	12.679	327.556	12.996	328.163	12.166	326.749	11.549
326.589	12.990	328.000	13.270	328.609	12.457	327.192	11.831
327.031	13.275	328.444	13.493	329.054	12.757	327.635	12.083
327.474	13.569	328.889	13.846	329.499	13.058	328.079	12.362
327.916	13.838	329.333	14.117	329.944	13.370	328.522	12.653
328.359	14.127	329.778	14.437	330.390	13.695	328.966	12.950
328.801	14.474	330.222	14.761	330.835	14.014	329.409	13.229
329.244	14.786	330.667	15.033	331.280	14.346	329.852	13.531
329.687	15.133	331.111	15.430	331.725	14.746	330.296	13.825
330.129	15.423	331.556	15.699	332.171	15.113	330.739	14.175
330.572	15.780	332.000	16.056	332.616	15.465	331.182	14.459
331.014	16.124	332.444	16.439	333.061	15.825	331.626	14.842
331.457	16.527	332.889	16.811	333.506	16.245	332.069	15.126
331.899	16.851	333.333	17.161	333.952	16.688	332.512	15.498
332.342	17.193	333.778	17.467	334.397	17.108	332.956	15.797
332.784	17.581	334.222	17.928	334.842	17.518	333.399	16.202
333.227	17.998	334.667	18.300	335.288	17.955	333.842	16.554
333.669	18.348	335.111	18.735	335.733	18.428	334.286	16.919
334.112	18.805	335.556	19.067	336.178	18.866	334.729	17.301
334.554	19.195	336.000	19.482	336.623	19.351	335.172	17.724
334.997	19.623	336.444	19.904	337.069	19.774	335.616	18.131
335.439	20.035	336.889	20.335	337.514	20.330	336.059	18.577
335.882	20.498	337.333	20.785	337.959	20.815	336.502	18.966
336.325	20.880	337.778	21.165	338.404	21.290	336.946	19.384
336.767	21.358	338.222	21.642	338.850	21.818	337.389	19.784
337.210	21.803	338.667	22.115	339.295	22.294	337.833	20.231
337.652	22.311	339.111	22.560	339.740	22.789	338.276	20.697
338.095	22.731	339.556	22.965	340.186	23.260	338.719	21.144
338.537	23.179	340.000	23.458	340.631	23.770	339.163	21.627
338.980	23.677	340.444	23.903	341.076	24.316	339.606	22.105
339.422	24.165	340.889	24.339	341.521	24.829	340.049	22.550
339.865	24.645	341.333	24.864	341.967	25.342	340.493	23.046
340.307	25.156	341.778	25.357	342.412	25.873	340.936	23.486

Table A8: Pressure at different Crank angle at 50% load for diesel with varying ethanol content

340.750	25.664	342.222	25.883	342.857	26.409	341.379	23.966
341.192	26.162	342.667	26.328	343.302	26.937	341.823	24.462
341.635	26.673	343.111	26.831	343.748	27.475	342.266	25.020
342.077	27.193	343.556	27.327	344.193	28.008	342.709	25.478
342.520	27.674	344.000	27.814	344.638	28.561	343.153	25.994
342.963	28.207	344.444	28.345	345.083	29.042	343.596	26.504
343.405	28.722	344.889	28.823	345.529	29.573	344.039	26.995
343.848	29.210	345.333	29.230	345.974	30.093	344.483	27.495
344.290	29.713	345.778	29.769	346.419	30.591	344.926	28.016
344.733	30.211	346.222	30.204	346.865	31.102	345.369	28.539
345.175	30.717	346.667	30.707	347.310	31.602	345.813	29.017
345.618	31.207	347.111	31.210	347.755	32.062	346.256	29.515
346.060	31.660	347.556	31.597	348.200	32.503	346.700	29.980
346.503	32.130	348.000	32.083	348.646	33.018	347.143	30.463
346.945	32.618	348.444	32.425	349.091	33.446	347.586	30.976
347.388	33.056	348.889	32.925	349.536	33.873	348.030	31.401
347.830	33.483	349.333	33.320	349.981	34.301	348.473	31.901
348.273	33.868	349.778	33.657	350.427	34.746	348.916	32.322
348.715	34.313	350.222	34.059	350.872	35.146	349.360	32.724
349.158	34.754	350.667	34.434	351.317	35.523	349.803	33.162
349.600	35.098	351.111	34.774	351.763	35.838	350.246	33.592
350.043	35.528	351.556	35.156	352.208	36.238	350.690	34.012
350.486	35.906	352.000	35.438	352.653	36.605	351.133	34.402
350.928	36.318	352.444	35.818	353.098	36.957	351.576	34.806
351.371	36.668	352.889	36.147	353.544	37.339	352.020	35.206
351.813	37.080	353.333	36.471	353.989	37.648	352.463	35.662
352.256	37.480	353.778	36.808	354.434	37.925	352.906	36.074
352.698	38.001	354.222	37.113	354.879	38.252	353.350	36.612
353.141	38.546	354.667	37.470	355.325	38.665	353.793	37.201
353.583	39.303	355.111	37.978	355.770	39.125	354.236	37.930
354.026	40.138	355.556	38.544	356.215	39.721	354.680	38.798
354.468	41.165	356.000	39.296	356.660	40.493	355.123	39.877
354.911	42.573	356.444	40.287	357.106	41.464	355.567	41.192
355.353	44.213	356.889	41.419	357.551	42.566	356.010	42.676
355.796	45.946	357.333	42.749	357.996	43.810	356.453	44.344
356.238	47.913	357.778	44.190	358.442	45.181	356.897	46.099
356.681	49.862	358.222	45.797	358.887	46.725	357.340	47.832
357.124	51.693	358.667	47.369	359.332	48.187	357.783	49.585
357.566	53.695	359.111	49.024	359.777	49.701	358.227	51.122
358.009	55.264	359.556	50.631	360.223	51.228	358.670	52.555
358.451	56.778	360.000	52.218	360.668	52.679	359.113	53.705
358.894	57.960	360.444	53.534	361.113	54.017	359.557	54.678
359.336	58.795	360.889	54.749	361.558	55.156	360.000	55.488
359.779	59.472	361.333	55.599	362.004	56.107	360.443	56.124
360.221	59.781	361.778	56.220	362.449	56.819	360.887	56.602
360.664	60.106	362.222	56.615	362.894	57.334	361.330	57.040
361.106	60.264	362.667	56.786	363.340	57.661	361.773	57.312
361.549	60.418	363.111	56.819	363.785	57.779	362.217	57.583
361.991	60.496	363.556	56.806	364.230	57.789	362.660	57.676
362.434	60.566	364.000	56.723	364.675	57.676	363.103	57.757
362.876	60.468	364.444	56.665	365.121	57.525	363.547	57.822

Table A8: Pressure at different Crank angle at 50% load for diesel with varying ethanol content

363.319	60.513	364.889	56.479	365.566	57.299	363.990	57.804
363.762	60.370	365.333	56.311	366.011	57.037	364.433	57.757
364.204	60.269	365.778	56.077	366.456	56.738	364.877	57.626
364.647	60.040	366.222	55.767	366.902	56.399	365.320	57.442
365.089	59.824	366.667	55.450	367.347	56.014	365.764	57.236
365.532	59.595	367.111	55.096	367.792	55.659	366.207	57.010
365.974	59.296	367.556	54.791	368.237	55.219	366.650	56.685
366.417	58.946	368.000	54.351	368.683	54.771	367.094	56.376
366.859	58.622	368.444	53.914	369.128	54.298	367.537	56.046
367.302	58.217	368.889	53.509	369.573	53.813	367.980	55.647
367.744	57.817	369.333	53.028	370.019	53.295	368.424	55.287
368.187	57.382	369.778	52.530	370.464	52.734	368.867	54.839
368.629	56.879	370.222	52.002	370.909	52.196	369.310	54.412
369.072	56.381	370.667	51.507	371.354	51.670	369.754	53.921
369.514	55.815	371.111	50.885	371.800	51.072	370.197	53.446
369.957	55.254	371.556	50.372	372.245	50.465	370.640	52.877
370.400	54.633	372.000	49.729	372.690	49.857	371.084	52.354
370.842	54.017	372.444	49.132	373.135	49.220	371.527	51.836
371.285	53.383	372.889	48.519	373.581	48.584	371.970	51.265
371.727	52.749	373.333	47.840	374.026	47.940	372.414	50.702
372.170	52.065	373.778	47.206	374.471	47.304	372.857	50.088
372.612	51.391	374.222	46.575	374.917	46.582	373.300	49.515
373.055	50.619	374.667	45.875	375.362	45.916	373.744	48.861
373.497	49.920	375.111	45.211	375.807	45.237	374.187	48.285
373.940	49.190	375.556	44.492	376.252	44.540	374.631	47.696
374.382	48.506	376.000	43.858	376.698	43.891	375.074	47.070
374.825	47.769	376.444	43.184	377.143	43.159	375.517	46.396
375.267	47.060	376.889	42.485	377.588	42.462	375.961	45.757
375.710	46.270	377.333	41.819	378.033	41.783	376.404	45.028
376.152	45.561	377.778	41.172	378.479	41.107	376.847	44.452
376.595	44.824	378.222	40.501	378.924	40.453	377.291	43.750
377.037	44.080	378.667	39.801	379.369	39.759	377.734	43.106
377.480	43.330	379.111	39.145	379.814	39.130	378.177	42.397
377.923	42.621	379.556	38.496	380.260	38.443	378.621	41.766
378.365	41.869	380.000	37.842	380.705	37.855	379.064	41.067
378.808	41.139	380.444	37.176	381.150	37.206	379.507	40.418
379.250	40.405	380.889	36.497	381.596	36.570	379.951	39.734
379.693	39.708	381.333	35.835	382.041	35.928	380.394	39.075
380.135	38.981	381.778	35.199	382.486	35.322	380.837	38.390
380.578	38.277	382.222	34.525	382.931	34.706	381.281	37.739
381.020	37.513	382.667	33.848	383.377	34.117	381.724	37.078
381.463	36.824	383.111	33.295	383.822	33.504	382.167	36.393
381.905	36.137	383.556	32.638	384.267	32.913	382.611	35.722
382.348	35.430	384.000	32.017	384.712	32.314	383.054	35.098
382.790	34.756	384.444	31.388	385.158	31.756	383.498	34.472
383.233	34.107	384.889	30.800	385.603	31.202	383.941	33.856
383.675	33.423	385.333	30.242	386.048	30.657	384.384	33.245
384.118	32.782	385.778	29.615	386.494	30.138	384.828	32.661
384.561	32.138	386.222	29.097	386.939	29.645	385.271	32.062
385.003	31.554	386.667	28.592	387.384	29.158	385.714	31.476
385.446	30.883	387.111	28.033	387.829	28.660	386.158	30.911

Table A8: Pressure at different Crank angle at 50% load for diesel with varying ethanol content

385.888	30.287	387.556	27.490	388.275	28.212	386.601	30.342
386.331	29.706	388.000	26.990	388.720	27.729	387.044	29.799
386.773	29.132	388.444	26.479	389.165	27.271	387.488	29.253
387.216	28.566	388.889	25.908	389.610	26.821	387.931	28.720
387.658	28.006	389.333	25.450	390.056	26.358	388.374	28.157
388.101	27.465	389.778	24.967	390.501	25.850	388.818	27.633
388.543	26.937	390.222	24.495	390.946	25.526	389.261	27.176
388.986	26.426	390.667	23.984	391.391	25.020	389.704	26.673
389.428	25.880	391.111	23.619	391.837	24.620	390.148	26.190
389.871	25.435	391.556	23.154	392.282	24.200	390.591	25.719
390.313	24.879	392.000	22.689	392.727	23.828	391.034	25.194
390.756	24.394	392.444	22.311	393.173	23.416	391.478	24.754
391.199	23.911	392.889	21.917	393.618	23.058	391.921	24.286
391.641	23.458	393.333	21.512	394.063	22.661	392.365	23.851
392.084	22.998	393.778	21.149	394.508	22.271	392.808	23.443
392.526	22.608	394.222	20.659	394.954	21.912	393.251	22.975
392.969	22.158	394.667	20.234	395.399	21.534	393.695	22.596
393.411	21.693	395.111	19.821	395.844	21.127	394.138	22.176
393.854	21.245	395.556	19.474	396.289	20.757	394.581	21.808
394.296	20.848	396.000	19.092	396.735	20.418	395.025	21.424
394.739	20.455	396.444	18.697	397.180	20.070	395.468	21.009
395.181	20.070	396.889	18.441	397.625	19.671	395.911	20.614
395.624	19.696	397.333	18.043	398.071	19.384	396.355	20.234
396.066	19.344	397.778	17.669	398.516	18.992	396.798	19.867
396.509	18.936	398.222	17.374	398.961	18.705	397.241	19.495
396.951	18.579	398.667	17.052	399.406	18.280	397.685	19.145
397.394	18.189	399.111	16.728	399.852	17.970	398.128	18.805
397.837	17.814	399.556	16.396	400.297	17.651	398.571	18.468
398.279	17.500	400.000	16.139	400.742	17.364	399.015	18.146
398.722	17.166	400.444	15.767	401.187	17.080	399.458	17.824
399.164	16.861	400.889	15.493	401.633	16.801	399.901	17.548
399.607	16.552	401.333	15.226	402.078	16.502	400.345	17.223
400.049	16.185	401.778	14.967	402.523	16.263	400.788	16.929
400.492	15.933	402.222	14.759	402.968	15.981	401.232	16.625
400.934	15.611	402.667	14.442	403.414	15.704	401.675	16.338
401.377	15.375	403.111	14.198	403.859	15.468	402.118	16.074
401.819	15.081	403.556	13.971	404.304	15.199	402.562	15.780
402.262	14.844	404.000	13.702	404.750	14.945	403.005	15.501
402.704	14.547	404.444	13.468	405.195	14.718	403.448	15.221
403.147	14.336	404.889	13.250	405.640	14.439	403.892	14.980
403.589	14.037	405.333	12.996	406.085	14.205	404.335	14.733
404.032	13.810	405.778	12.772	406.531	13.969	404.778	14.444
404.474	13.569	406.222	12.545	406.976	13.740	405.222	14.210
404.917	13.335	406.667	12.291	407.421	13.496	405.665	13.949
405.360	13.076	407.111	12.125	407.866	13.335	406.108	13.722
405.802	12.819	407.556	11.886	408.312	13.038	406.552	13.476
406.245	12.588	408.000	11.698	408.757	12.840	406.995	13.234
406.687	12.389	408.444	11.514	409.202	12.638	407.438	13.011
407.130	12.173	408.889	11.315	409.647	12.420	407.882	12.789
407.572	11.972	409.333	11.127	410.093	12.201	408.325	12.611
408.015	11.756	409.778	10.991	410.538	11.989	408.768	12.374

Table A8: Pressure at different Crank angle at 50% load for diesel with varying ethanol content

408.457	11.602	410.222	10.760	410.983	11.818	409.212	12.183
408.900	11.368	410.667	10.636	411.429	11.607	409.655	11.967
409.342	11.225	411.111	10.420	411.874	11.469	410.099	11.773
409.785	11.011	411.556	10.297	412.319	11.283	410.542	11.630
410.227	10.830	412.000	10.101	412.764	11.104	410.985	11.416
410.670	10.659	412.444	9.925	413.210	10.908	411.429	11.217
411.112	10.490	412.889	9.779	413.655	10.762	411.872	11.082
411.555	10.324	413.333	9.590	414.100	10.626	412.315	10.875
411.998	10.169	413.778	9.494	414.545	10.425	412.759	10.687
412.440	10.010	414.222	9.321	414.991	10.309	413.202	10.533
412.883	9.869	414.667	9.110	415.436	10.075	413.645	10.350
413.325	9.688	415.111	8.994	415.881	9.967	414.089	10.133
413.768	9.522	415.556	8.876	416.327	9.834	414.532	9.990
414.210	9.396	416.000	8.730	416.772	9.653	414.975	9.897
414.653	9.238	416.444	8.597	417.217	9.525	415.419	9.698
415.095	9.085	416.889	8.478	417.662	9.386	415.862	9.583
415.538	8.954	417.333	8.375	418.108	9.228	416.305	9.427
415.980	8.798	417.778	8.250	418.553	9.127	416.749	9.311
416.423	8.637	418.222	8.131	418.998	8.926	417.192	9.130
416.865	8.456	418.667	8.021	419.443	8.825	417.635	8.979
417.308	8.358	419.111	7.918	419.889	8.665	418.079	8.805
417.750	8.222	419.556	7.792	420.334	8.574	418.522	8.685
418.193	8.089	420.000	7.656	420.779	8.418	418.966	8.516
418.636	7.965	420.444	7.495	421.224	8.287	419.409	8.370
419.078	7.867	420.889	7.417	421.670	8.189	419.852	8.315
419.521	7.741	421.333	7.349	422.115	8.028	420.296	8.177
419.963	7.658	421.778	7.196	422.560	7.958	420.739	8.043
420.406	7.508	422.222	7.072	423.006	7.837	421.182	7.923
420.848	7.409	422.667	6.952	423.451	7.724	421.626	7.799

Table A9: Pressure at different Crank angle at 100% load for diesel with varying ethanol content

Diesel + 0% Ethanol		Diesel + 10% Ethanol		Diesel + 20% Ethanol		Diesel + 30% Ethanol	
Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)
320.293	9.205	322.454	10.244	322.059	9.638	323.247	10.760
320.731	9.394	322.896	10.443	322.500	9.832	323.690	10.993
321.170	9.588	323.337	10.659	322.941	10.008	324.133	11.190
321.609	9.781	323.779	10.943	323.382	10.224	324.576	11.441
322.048	9.957	324.221	11.114	323.824	10.430	325.018	11.693
322.486	10.164	324.663	11.346	324.265	10.654	325.461	11.929
322.925	10.372	325.104	11.607	324.706	10.858	325.904	12.196
323.364	10.571	325.546	11.836	325.147	11.099	326.347	12.437
323.803	10.790	325.988	12.138	325.588	11.343	326.790	12.714
324.241	11.009	326.429	12.392	326.029	11.569	327.232	13.023
324.680	11.187	326.871	12.601	326.471	11.813	327.675	13.260
325.119	11.444	327.313	12.945	326.912	12.085	328.118	13.549
325.558	11.688	327.755	13.232	327.353	12.324	328.561	13.831
325.996	11.934	328.196	13.519	327.794	12.586	329.004	14.140
326.435	12.183	328.638	13.788	328.235	12.885	329.446	14.479
326.874	12.477	329.080	14.110	328.676	13.144	329.889	14.789
327.313	12.739	329.521	14.417	329.118	13.456	330.332	15.106
327.751	12.996	329.963	14.754	329.559	13.720	330.775	15.430
328.190	13.295	330.405	15.053	330.000	14.019	331.218	15.750
328.629	13.564	330.847	15.385	330.441	14.298	331.661	16.114
329.068	13.838	331.288	15.692	330.882	14.645	332.103	16.461
329.506	14.163	331.730	16.107	331.324	14.927	332.546	16.816
329.945	14.429	332.172	16.419	331.765	15.264	332.989	17.178
330.384	14.789	332.613	16.811	332.206	15.616	333.432	17.581
330.823	15.091	333.055	17.148	332.647	15.931	333.875	17.915
331.261	15.420	333.497	17.548	333.088	16.280	334.317	18.343
331.700	15.747	333.939	17.938	333.529	16.637	334.760	18.702
332.139	16.142	334.380	18.287	333.971	17.017	335.203	19.130
332.578	16.464	334.822	18.687	334.412	17.377	335.646	19.515
333.016	16.831	335.264	19.132	334.853	17.744	336.089	19.945
333.455	17.206	335.706	19.512	335.294	18.109	336.531	20.365
333.894	17.581	336.147	19.932	335.735	18.504	336.974	20.792
334.333	17.953	336.589	20.352	336.176	18.888	337.417	21.200
334.771	18.393	337.031	20.767	336.618	19.316	337.860	21.645
335.210	18.775	337.472	21.250	337.059	19.693	338.303	22.123
335.649	19.195	337.914	21.713	337.500	20.123	338.745	22.565
336.088	19.590	338.356	22.133	337.941	20.558	339.188	23.031
336.527	20.003	338.798	22.601	338.382	20.973	339.631	23.448
336.965	20.405	339.239	23.094	338.824	21.378	340.074	23.926
337.404	20.868	339.681	23.526	339.265	21.889	340.517	24.422
337.843	21.333	340.123	23.964	339.706	22.319	340.959	24.899
338.282	21.793	340.564	24.454	340.147	22.817	341.402	25.365
338.720	22.286	341.006	24.950	340.588	23.252	341.845	25.850
339.159	22.739	341.448	25.415	341.029	23.722	342.288	26.333
339.598	23.164	341.890	25.898	341.471	24.195	342.731	26.813
340.037	23.617	342.331	26.451	341.912	24.656	343.173	27.264

Table A9: Pressure at different Crank angle at 100% load for diesel with varying ethanol content

340.475	24.057	342.773	26.879	342.353	25.146	343.616	27.822
340.914	24.585	343.215	27.417	342.794	25.669	344.059	28.292
341.353	25.121	343.656	27.910	343.235	26.172	344.502	28.753
341.792	25.584	344.098	28.395	343.676	26.647	344.945	29.238
342.230	26.082	344.540	28.891	344.118	27.138	345.387	29.698
342.669	26.610	344.982	29.404	344.559	27.659	345.830	30.156
343.108	27.070	345.423	29.877	345.000	28.151	346.273	30.629
343.547	27.646	345.865	30.380	345.441	28.612	346.716	31.097
343.985	28.071	346.307	30.760	345.882	29.160	347.159	31.492
344.424	28.632	346.748	31.243	346.324	29.615	347.601	31.937
344.863	29.095	347.190	31.670	346.765	30.106	348.044	32.339
345.302	29.537	347.632	32.120	347.206	30.536	348.487	32.739
345.740	30.038	348.074	32.550	347.647	31.026	348.930	33.119
346.179	30.485	348.515	32.918	348.088	31.476	349.373	33.531
346.618	30.885	348.957	33.338	348.529	31.952	349.815	33.886
347.057	31.368	349.399	33.722	348.971	32.349	350.258	34.228
347.495	31.849	349.840	34.132	349.412	32.774	350.701	34.603
347.934	32.223	350.282	34.444	349.853	33.167	351.144	34.937
348.373	32.664	350.724	34.897	350.294	33.644	351.587	35.294
348.812	33.021	351.166	35.229	350.735	34.017	352.030	35.619
349.250	33.443	351.607	35.606	351.176	34.396	352.472	35.968
349.689	33.878	352.049	36.006	351.618	34.796	352.915	36.323
350.128	34.308	352.491	36.414	352.059	35.186	353.358	36.668
350.567	34.703	352.933	36.801	352.500	35.591	353.801	37.020
351.005	35.108	353.374	37.344	352.941	35.994	354.244	37.508
351.444	35.579	353.816	37.960	353.382	36.504	354.686	38.011
351.883	36.044	354.258	38.785	353.824	36.967	355.129	38.755
352.322	36.635	354.699	39.827	354.265	37.611	355.572	39.718
352.761	37.367	355.141	41.079	354.706	38.363	356.015	40.795
353.199	38.441	355.583	42.606	355.147	39.303	356.458	42.113
353.638	39.910	356.025	44.288	355.588	40.478	356.900	43.634
354.077	41.645	356.466	46.192	356.029	41.819	357.343	45.327
354.516	43.504	356.908	48.262	356.471	43.320	357.786	47.161
354.954	45.893	357.350	50.518	356.912	45.045	358.229	49.122
355.393	48.637	357.791	52.827	357.353	46.917	358.672	51.139
355.832	51.831	358.233	55.030	357.794	48.916	359.114	53.084
356.271	54.552	358.675	57.070	358.235	50.918	359.557	55.020
356.709	57.163	359.117	58.466	358.676	52.935	360.000	56.655
357.148	59.019	359.558	59.693	359.118	54.734	360.443	58.101
357.587	60.227	360.000	60.435	359.559	56.336	360.886	59.097
358.026	61.326	360.442	61.016	360.000	57.666	361.328	59.907
358.464	61.809	360.883	61.572	360.441	58.793	361.771	60.433
358.903	62.908	361.325	61.761	360.882	59.656	362.214	60.770
359.342	62.988	361.767	62.241	361.324	60.405	362.657	61.089
359.781	63.758	362.209	62.387	361.765	60.906	363.100	61.205
360.219	63.977	362.650	62.646	362.206	61.383	363.542	61.288
360.658	64.449	363.092	62.862	362.647	61.655	363.985	61.308
361.097	64.796	363.534	62.784	363.088	62.012	364.428	61.311
361.536	64.967	363.975	63.026	363.529	62.188	364.871	61.328
361.974	65.453	364.417	62.877	363.971	62.390	365.314	61.147
362.413	65.516	364.859	62.953	364.412	62.475	365.756	61.119

Table A9: Pressure at different Crank angle at 100% load for diesel with varying ethanol content

362.852	65.745	365.301	62.840	364.853	62.523	366.199	60.883
363.291	65.888	365.742	62.727	365.294	62.561	366.642	60.697
363.729	65.737	366.184	62.568	365.735	62.427	367.085	60.453
364.168	65.953	366.626	62.304	366.176	62.332	367.528	60.166
364.607	65.704	367.067	62.128	366.618	62.203	367.970	59.889
365.046	65.805	367.509	61.803	367.059	61.992	368.413	59.495
365.484	65.528	367.951	61.512	367.500	61.783	368.856	59.130
365.923	65.415	368.393	61.182	367.941	61.504	369.299	58.707
366.362	65.206	368.834	60.740	368.382	61.172	369.742	58.272
366.801	64.890	369.276	60.297	368.824	60.800	370.185	57.812
367.239	64.711	369.718	59.801	369.265	60.370	370.627	57.213
367.678	64.210	370.160	59.331	369.706	60.020	371.070	56.705
368.117	63.966	370.601	58.738	370.147	59.492	371.513	56.099
368.556	63.413	371.043	58.157	370.588	59.024	371.956	55.483
368.995	62.978	371.485	57.603	371.029	58.481	372.399	54.877
369.433	62.493	371.926	56.884	371.471	57.928	372.841	54.183
369.872	61.897	372.368	56.238	371.912	57.317	373.284	53.526
370.311	61.416	372.810	55.516	372.353	56.678	373.727	52.815
370.750	60.667	373.252	54.822	372.794	56.041	374.170	52.075
371.188	60.076	373.693	54.153	373.235	55.362	374.613	51.346
371.627	59.364	374.135	53.328	373.676	54.698	375.055	50.659
372.066	58.662	374.577	52.644	374.118	54.027	375.498	49.965
372.505	57.948	375.018	51.889	374.559	53.318	375.941	49.220
372.943	57.163	375.460	51.062	375.000	52.623	376.384	48.458
373.382	56.449	375.902	50.367	375.441	51.897	376.827	47.827
373.821	55.667	376.344	49.552	375.882	51.205	377.269	47.055
374.260	54.849	376.785	48.823	376.324	50.496	377.712	46.318
374.698	54.115	377.227	48.023	376.765	49.741	378.155	45.566
375.137	53.247	377.669	47.274	377.206	49.032	378.598	44.819
375.576	52.493	378.110	46.497	377.647	48.285	379.041	44.097
376.015	51.708	378.552	45.740	378.088	47.533	379.483	43.431
376.453	50.906	378.994	44.970	378.529	46.806	379.926	42.691
376.892	50.164	379.436	44.205	378.971	46.036	380.369	42.007
377.331	49.293	379.877	43.451	379.412	45.382	380.812	41.250
377.770	48.456	380.319	42.671	379.853	44.588	381.255	40.569
378.208	47.686	380.761	41.959	380.294	43.871	381.697	39.869
378.647	46.808	381.202	41.187	380.735	43.089	382.140	39.165
379.086	46.087	381.644	40.440	381.176	42.410	382.583	38.473
379.525	45.254	382.086	39.746	381.618	41.668	383.026	37.814
379.963	44.474	382.528	38.944	382.059	40.918	383.469	37.108
380.402	43.745	382.969	38.235	382.500	40.194	383.911	36.461
380.841	42.943	383.411	37.535	382.941	39.482	384.354	35.858
381.280	42.143	383.853	36.846	383.382	38.753	384.797	35.189
381.718	41.371	384.294	36.122	383.824	38.079	385.240	34.550
382.157	40.609	384.736	35.460	384.265	37.359	385.683	33.896
382.596	39.847	385.178	34.741	384.706	36.725	386.125	33.277
383.035	39.082	385.620	34.107	385.147	35.966	386.568	32.706
383.473	38.338	386.061	33.436	385.588	35.355	387.011	32.113
383.912	37.648	386.503	32.814	386.029	34.701	387.454	31.512
384.351	36.909	386.945	32.193	386.471	34.042	387.897	30.971
384.790	36.185	387.387	31.570	386.912	33.463	388.339	30.428

Table A9: Pressure at different Crank angle at 100% load for diesel with varying ethanol content

385.229	35.503	387.828	30.956	387.353	32.799	388.782	29.822
385.667	34.844	388.270	30.380	387.794	32.191	389.225	29.293
386.106	34.160	388.712	29.791	388.235	31.577	389.668	28.775
386.545	33.521	389.153	29.210	388.676	31.011	390.111	28.257
386.984	32.845	389.595	28.680	389.118	30.370	390.554	27.787
387.422	32.284	390.037	28.136	389.559	29.819	390.996	27.279
387.861	31.653	390.479	27.638	390.000	29.243	391.439	26.801
388.300	31.009	390.920	27.115	390.441	28.695	391.882	26.346
388.739	30.440	391.362	26.627	390.882	28.162	392.325	25.850
389.177	29.857	391.804	26.134	391.324	27.669	392.768	25.413
389.616	29.303	392.245	25.634	391.765	27.156	393.210	24.945
390.055	28.743	392.687	25.101	392.206	26.635	393.653	24.512
390.494	28.222	393.129	24.638	392.647	26.117	394.096	24.047
390.932	27.666	393.571	24.160	393.088	25.639	394.539	23.662
391.371	27.150	394.012	23.748	393.529	25.151	394.982	23.229
391.810	26.635	394.454	23.275	393.971	24.671	395.424	22.825
392.249	26.182	394.896	22.847	394.412	24.198	395.867	22.392
392.687	25.682	395.337	22.420	394.853	23.725	396.310	21.995
393.126	25.214	395.779	22.017	395.294	23.302	396.753	21.575
393.565	24.703	396.221	21.534	395.735	22.860	397.196	21.160
394.004	24.225	396.663	21.180	396.176	22.480	397.638	20.772
394.442	23.788	397.104	20.807	396.618	22.012	398.081	20.413
394.881	23.340	397.546	20.397	397.059	21.605	398.524	20.053
395.320	22.905	397.988	20.023	397.500	21.207	398.967	19.663
395.759	22.482	398.429	19.653	397.941	20.807	399.410	19.386
396.197	22.100	398.871	19.271	398.382	20.380	399.852	19.004
396.636	21.675	399.313	18.979	398.824	20.035	400.295	18.682
397.075	21.235	399.755	18.592	399.265	19.683	400.738	18.403
397.514	20.850	400.196	18.204	399.706	19.266	401.181	18.079
397.952	20.483	400.638	17.953	400.147	18.954	401.624	17.754
398.391	20.121	401.080	17.565	400.588	18.607	402.066	17.440
398.830	19.741	401.521	17.276	401.029	18.423	402.509	17.158
399.269	19.401	401.963	17.002	401.471	18.006	402.952	16.823
399.707	19.049	402.405	16.652	401.912	17.686	403.395	16.537
400.146	18.727	402.847	16.461	402.353	17.349	403.838	16.230
400.585	18.481	403.288	16.122	402.794	17.037	404.280	15.936
401.024	18.106	403.730	15.893	403.235	16.758	404.723	15.656
401.463	17.832	404.172	15.553	403.676	16.441	405.166	15.365
401.901	17.513	404.613	15.309	404.118	16.202	405.609	15.118
402.340	17.271	405.055	15.060	404.559	15.860	406.052	14.854
402.779	16.997	405.497	14.821	405.000	15.591	406.494	14.613
403.218	16.683	405.939	14.507	405.441	15.287	406.937	14.354
403.656	16.451	406.380	14.321	405.882	15.050	407.380	14.137
404.095	16.160	406.822	14.042	406.324	14.794	407.823	13.896
404.534	15.878	407.264	13.818	406.765	14.510	408.266	13.665
404.973	15.621	407.706	13.594	407.206	14.276	408.708	13.458
405.411	15.405	408.147	13.378	407.647	14.029	409.151	13.232
405.850	15.146	408.589	13.154	408.088	13.795	409.594	13.043
406.289	14.917	409.031	12.955	408.529	13.566	410.037	12.812
406.728	14.676	409.472	12.716	408.971	13.355	410.480	12.593
407.166	14.401	409.914	12.472	409.412	13.126	410.923	12.382

Table A9: Pressure at different Crank angle at 100% load for diesel with varying ethanol content

407.605	14.125	410.356	12.281	409.853	12.877	411.365	12.160
408.044	13.896	410.798	12.088	410.294	12.669	411.808	11.969
408.483	13.654	411.239	11.851	410.735	12.432	412.251	11.763
408.921	13.428	411.681	11.627	411.176	12.246	412.694	11.597
409.360	13.204	412.123	11.456	411.618	12.042	413.137	11.386
409.799	13.006	412.564	11.280	412.059	11.869	413.579	11.202
410.238	12.804	413.006	11.119	412.500	11.625	414.022	11.034
410.676	12.548	413.448	10.893	412.941	11.464	414.465	10.868
411.115	12.367	413.890	10.742	413.382	11.263	414.908	10.704
411.554	12.123	414.331	10.604	413.824	11.097	415.351	10.523
411.993	11.984	414.773	10.468	414.265	10.918	415.793	10.387
412.431	11.793	415.215	10.350	414.706	10.770	416.236	10.284
412.870	11.607	415.656	10.189	415.147	10.621	416.679	10.113
413.309	11.444	416.098	10.063	415.588	10.453	417.122	10.018
413.748	11.235	416.540	9.909	416.029	10.292	417.565	9.869
414.186	11.112	416.982	9.781	416.471	10.164	418.007	9.726
414.625	10.923	417.423	9.660	416.912	10.018	418.450	9.598
415.064	10.765	417.865	9.489	417.353	9.854	418.893	9.439
415.503	10.594	418.307	9.374	417.794	9.716	419.336	9.313
415.941	10.435	418.748	9.203	418.235	9.560	419.779	9.150
416.380	10.299	419.190	9.082	418.676	9.447	420.221	9.014
416.819	10.148	419.632	8.929	419.118	9.288	420.664	8.861
417.258	9.965	420.074	8.820	419.559	9.127	421.107	8.690
417.697	9.814	420.515	8.662	420.000	8.981	421.550	8.564
418.135	9.696	420.957	8.501	420.441	8.841	421.993	8.451
418.574	9.565	421.399	8.408	420.882	8.682	422.435	8.325
419.013	9.427	421.840	8.287	421.324	8.602	422.878	8.204
419.452	9.288	422.282	8.169	421.765	8.471	423.321	8.141
419.890	9.168	422.724	8.071	422.206	8.348	423.764	8.003
420.329	9.012	423.166	7.948	422.647	8.270	424.207	7.912
420.768	8.924	423.607	7.852	423.088	8.159	424.649	7.852

Table A10: Pressure at different Crank angle at no load for Biodiesel with varying ethanol content

Biodiesel + 0% Ethanol		Biodiesel + 10% Ethanol		Biodiesel + 20% Ethanol		Biodiesel + 30% Ethanol	
Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)
320.252	9.703	320.455	10.055	319.849	9.494	321.877	7.206
320.707	9.927	320.909	10.226	320.302	9.668	322.334	7.465
321.161	10.153	321.364	10.490	320.756	9.864	322.790	7.741
321.615	10.357	321.818	10.712	321.210	10.086	323.247	8.021
322.069	10.591	322.273	10.958	321.664	10.312	323.703	8.217
322.524	10.795	322.727	11.205	322.117	10.536	324.160	8.438
322.978	11.039	323.182	11.424	322.571	10.747	324.616	8.652
323.432	11.310	323.636	11.647	323.025	10.996	325.073	8.944
323.886	11.524	324.091	11.906	323.478	11.253	325.529	9.213
324.341	11.788	324.545	12.173	323.932	11.446	325.986	9.648
324.795	12.072	325.000	12.467	324.386	11.733	326.443	10.211
325.249	12.294	325.455	12.754	324.839	11.972	326.899	10.556
325.703	12.623	325.909	13.031	325.293	12.251	327.356	10.785
326.158	12.885	326.364	13.335	325.747	12.548	327.812	10.978
326.612	13.179	326.818	13.602	326.200	12.857	328.269	11.265
327.066	13.476	327.273	13.896	326.654	13.126	328.725	11.544
327.521	13.790	327.727	14.198	327.108	13.360	329.182	11.796
327.975	14.097	328.182	14.540	327.561	13.652	329.639	12.085
328.429	14.417	328.636	14.894	328.015	14.019	330.095	12.397
328.883	14.754	329.091	15.252	328.469	14.339	330.552	12.694
329.338	15.070	329.545	15.533	328.922	14.650	331.008	13.048
329.792	15.387	330.000	15.913	329.376	14.982	331.465	13.353
330.246	15.760	330.455	16.293	329.830	15.292	331.921	13.737
330.700	16.104	330.909	16.663	330.284	15.649	332.378	14.032
331.155	16.489	331.364	17.017	330.737	16.001	332.834	14.401
331.609	16.831	331.818	17.415	331.191	16.368	333.291	14.774
332.063	17.226	332.273	17.774	331.645	16.728	333.748	15.141
332.517	17.586	332.727	18.199	332.098	17.078	334.204	15.478
332.972	18.008	333.182	18.634	332.552	17.472	334.661	15.868
333.426	18.373	333.636	19.042	333.006	17.882	335.117	16.273
333.880	18.833	334.091	19.495	333.459	18.297	335.574	16.642
334.334	19.258	334.545	19.907	333.913	18.670	336.030	17.080
334.789	19.678	335.000	20.395	334.367	19.105	336.487	17.475
335.243	20.128	335.455	20.792	334.820	19.527	336.944	17.920
335.697	20.538	335.909	21.305	335.274	19.957	337.400	18.335
336.151	21.014	336.364	21.725	335.728	20.397	337.857	18.755
336.606	21.499	336.818	22.249	336.181	20.840	338.313	19.208
337.060	21.987	337.273	22.689	336.635	21.288	338.770	19.678
337.514	22.432	337.727	23.187	337.089	21.743	339.226	20.148
337.968	22.895	338.182	23.672	337.543	22.208	339.683	20.591
338.423	23.373	338.636	24.165	337.996	22.664	340.140	21.066
338.877	23.851	339.091	24.683	338.450	23.182	340.596	21.547
339.331	24.364	339.545	25.206	338.904	23.612	341.053	22.035
339.785	24.852	340.000	25.737	339.357	24.158	341.509	22.508
340.240	25.413	340.455	26.285	339.811	24.613	341.966	22.983
340.694	25.916	340.909	26.788	340.265	25.179	342.422	23.478

Table A10: Pressure at different Crank angle at no load for Biodiesel with varying ethanol content

341.148	26.431	341.364	27.334	340.718	25.669	342.879	24.022
341.603	27.015	341.818	27.845	341.172	26.205	343.335	24.490
342.057	27.475	342.273	28.380	341.626	26.728	343.792	24.990
342.511	28.023	342.727	28.919	342.079	27.284	344.249	25.503
342.965	28.589	343.182	29.452	342.533	27.787	344.705	26.016
343.420	29.102	343.636	29.990	342.987	28.290	345.162	26.532
343.874	29.620	344.091	30.541	343.440	28.813	345.618	27.032
344.328	30.156	344.545	31.082	343.894	29.371	346.075	27.515
344.782	30.699	345.000	31.625	344.348	29.902	346.531	28.046
345.237	31.207	345.455	32.166	344.802	30.410	346.988	28.509
345.691	31.723	345.909	32.731	345.255	30.991	347.445	29.012
346.145	32.271	346.364	33.242	345.709	31.476	347.901	29.490
346.599	32.744	346.818	33.715	346.163	32.010	348.358	29.970
347.054	33.240	347.273	34.246	346.616	32.560	348.814	30.438
347.508	33.730	347.727	34.718	347.070	33.051	349.271	30.878
347.962	34.180	348.182	35.199	347.524	33.534	349.727	31.361
348.416	34.650	348.636	35.667	347.977	34.052	350.184	31.771
348.871	35.068	349.091	36.072	348.431	34.522	350.640	32.218
349.325	35.486	349.545	36.512	348.885	34.937	351.097	32.616
349.779	35.921	350.000	36.942	349.338	35.418	351.554	33.053
350.233	36.293	350.455	37.309	349.792	35.835	352.010	33.438
350.688	36.675	350.909	37.709	350.246	36.258	352.467	33.818
351.142	37.020	351.364	38.051	350.699	36.655	352.923	34.135
351.596	37.407	351.818	38.426	351.153	37.022	353.380	34.462
352.050	37.734	352.273	38.785	351.607	37.387	353.836	34.779
352.505	38.079	352.727	39.054	352.060	37.737	354.293	35.086
352.959	38.426	353.182	39.349	352.514	38.079	354.750	35.362
353.413	38.665	353.636	39.573	352.968	38.390	355.206	35.616
353.868	38.904	354.091	39.761	353.422	38.692	355.663	35.823
354.322	39.178	354.545	39.985	353.875	38.944	356.119	36.069
354.776	39.437	355.000	40.179	354.329	39.120	356.576	36.298
355.230	39.728	355.455	40.345	354.783	39.336	357.032	36.527
355.685	40.060	355.909	40.501	355.236	39.512	357.489	36.728
356.139	40.458	356.364	40.684	355.690	39.661	357.945	36.952
356.593	40.898	356.818	40.828	356.144	39.819	358.402	37.161
357.047	41.487	357.273	41.016	356.597	39.920	358.859	37.420
357.502	42.208	357.727	41.233	357.051	40.015	359.315	37.787
357.956	42.986	358.182	41.446	357.505	40.151	359.772	38.164
358.410	43.853	358.636	41.831	357.958	40.249	360.228	38.549
358.864	44.734	359.091	42.244	358.412	40.390	360.685	38.961
359.319	45.483	359.545	42.747	358.866	40.508	361.141	39.379
359.773	46.172	360.000	43.370	359.319	40.646	361.598	39.894
360.227	46.776	360.455	43.994	359.773	40.888	362.055	40.249
360.681	47.309	360.909	44.673	360.227	41.182	362.511	40.714
361.136	47.764	361.364	45.269	360.681	41.534	362.968	41.059
361.590	48.096	361.818	45.775	361.134	42.002	363.424	41.421
362.044	48.438	362.273	46.270	361.588	42.462	363.881	41.736
362.498	48.604	362.727	46.637	362.042	42.998	364.337	41.990
362.953	48.750	363.182	46.990	362.495	43.496	364.794	42.148
363.407	48.740	363.636	47.223	362.949	43.901	365.250	42.389
363.861	48.697	364.091	47.432	363.403	44.273	365.707	42.410

Table A10: Pressure at different Crank angle at no load for Biodiesel with varying ethanol content

364.315	48.567	364.545	47.500	363.856	44.640	366.864	43.520
364.770	48.383	365.000	47.508	364.310	44.889	366.920	42.347
365.224	48.124	365.455	47.447	364.764	45.091	367.077	42.259
365.678	47.807	365.909	47.254	365.217	45.237	367.533	42.025
366.132	47.495	366.364	47.002	365.671	45.365	367.990	41.813
366.587	47.103	366.818	46.758	366.125	45.365	368.446	41.484
367.041	46.678	367.273	46.391	366.578	45.315	368.903	41.170
367.495	46.207	367.727	45.991	367.032	45.189	369.360	40.820
367.950	45.760	368.182	45.571	367.486	44.990	369.816	40.408
368.404	45.262	368.636	45.116	367.940	44.723	370.273	40.003
368.858	44.696	369.091	44.595	368.393	44.366	370.729	39.507
369.312	44.180	369.545	44.067	368.847	44.004	371.186	39.127
369.767	43.604	370.000	43.554	369.301	43.594	371.642	38.619
370.221	43.043	370.455	42.978	369.754	43.114	372.099	38.184
370.675	42.447	370.909	42.415	370.208	42.706	372.555	37.679
371.129	41.854	371.364	41.831	370.662	42.176	373.012	37.201
371.584	41.290	371.818	41.258	371.115	41.645	373.469	36.693
372.038	40.631	372.273	40.626	371.569	41.117	373.925	36.185
372.492	40.008	372.727	40.033	372.023	40.579	374.382	35.659
372.946	39.331	373.182	39.361	372.476	40.033	374.838	35.101
373.401	38.697	373.636	38.743	372.930	39.454	375.295	34.575
373.855	38.046	374.091	38.101	373.384	38.866	375.751	34.042
374.309	37.369	374.545	37.447	373.837	38.227	376.208	33.461
374.763	36.708	375.000	36.748	374.291	37.674	376.665	32.918
375.218	36.069	375.455	36.112	374.745	37.030	377.121	32.369
375.672	35.445	375.909	35.491	375.198	36.396	377.578	31.859
376.126	34.749	376.364	34.827	375.652	35.782	378.034	31.268
376.580	34.120	376.818	34.220	376.106	35.116	378.491	30.740
377.035	33.468	377.273	33.564	376.560	34.542	378.947	30.161
377.489	32.802	377.727	32.923	377.013	33.901	379.404	29.613
377.943	32.163	378.182	32.301	377.467	33.255	379.860	29.077
378.397	31.554	378.636	31.695	377.921	32.661	380.317	28.584
378.852	30.926	379.091	31.049	378.374	32.030	380.774	28.089
379.306	30.249	379.545	30.458	378.828	31.421	381.230	27.515
379.760	29.703	380.000	29.837	379.282	30.787	381.687	27.012
380.215	29.069	380.455	29.263	379.735	30.201	382.143	26.449
380.669	28.476	380.909	28.644	380.189	29.605	382.600	25.978
381.123	27.938	381.364	28.021	380.643	29.029	383.056	25.503
381.577	27.369	381.818	27.425	381.096	28.456	383.513	25.081
382.032	26.829	382.273	26.869	381.550	27.837	383.970	24.603
382.486	26.263	382.727	26.333	382.004	27.279	384.426	24.170
382.940	25.712	383.182	25.797	382.457	26.703	384.883	23.753
383.394	25.186	383.636	25.274	382.911	26.124	385.339	23.300
383.849	24.623	384.091	24.766	383.365	25.629	385.796	22.875
384.303	24.075	384.545	24.241	383.819	25.078	386.252	22.447
384.757	23.566	385.000	23.717	384.272	24.560	386.709	22.042
385.211	23.046	385.455	23.252	384.726	24.072	387.166	21.587
385.666	22.520	385.909	22.782	385.180	23.579	387.622	21.190
386.120	21.979	386.364	22.261	385.633	23.111	388.079	20.729
386.574	21.527	386.818	21.798	386.087	22.648	388.535	20.312
387.028	21.011	387.273	21.318	386.541	22.216	388.992	19.867

Table A10: Pressure at different Crank angle at no load for Biodiesel with varying ethanol content

387.483	20.548	387.727	20.878	386.994	21.788	389.448	19.406
387.937	20.123	388.182	20.415	387.448	21.305	389.905	18.974
388.391	19.713	388.636	20.020	387.902	20.870	390.361	18.501
388.845	19.273	389.091	19.557	388.355	20.372	390.818	18.081
389.300	18.898	389.545	19.185	388.809	19.967	391.275	17.638
389.754	18.471	390.000	18.743	389.263	19.472	391.731	17.218
390.208	18.139	390.455	18.398	389.716	19.087	392.188	16.796
390.662	17.739	390.909	17.975	390.170	18.675	392.644	16.426
391.117	17.332	391.364	17.586	390.624	18.257	393.101	15.976
391.571	16.987	391.818	17.223	391.078	17.882	393.557	15.636
392.025	16.612	392.273	16.821	391.531	17.487	394.014	15.254
392.479	16.310	392.727	16.489	391.985	17.140	394.471	14.917
392.934	15.900	393.182	16.137	392.439	16.761	394.927	14.560
393.388	15.614	393.636	15.830	392.892	16.436	395.384	14.311
393.842	15.317	394.091	15.523	393.346	16.054	395.840	13.961
394.297	15.013	394.545	15.206	393.800	15.752	396.297	13.687
394.751	14.655	395.000	14.892	394.253	15.367	396.753	13.390
395.205	14.379	395.455	14.623	394.707	15.113	397.210	13.169
395.659	14.100	395.909	14.341	395.161	14.756	397.666	12.900
396.114	13.823	396.364	14.037	395.614	14.462	398.123	12.656
396.568	13.531	396.818	13.798	396.068	14.145	398.580	12.377
397.022	13.275	397.273	13.493	396.522	13.868	399.036	12.148
397.476	13.026	397.727	13.232	396.975	13.592	399.493	11.876
397.931	12.779	398.182	12.948	397.429	13.300	399.949	11.640
398.385	12.520	398.636	12.661	397.883	13.048	400.406	11.381
398.839	12.306	399.091	12.445	398.336	12.792	400.862	11.175
399.293	12.017	399.545	12.178	398.790	12.513	401.319	10.931
399.748	11.808	400.000	11.962	399.244	12.266	401.776	10.704
400.202	11.600	400.455	11.735	399.698	12.015	402.232	10.470
400.656	11.368	400.909	11.529	400.151	11.826	402.689	10.292
401.110	11.172	401.364	11.323	400.605	11.582	403.145	10.078
401.565	10.966	401.818	11.112	401.059	11.358	403.602	9.869
402.019	10.765	402.273	10.903	401.512	11.159	404.058	9.660
402.473	10.526	402.727	10.719	401.966	10.943	404.515	9.447
402.927	10.330	403.182	10.478	402.420	10.767	404.971	9.248
403.382	10.161	403.636	10.312	402.873	10.571	405.428	9.024
403.836	9.957	404.091	10.101	403.327	10.342	405.885	8.856
404.290	9.801	404.545	9.912	403.781	10.179	406.341	8.652
404.744	9.618	405.000	9.718	404.234	9.960	406.798	8.456
405.199	9.447	405.455	9.540	404.688	9.799	407.254	8.280
405.653	9.298	405.909	9.364	405.142	9.625	407.711	8.136
406.107	9.105	406.364	9.162	405.595	9.444	408.167	7.965
406.562	9.009	406.818	8.989	406.049	9.281	408.624	7.845
407.016	8.818	407.273	8.873	406.503	9.122	409.081	7.694
407.470	8.659	407.727	8.687	406.957	8.976	409.537	7.540
407.924	8.486	408.182	8.534	407.410	8.795	409.994	7.415
408.379	8.335	408.636	8.360	407.864	8.670	410.450	7.294
408.833	8.167	409.091	8.207	408.318	8.504	410.907	7.140
409.287	8.031	409.545	8.081	408.771	8.388	411.363	7.045
409.741	7.870	410.000	7.895	409.225	8.214	411.820	6.917
410.196	7.699	410.455	7.767	409.679	8.076	412.276	6.818

Table A10: Pressure at different Crank angle at no load for Biodiesel with varying ethanol content

410.650	7.593	410.909	7.611	410.132	7.958	412.733	6.675
411.104	7.498	411.364	7.480	410.586	7.777	413.190	6.605
411.558	7.319	411.818	7.354	411.040	7.648	413.646	6.459
412.013	7.256	412.273	7.213	411.493	7.543	414.103	6.351
412.467	7.113	412.727	7.055	411.947	7.415	414.559	6.298
412.921	6.984	413.182	6.927	412.401	7.306	415.016	6.197
413.375	6.894	413.636	6.826	412.854	7.183	415.472	6.092
413.830	6.791	414.091	6.740	413.308	7.045	415.929	6.024
414.284	6.680	414.545	6.642	413.762	6.947	416.386	5.910
414.738	6.610	415.000	6.544	414.216	6.786	416.842	5.853
415.192	6.557	415.455	6.441	414.669	6.690	417.299	5.817
415.647	6.484	415.909	6.310	415.123	6.554	417.755	5.699
416.101	6.413	416.364	6.222	415.577	6.491	418.212	5.594
416.555	6.336	416.818	6.127	416.030	6.381	418.668	5.518
417.009	6.305	417.273	6.056	416.484	6.245	419.125	5.425
417.464	6.270	417.727	6.039	416.938	6.152	419.581	5.367
417.918	6.187	418.182	5.938	417.391	6.034	420.038	5.307
418.372	6.124	418.636	5.918	417.845	5.953	420.495	5.224
418.826	6.109	419.091	5.863	418.299	5.845	420.951	5.181
419.281	6.029	419.545	5.873	418.752	5.742	421.408	5.093
419.735	5.966	420.000	5.822	419.206	5.651	421.864	5.038
420.189	5.898	420.455	5.780	419.660	5.589	422.321	4.937
420.644	5.845	420.909	5.744	420.113	5.468	422.777	4.912

Table A11: Pressure at different Crank angle at 50% load for Biodiesel with varying ethanol content

Biodiesel + 0% Ethanol		Biodiesel + 10% Ethanol		Biodiesel + 20% Ethanol		Biodiesel + 30% Ethanol	
Crank Angle (deg)	Pressure(bar)	Crank Angle (deg)	Pressure(bar)	Crank Angle (deg)	Pressure(bar)	Crank Angle (deg)	Pressure(bar)
320.354	8.398	319.142	7.824	318.941	8.403	319.949	8.529
320.810	8.592	319.596	8.018	319.395	8.602	320.405	8.695
321.266	8.695	320.050	8.260	319.849	8.795	320.860	8.898
321.722	8.911	320.504	8.481	320.302	8.997	321.315	9.097
322.177	9.092	320.958	8.677	320.756	9.183	321.770	9.344
322.633	9.238	321.412	8.891	321.210	9.409	322.225	9.590
323.089	9.454	321.866	9.115	321.664	9.610	322.680	9.806
323.544	9.610	322.320	9.401	322.117	9.839	323.135	10.030
324.000	9.826	322.774	9.681	322.571	10.060	323.590	10.284
324.456	10.030	323.228	9.975	323.025	10.277	324.046	10.528
324.911	10.259	323.682	10.244	323.478	10.563	324.501	10.787
325.367	10.521	324.136	10.641	323.932	10.822	324.956	11.044
325.823	10.719	324.590	10.888	324.386	11.087	325.411	11.331
326.278	10.988	325.044	11.094	324.839	11.356	325.866	11.595
326.734	11.215	325.498	11.466	325.293	11.685	326.321	11.891
327.190	11.507	325.952	12.088	325.747	11.949	326.776	12.196
327.646	11.758	326.406	12.699	326.200	12.261	327.231	12.465
328.101	12.060	326.860	12.915	326.654	12.565	327.686	12.759
328.557	12.369	327.314	13.174	327.108	12.867	328.142	13.109
329.013	12.648	327.768	13.451	327.561	13.126	328.597	13.438
329.468	13.023	328.222	13.768	328.015	13.446	329.052	13.715
329.924	13.363	328.676	14.132	328.469	13.737	329.507	14.062
330.380	13.750	329.130	14.452	328.922	14.047	329.962	14.401
330.835	14.163	329.584	14.826	329.376	14.356	330.417	14.796
331.291	14.585	330.038	15.141	329.830	14.683	330.872	15.118
331.747	15.025	330.492	15.523	330.284	15.030	331.327	15.506
332.203	15.501	330.946	15.893	330.737	15.332	331.783	15.855
332.658	15.918	331.400	16.290	331.191	15.712	332.238	16.240
333.114	16.471	331.854	16.612	331.645	16.021	332.693	16.655
333.570	17.005	332.308	17.052	332.098	16.403	333.148	17.022
334.025	17.515	332.762	17.407	332.552	16.783	333.603	17.470
334.481	18.101	333.216	17.812	333.006	17.145	334.058	17.860
334.937	18.675	333.670	18.224	333.459	17.533	334.513	18.262
335.392	19.215	334.124	18.654	333.913	17.923	334.968	18.732
335.848	19.791	334.578	19.090	334.367	18.363	335.424	19.170
336.304	20.433	335.032	19.495	334.820	18.745	335.879	19.635
336.759	21.029	335.485	19.967	335.274	19.195	336.334	20.101
337.215	21.637	335.939	20.423	335.728	19.600	336.789	20.566
337.671	22.241	336.393	20.953	336.181	20.068	337.244	21.014
338.127	22.819	336.847	21.680	336.635	20.518	337.699	21.517
338.582	23.380	337.301	22.261	337.089	20.961	338.154	22.007
339.038	23.992	337.755	22.706	337.543	21.434	338.609	22.498
339.494	24.552	338.209	23.189	337.996	21.896	339.064	23.018
339.949	25.128	338.663	23.702	338.450	22.435	339.520	23.504
340.405	25.742	339.117	24.208	338.904	22.862	339.975	24.004
340.861	26.278	339.571	24.716	339.357	23.373	340.430	24.517

Table A11: Pressure at different Crank angle at 50% load for Biodiesel with varying ethanol content

341.316	26.864	340.025	25.242	339.811	23.858	340.885	25.073
341.772	27.462	340.479	25.777	340.265	24.346	341.340	25.594
342.228	28.016	340.933	26.275	340.718	24.882	341.795	26.122
342.684	28.516	341.387	26.826	341.172	25.395	342.250	26.655
343.139	29.115	341.841	27.359	341.626	25.900	342.705	27.158
343.595	29.668	342.295	27.925	342.079	26.429	343.161	27.716
344.051	30.214	342.749	28.421	342.533	26.959	343.616	28.245
344.506	30.777	343.203	28.984	342.987	27.493	344.071	28.758
344.962	31.270	343.657	29.520	343.440	28.033	344.526	29.291
345.418	31.803	344.111	30.088	343.894	28.566	344.981	29.814
345.873	32.339	344.565	30.621	344.348	29.072	345.436	30.319
346.329	32.862	345.019	31.172	344.802	29.623	345.891	30.812
346.785	33.385	345.473	31.660	345.255	30.123	346.346	31.343
347.241	33.873	345.927	32.206	345.709	30.697	346.802	31.806
347.696	34.329	346.381	32.701	346.163	31.170	347.257	32.316
348.152	34.862	346.835	33.224	346.616	31.698	347.712	32.762
348.608	35.330	347.289	33.670	347.070	32.193	348.167	33.260
349.063	35.719	347.743	34.170	347.524	32.684	348.622	33.634
349.519	36.225	348.197	34.620	347.977	33.162	349.077	34.122
349.975	36.622	348.651	35.106	348.431	33.660	349.532	34.540
350.430	37.057	349.105	35.521	348.885	34.102	349.987	34.960
350.886	37.427	349.559	35.961	349.338	34.588	350.442	35.375
351.342	37.837	350.013	36.348	349.792	35.033	350.898	35.740
351.797	38.247	350.467	36.826	350.246	35.458	351.353	36.165
352.253	38.655	350.921	37.239	350.699	35.885	351.808	36.559
352.709	39.122	351.375	37.608	351.153	36.278	352.263	36.974
353.165	39.557	351.828	37.988	351.607	36.700	352.718	37.472
353.620	40.164	352.282	38.395	352.060	37.110	353.173	38.033
354.076	40.820	352.736	38.848	352.514	37.573	353.628	38.680
354.532	41.693	353.190	39.349	352.968	37.991	354.083	39.505
354.987	42.749	353.644	39.874	353.422	38.536	354.539	40.541
355.443	43.982	354.098	40.574	353.875	39.132	354.994	41.791
355.899	45.395	354.552	41.509	354.329	39.854	355.449	43.222
356.354	46.816	355.006	42.651	354.783	40.702	355.904	44.728
356.810	48.219	355.460	44.002	355.236	41.741	356.359	46.270
357.266	49.723	355.914	45.475	355.690	42.948	356.814	47.862
357.722	50.979	356.368	47.100	356.144	44.271	357.269	49.336
358.177	52.314	356.822	48.687	356.597	45.611	357.724	50.810
358.633	53.484	357.276	50.299	357.051	46.977	358.180	52.133
359.089	54.505	357.730	51.876	357.505	48.360	358.635	53.310
359.544	55.393	358.184	53.340	357.958	49.663	359.090	54.326
360.000	56.109	358.638	54.688	358.412	50.903	359.545	55.081
360.456	56.648	359.092	55.790	358.866	52.052	360.000	55.659
360.911	56.975	359.546	56.645	359.319	53.023	360.455	55.971
361.367	57.176	360.000	57.349	359.773	53.878	360.910	56.192
361.823	57.284	360.454	57.727	360.227	54.605	361.365	56.308
362.278	57.304	360.908	58.031	360.681	55.138	361.820	56.316
362.734	57.218	361.362	58.126	361.134	55.606	362.276	56.321
363.190	57.193	361.816	58.177	361.588	55.933	362.731	56.220
363.646	56.975	362.270	58.267	362.042	56.187	363.186	56.122
364.101	56.894	362.724	58.056	362.495	56.373	363.641	55.926

Table A11: Pressure at different Crank angle at 50% load for Biodiesel with varying ethanol content

364.557	56.552	363.178	58.081	362.949	56.441	364.096	55.755
365.013	56.394	363.632	57.842	363.403	56.492	364.551	55.528
365.468	56.039	364.086	57.681	363.856	56.424	365.006	55.244
365.924	55.772	364.540	57.483	364.310	56.316	365.461	54.947
366.380	55.340	364.994	57.173	364.764	56.142	365.917	54.563
366.835	55.005	365.448	56.919	365.217	55.941	366.372	54.143
367.291	54.525	365.902	56.562	365.671	55.679	366.827	53.773
367.747	54.105	366.356	56.202	366.125	55.332	367.282	53.270
368.203	53.572	366.810	55.818	366.578	55.008	367.737	52.832
368.658	53.074	367.264	55.317	367.032	54.618	368.192	52.279
369.114	52.586	367.718	54.874	367.486	54.185	368.647	51.733
369.570	51.952	368.172	54.369	367.940	53.730	369.102	51.175
370.025	51.406	368.625	53.851	368.393	53.252	369.558	50.584
370.481	50.800	369.079	53.300	368.847	52.744	370.013	49.995
370.937	50.206	369.533	52.704	369.301	52.213	370.468	49.354
371.392	49.575	369.987	52.123	369.754	51.675	370.923	48.727
371.848	48.866	370.441	51.509	370.208	51.087	371.378	48.056
372.304	48.172	370.895	50.865	370.662	50.526	371.833	47.440
372.759	47.518	371.349	50.201	371.115	49.912	372.288	46.708
373.215	46.796	371.803	49.510	371.569	49.303	372.743	46.082
373.671	46.142	372.257	48.831	372.023	48.650	373.198	45.297
374.127	45.405	372.711	48.189	372.476	48.046	373.654	44.623
374.582	44.676	373.165	47.480	372.930	47.379	374.109	43.891
375.038	43.883	373.619	46.773	373.384	46.688	374.564	43.177
375.494	43.219	374.073	45.999	373.837	46.031	375.019	42.455
375.949	42.447	374.527	45.269	374.291	45.337	375.474	41.693
376.405	41.773	374.981	44.583	374.745	44.681	375.929	41.004
376.861	41.079	375.435	43.871	375.198	44.004	376.384	40.259
377.316	40.299	375.889	43.099	375.652	43.295	376.839	39.550
377.772	39.608	376.343	42.397	376.106	42.643	377.295	38.800
378.228	38.861	376.797	41.670	376.560	41.927	377.750	38.099
378.684	38.182	377.251	40.951	377.013	41.205	378.205	37.379
379.139	37.452	377.705	40.221	377.467	40.523	378.660	36.678
379.595	36.751	378.159	39.512	377.921	39.849	379.115	35.938
380.051	36.127	378.613	38.795	378.374	39.163	379.570	35.247
380.506	35.380	379.067	38.119	378.828	38.458	380.025	34.520
380.962	34.686	379.521	37.372	379.282	37.787	380.480	33.841
381.418	34.047	379.975	36.708	379.735	37.093	380.936	33.162
381.873	33.375	380.429	36.019	380.189	36.434	381.391	32.460
382.329	32.726	380.883	35.327	380.643	35.760	381.846	31.791
382.785	32.078	381.337	34.653	381.096	35.086	382.301	31.170
383.241	31.426	381.791	33.979	381.550	34.381	382.756	30.503
383.696	30.820	382.245	33.320	382.004	33.765	383.211	29.867
384.152	30.191	382.699	32.659	382.457	33.061	383.666	29.281
384.608	29.600	383.153	32.065	382.911	32.452	384.121	28.649
385.063	28.946	383.607	31.386	383.365	31.715	384.576	28.086
385.519	28.390	384.061	30.802	383.819	31.072	385.032	27.477
385.975	27.787	384.515	30.169	384.272	30.460	385.487	26.927
386.430	27.276	384.968	29.583	384.726	29.852	385.942	26.376
386.886	26.713	385.422	28.986	385.180	29.243	386.397	25.810
387.342	26.177	385.876	28.433	385.633	28.662	386.852	25.219

Table A11: Pressure at different Crank angle at 50% load for Biodiesel with varying ethanol content

387.797	25.629	386.330	27.837	386.087	28.121	387.307	24.645
388.253	25.143	386.784	27.289	386.541	27.591	387.762	24.077
388.709	24.628	387.238	26.751	386.994	27.067	388.217	23.529
389.165	24.132	387.692	26.205	387.448	26.517	388.673	23.011
389.620	23.604	388.146	25.717	387.902	26.041	389.128	22.475
390.076	23.126	388.600	25.209	388.355	25.558	389.583	22.035
390.532	22.656	389.054	24.655	388.809	25.028	390.038	21.489
390.987	22.216	389.508	24.180	389.263	24.580	390.493	21.029
391.443	21.738	389.962	23.695	389.716	24.107	390.948	20.571
391.899	21.323	390.416	23.265	390.170	23.619	391.403	20.108
392.354	20.843	390.870	22.784	390.624	23.129	391.858	19.663
392.810	20.395	391.324	22.367	391.078	22.674	392.314	19.248
393.266	19.985	391.778	21.869	391.531	22.223	392.769	18.823
393.722	19.615	392.232	21.436	391.985	21.741	393.224	18.433
394.177	19.228	392.686	21.034	392.439	21.343	393.679	18.058
394.633	18.783	393.140	20.576	392.892	20.923	394.134	17.618
395.089	18.481	393.594	20.169	393.346	20.470	394.589	17.269
395.544	18.099	394.048	19.789	393.800	20.076	395.044	16.906
396.000	17.754	394.502	19.374	394.253	19.686	395.499	16.547
396.456	17.410	394.956	19.057	394.707	19.251	395.954	16.180
396.911	17.143	395.410	18.665	395.161	18.866	396.410	15.895
397.367	16.783	395.864	18.373	395.614	18.488	396.865	15.558
397.823	16.491	396.318	17.985	396.068	18.141	397.320	15.249
398.278	16.212	396.772	17.653	396.522	17.782	397.775	14.932
398.734	15.900	397.226	17.339	396.975	17.457	398.230	14.640
399.190	15.644	397.680	16.959	397.429	17.057	398.685	14.318
399.646	15.385	398.134	16.690	397.883	16.761	399.140	14.039
400.101	15.106	398.588	16.320	398.336	16.421	399.595	13.725
400.557	14.854	399.042	16.056	398.790	16.066	400.051	13.463
401.013	14.603	399.496	15.719	399.244	15.734	400.506	13.174
401.468	14.323	399.950	15.460	399.698	15.402	400.961	12.837
401.924	14.107	400.404	15.126	400.151	15.126	401.416	12.621
402.380	13.853	400.858	14.852	400.605	14.819	401.871	12.342
402.835	13.644	401.311	14.590	401.059	14.495	402.326	12.115
403.291	13.428	401.765	14.311	401.512	14.205	402.781	11.841
403.747	13.194	402.219	14.067	401.966	13.944	403.236	11.640
404.203	12.953	402.673	13.808	402.420	13.637	403.692	11.436
404.658	12.731	403.127	13.551	402.873	13.405	404.147	11.180
405.114	12.533	403.581	13.317	403.327	13.134	404.602	10.953
405.570	12.352	404.035	13.131	403.781	12.902	405.057	10.795
406.025	12.148	404.489	12.817	404.234	12.646	405.512	10.576
406.481	11.974	404.943	12.596	404.688	12.407	405.967	10.382
406.937	11.773	405.397	12.397	405.142	12.171	406.422	10.151
407.392	11.615	405.851	12.203	405.595	11.977	406.877	9.967
407.848	11.471	406.305	11.994	406.049	11.740	407.332	9.791
408.304	11.242	406.759	11.816	406.503	11.549	407.788	9.580
408.759	11.114	407.213	11.622	406.957	11.361	408.243	9.404
409.215	10.921	407.667	11.436	407.410	11.172	408.698	9.208
409.671	10.752	408.121	11.248	407.864	11.001	409.153	9.069
410.127	10.626	408.575	11.076	408.318	10.805	409.608	8.876
410.582	10.490	409.029	10.890	408.771	10.636	410.063	8.717

Table A11: Pressure at different Crank angle at 50% load for Biodiesel with varying ethanol content

411.038	10.367	409.483	10.739	409.225	10.445	410.518	8.539
411.494	10.229	409.937	10.536	409.679	10.239	410.973	8.393
411.949	10.101	410.391	10.407	410.132	10.078	411.429	8.202
412.405	9.972	410.845	10.226	410.586	9.902	411.884	8.063
412.861	9.894	411.299	10.038	411.040	9.771	412.339	7.907
413.316	9.754	411.753	9.940	411.493	9.570	412.794	7.759
413.772	9.623	412.207	9.759	411.947	9.429	413.249	7.593
414.228	9.535	412.661	9.633	412.401	9.271	413.704	7.462
414.684	9.414	413.115	9.484	412.854	9.097	414.159	7.264
415.139	9.266	413.569	9.356	413.308	8.916	414.614	7.148
415.595	9.213	414.023	9.198	413.762	8.790	415.070	7.012
416.051	9.069	414.477	9.019	414.216	8.665	415.525	6.884
416.506	8.994	414.931	8.908	414.669	8.514	415.980	6.740
416.962	8.896	415.385	8.773	415.123	8.370	416.435	6.655
417.418	8.795	415.839	8.659	415.577	8.224	416.890	6.532
417.873	8.705	416.293	8.519	416.030	8.104	417.345	6.378
418.329	8.652	416.747	8.410	416.484	7.948	417.800	6.280
418.785	8.607	417.201	8.307	416.938	7.860	418.255	6.187
419.241	8.436	417.654	8.134	417.391	7.719	418.710	6.044
419.696	8.461	418.108	8.063	417.845	7.613	419.166	5.933
420.152	8.310	418.562	7.945	418.299	7.498	419.621	5.795
420.608	8.252	419.016	7.895	418.752	7.425	420.076	5.682

Table A12: Pressure at different Crank angle at 100% load for Biodiesel with varying ethanol content

Biodiesel + 0% Ethanol		Biodiesel + 10% Ethanol		Biodiesel + 20% Ethanol		Biodiesel + 30% Ethanol	
Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)	Crank Angle (deg)	Pressure (bar)
320.244	9.379	321.224	9.706	321.815	10.302	322.210	10.858
320.683	9.575	321.665	9.902	322.256	10.521	322.652	11.084
321.123	9.766	322.105	10.081	322.698	10.744	323.094	11.331
321.562	9.987	322.546	10.302	323.139	10.978	323.536	11.539
322.001	10.169	322.987	10.493	323.581	11.220	323.978	11.786
322.441	10.372	323.427	10.724	324.022	11.469	324.420	12.042
322.880	10.626	323.868	10.938	324.464	11.690	324.862	12.284
323.319	10.810	324.308	11.122	324.905	11.924	325.304	12.588
323.758	11.061	324.749	11.383	325.346	12.191	325.746	12.827
324.198	11.268	325.190	11.615	325.788	12.452	326.188	13.121
324.637	11.537	325.630	11.854	326.229	12.747	326.630	13.388
325.076	11.788	326.071	12.062	326.671	13.048	327.072	13.654
325.516	12.027	326.512	12.342	327.112	13.343	327.514	13.974
325.955	12.324	326.952	12.598	327.554	13.604	327.956	14.336
326.394	12.631	327.393	12.875	327.995	13.924	328.398	14.598
326.833	12.860	327.834	13.174	328.437	14.190	328.840	14.952
327.273	13.162	328.274	13.476	328.878	14.542	329.282	15.309
327.712	13.461	328.715	13.753	329.319	14.864	329.724	15.604
328.151	13.742	329.155	14.052	329.761	15.204	330.166	15.908
328.591	14.032	329.596	14.331	330.202	15.579	330.608	16.308
329.030	14.399	330.037	14.645	330.644	15.883	331.050	16.663
329.469	14.668	330.477	14.947	331.085	16.240	331.492	17.035
329.908	15.040	330.918	15.249	331.527	16.587	331.934	17.397
330.348	15.372	331.359	15.533	331.968	16.954	332.376	17.716
330.787	15.707	331.799	15.883	332.410	17.334	332.818	18.172
331.226	16.064	332.240	16.205	332.851	17.704	333.260	18.539
331.666	16.401	332.681	16.595	333.292	18.126	333.702	18.939
332.105	16.776	333.121	16.949	333.734	18.504	334.144	19.334
332.544	17.113	333.562	17.314	334.175	18.934	334.586	19.769
332.984	17.485	334.002	17.646	334.617	19.306	335.028	20.189
333.423	17.910	334.443	18.003	335.058	19.688	335.470	20.621
333.862	18.280	334.884	18.451	335.500	20.143	335.912	21.097
334.301	18.715	335.324	18.778	335.941	20.558	336.354	21.502
334.741	19.102	335.765	19.235	336.383	21.016	336.796	21.974
335.180	19.560	336.206	19.618	336.824	21.454	337.238	22.475
335.619	19.950	336.646	20.008	337.265	21.952	337.680	22.902
336.059	20.387	337.087	20.423	337.707	22.367	338.122	23.388
336.498	20.817	337.528	20.830	338.148	22.855	338.564	23.828
336.937	21.283	337.968	21.308	338.590	23.338	339.006	24.331
337.376	21.738	338.409	21.705	339.031	23.805	339.448	24.781
337.816	22.196	338.849	22.145	339.473	24.291	339.890	25.342
338.255	22.674	339.290	22.636	339.914	24.751	340.331	25.800
338.694	23.144	339.731	23.018	340.356	25.267	340.773	26.326
339.134	23.609	340.171	23.531	340.797	25.750	341.215	26.831
339.573	24.110	340.612	23.909	341.239	26.215	341.657	27.337
340.012	24.575	341.053	24.384	341.680	26.746	342.099	27.840

Table A12: Pressure at different Crank angle at 100% load for Biodiesel with varying ethanol content

340.451	25.043	341.493	24.811	342.121	27.244	342.541	28.375
340.891	25.543	341.934	25.277	342.563	27.774	342.983	28.896
341.330	26.049	342.375	25.770	343.004	28.272	343.425	29.401
341.769	26.504	342.815	26.268	343.446	28.813	343.867	29.892
342.209	27.045	343.256	26.728	343.887	29.301	344.309	30.385
342.648	27.543	343.696	27.269	344.329	29.884	344.751	30.870
343.087	28.063	344.137	27.757	344.770	30.332	345.193	31.383
343.527	28.574	344.578	28.280	345.212	30.823	345.635	31.829
343.966	29.112	345.018	28.760	345.653	31.313	346.077	32.304
344.405	29.567	345.459	29.261	346.094	31.796	346.519	32.759
344.844	30.050	345.900	29.801	346.536	32.251	346.961	33.212
345.284	30.551	346.340	30.304	346.977	32.752	347.403	33.687
345.723	30.981	346.781	30.770	347.419	33.162	347.845	34.049
346.162	31.499	347.222	31.245	347.860	33.607	348.287	34.507
346.602	31.914	347.662	31.708	348.302	34.032	348.729	34.877
347.041	32.399	348.103	32.216	348.743	34.454	349.171	35.279
347.480	32.774	348.543	32.654	349.185	34.847	349.613	35.654
347.919	33.222	348.984	33.172	349.626	35.226	350.055	35.996
348.359	33.657	349.425	33.584	350.067	35.631	350.497	36.383
348.798	34.075	349.865	34.029	350.509	36.021	350.939	36.761
349.237	34.474	350.306	34.429	350.950	36.409	351.381	37.075
349.677	34.847	350.747	34.887	351.392	36.751	351.823	37.460
350.116	35.277	351.187	35.289	351.833	37.095	352.265	37.847
350.555	35.677	351.628	35.712	352.275	37.445	352.707	38.237
350.995	36.066	352.069	36.092	352.716	37.789	353.149	38.690
351.434	36.476	352.509	36.499	353.158	38.177	353.591	39.223
351.873	36.894	352.950	36.934	353.599	38.602	354.033	39.907
352.312	37.399	353.390	37.392	354.040	39.140	354.475	40.805
352.752	37.978	353.831	37.845	354.482	39.671	354.917	41.949
353.191	38.891	354.272	38.390	354.923	40.460	355.359	43.428
353.630	39.879	354.712	39.027	355.365	41.534	355.801	45.030
354.070	41.288	355.153	39.894	355.806	42.857	356.243	46.897
354.509	42.885	355.594	41.061	356.248	44.608	356.685	48.795
354.948	44.696	356.034	42.477	356.689	46.391	357.127	50.621
355.387	46.653	356.475	44.054	357.131	48.401	357.569	52.493
355.827	48.665	356.916	45.845	357.572	50.322	358.011	54.391
356.266	50.790	357.356	47.729	358.013	52.337	358.453	55.966
356.705	52.799	357.797	49.656	358.455	54.281	358.895	57.520
357.145	54.693	358.237	51.610	358.896	55.991	359.337	58.524
357.584	56.323	358.678	53.423	359.338	57.563	359.779	59.437
358.023	57.603	359.119	55.121	359.779	58.795	360.221	59.940
358.462	58.541	359.559	56.519	360.221	59.703	360.663	60.252
358.902	59.213	360.000	57.757	360.662	60.274	361.105	60.559
359.341	59.630	360.441	58.624	361.104	60.626	361.547	60.541
359.780	60.013	360.881	59.412	361.545	60.845	361.989	60.679
360.220	60.239	361.322	59.952	361.987	60.943	362.431	60.616
360.659	60.541	361.763	60.425	362.428	61.057	362.873	60.589
361.098	60.684	362.203	60.692	362.869	60.989	363.315	60.511
361.538	60.885	362.644	60.956	363.311	61.041	363.757	60.345
361.977	60.966	363.084	61.077	363.752	60.918	364.199	60.234
362.016	61.067	363.525	61.217	364.194	60.810	364.641	59.980

Table A12: Pressure at different Crank angle at 100% load for Biodiesel with varying ethanol content

362.115	61.119	363.966	61.145	364.635	60.699	365.083	59.771
363.295	61.062	364.406	61.205	365.077	60.470	365.525	59.467
363.734	61.077	364.847	61.011	365.518	60.287	365.967	59.155
364.173	60.901	365.288	60.956	365.960	59.962	366.409	58.858
364.613	60.860	365.728	60.664	366.401	59.713	366.851	58.438
365.052	60.596	366.169	60.463	366.842	59.371	367.293	58.038
365.491	60.428	366.610	60.144	367.284	58.992	367.735	57.591
365.930	60.242	367.050	59.809	367.725	58.614	368.177	57.110
366.370	59.907	367.491	59.477	368.167	58.167	368.619	56.660
366.809	59.668	367.931	59.042	368.608	57.711	369.061	56.094
367.248	59.226	368.372	58.670	369.050	57.244	369.503	55.611
367.688	58.901	368.813	58.147	369.491	56.726	369.945	55.003
368.127	58.491	369.253	57.729	369.933	56.240	370.387	54.407
368.566	57.996	369.694	57.231	370.374	55.654	370.829	53.798
369.005	57.561	370.135	56.632	370.815	55.088	371.271	53.144
369.445	57.017	370.575	56.127	371.257	54.437	371.713	52.515
369.884	56.474	371.016	55.511	371.698	53.793	372.155	51.803
370.323	55.936	371.457	54.892	372.140	53.194	372.597	51.114
370.763	55.289	371.897	54.306	372.581	52.450	373.039	50.372
371.202	54.681	372.338	53.619	373.023	51.834	373.481	49.656
371.641	54.039	372.778	52.965	373.464	51.074	373.923	48.984
372.081	53.378	373.219	52.296	373.906	50.380	374.365	48.187
372.520	52.686	373.660	51.615	374.347	49.648	374.807	47.488
372.959	51.972	374.100	50.943	374.788	48.904	375.249	46.766
373.398	51.225	374.541	50.239	375.230	48.154	375.691	45.996
373.838	50.546	374.982	49.535	375.671	47.415	376.133	45.249
374.277	49.781	375.422	48.863	376.113	46.670	376.575	44.537
374.716	49.072	375.863	48.152	376.554	45.933	377.017	43.768
375.156	48.325	376.304	47.480	376.996	45.123	377.459	43.053
375.595	47.571	376.744	46.791	377.437	44.437	377.901	42.311
376.034	46.886	377.185	46.102	377.879	43.665	378.343	41.580
376.473	46.089	377.625	45.377	378.320	42.945	378.785	40.878
376.913	45.345	378.066	44.723	378.761	42.246	379.227	40.149
377.352	44.628	378.507	44.062	379.203	41.474	379.669	39.449
377.791	43.836	378.947	43.448	379.644	40.737	380.110	38.712
378.231	43.157	379.388	42.837	380.086	40.055	380.552	38.046
378.670	42.435	379.829	42.196	380.527	39.326	380.994	37.304
379.109	41.690	380.269	41.507	380.969	38.599	381.436	36.612
379.549	40.933	380.710	40.792	381.410	37.908	381.878	35.890
379.988	40.221	381.151	40.108	381.852	37.201	382.320	35.267
380.427	39.472	381.591	39.427	382.293	36.522	382.762	34.570
380.866	38.833	382.032	38.763	382.735	35.835	383.204	33.914
381.306	38.086	382.472	38.094	383.176	35.199	383.646	33.234
381.745	37.379	382.913	37.349	383.617	34.517	384.088	32.648
382.184	36.748	383.354	36.647	384.059	33.856	384.530	31.974
382.624	36.004	383.794	35.938	384.500	33.189	384.972	31.386
383.063	35.317	384.235	35.244	384.942	32.586	385.414	30.757
383.502	34.638	384.676	34.525	385.383	31.932	385.856	30.151
383.941	33.979	385.116	33.836	385.825	31.321	386.298	29.580
384.381	33.295	385.557	33.162	386.266	30.682	386.740	28.959
384.820	32.694	385.998	32.503	386.708	30.076	387.182	28.408

Table A12: Pressure at different Crank angle at 100% load for Biodiesel with varying ethanol content

385.259	32.055	386.438	31.803	387.149	29.477	387.624	27.852
385.699	31.424	386.879	31.220	387.590	28.919	388.066	27.304
386.138	30.800	387.319	30.606	388.032	28.388	388.508	26.808
386.577	30.226	387.760	30.023	388.473	27.835	388.950	26.273
387.016	29.650	388.201	29.467	388.915	27.274	389.392	25.775
387.456	29.107	388.641	28.893	389.356	26.730	389.834	25.239
387.895	28.526	389.082	28.340	389.798	26.210	390.276	24.781
388.334	27.983	389.523	27.857	390.239	25.724	390.718	24.324
388.774	27.460	389.963	27.271	390.681	25.206	391.160	23.861
389.213	26.917	390.404	26.808	391.122	24.769	391.602	23.421
389.652	26.353	390.845	26.248	391.563	24.263	392.044	22.973
390.092	25.878	391.285	25.825	392.005	23.866	392.486	22.601
390.531	25.397	391.726	25.322	392.446	23.390	392.928	22.100
390.970	24.899	392.166	24.872	392.888	22.923	393.370	21.728
391.409	24.464	392.607	24.391	393.329	22.487	393.812	21.318
391.849	23.974	393.048	23.946	393.771	22.072	394.254	20.870
392.288	23.539	393.488	23.506	394.212	21.658	394.696	20.493
392.727	23.109	393.929	23.079	394.654	21.217	395.138	20.116
393.167	22.709	394.370	22.623	395.095	20.807	395.580	19.701
393.606	22.251	394.810	22.181	395.536	20.410	396.022	19.361
394.045	21.839	395.251	21.768	395.978	20.008	396.464	18.984
394.484	21.414	395.692	21.386	396.419	19.668	396.906	18.617
394.924	21.024	396.132	20.983	396.861	19.238	397.348	18.255
395.363	20.621	396.573	20.586	397.302	18.893	397.790	17.930
395.802	20.194	397.013	20.229	397.744	18.549	398.232	17.593
396.242	19.816	397.454	19.849	398.185	18.177	398.674	17.269
396.681	19.432	397.895	19.487	398.627	17.852	399.116	16.962
397.120	19.122	398.335	19.183	399.068	17.563	399.558	16.663
397.559	18.758	398.776	18.793	399.510	17.256	400.000	16.371
397.999	18.393	399.217	18.501	399.951	16.992	400.442	16.099
398.438	18.073	399.657	18.099	400.392	16.690	400.884	15.797
398.877	17.719	400.098	17.804	400.834	16.393	401.326	15.513
399.317	17.440	400.539	17.462	401.275	16.104	401.768	15.229
399.756	17.110	400.979	17.171	401.717	15.797	402.210	14.957
400.195	16.831	401.420	16.866	402.158	15.563	402.652	14.696
400.635	16.509	401.860	16.532	402.600	15.267	403.094	14.442
401.074	16.242	402.301	16.265	403.041	15.023	403.536	14.152
401.513	15.973	402.742	15.981	403.483	14.769	403.978	13.931
401.952	15.651	403.182	15.702	403.924	14.484	404.420	13.659
402.392	15.392	403.623	15.397	404.365	14.240	404.862	13.471
402.831	15.146	404.064	15.126	404.807	14.022	405.304	13.229
403.270	14.874	404.504	14.882	405.248	13.770	405.746	12.988
403.710	14.643	404.945	14.605	405.690	13.556	406.188	12.757
404.149	14.394	405.386	14.374	406.131	13.343	406.630	12.553
404.588	14.120	405.826	14.102	406.573	13.119	407.072	12.377
405.027	13.856	406.267	13.883	407.014	12.925	407.514	12.148
405.467	13.619	406.707	13.652	407.456	12.739	407.956	11.952
405.906	13.405	407.148	13.400	407.897	12.480	408.398	11.751
406.345	13.189	407.589	13.174	408.338	12.269	408.840	11.580
406.785	12.950	408.029	12.980	408.780	12.110	409.282	11.351
407.224	12.782	408.470	12.759	409.221	11.909	409.724	11.192

Table A12: Pressure at different Crank angle at 100% load for Biodiesel with varying ethanol content

407.663	12.553	408.911	12.525	409.663	11.743	410.166	10.991
408.103	12.329	409.351	12.314	410.104	11.572	410.608	10.830
408.542	12.103	409.792	12.135	410.546	11.371	411.050	10.631
408.981	11.917	410.233	11.952	410.987	11.175	411.492	10.445
409.420	11.705	410.673	11.708	411.429	11.021	411.934	10.312
409.860	11.574	411.114	11.557	411.870	10.843	412.376	10.106
410.299	11.368	411.554	11.336	412.311	10.674	412.818	9.990
410.738	11.202	411.995	11.165	412.753	10.511	413.260	9.872
411.178	11.061	412.436	10.999	413.194	10.380	413.702	9.706
411.617	10.888	412.876	10.810	413.636	10.234	414.144	9.550
412.056	10.717	413.317	10.664	414.077	10.075	414.586	9.379
412.495	10.586	413.758	10.483	414.519	9.915	415.028	9.248
412.935	10.397	414.198	10.352	414.960	9.806	415.470	9.097
413.374	10.262	414.639	10.171	415.402	9.673	415.912	8.971
413.813	10.108	415.080	10.040	415.843	9.507	416.354	8.818
414.253	9.967	415.520	9.899	416.284	9.321	416.796	8.649
414.692	9.799	415.961	9.741	416.726	9.203	417.238	8.529
415.131	9.660	416.401	9.588	417.167	9.087	417.680	8.368
415.570	9.532	416.842	9.427	417.609	8.898	418.122	8.275
416.010	9.341	417.283	9.271	418.050	8.793	418.564	8.114
416.449	9.193	417.723	9.130	418.492	8.667	419.006	8.021
416.888	9.110	418.164	8.991	418.933	8.514	419.448	7.892
417.328	8.901	418.605	8.858	419.375	8.441	419.890	7.774
417.767	8.790	419.045	8.712	419.816	8.287	420.331	7.666
418.206	8.639	419.486	8.531	420.258	8.202	420.773	7.593
418.646	8.546	419.927	8.466	420.699	8.066	421.215	7.487
419.085	8.453	420.367	8.327	421.140	7.978	421.657	7.364
419.524	8.312	420.808	8.207	421.582	7.885	422.099	7.241
419.963	8.222	421.248	8.114	422.023	7.774	422.541	7.173
420.403	8.124	421.689	8.001	422.465	7.694	422.983	7.057
420.842	8.006	422.130	7.885	422.906	7.553	423.425	6.959

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EDUCATION

1.	**M.E.**	**:**	Master of Engineering in CAD/CAM Motilal Nehru Regional Engineering College, Allahabad
2.	**SIMAP**	**:**	Small Industries Management Assistance Program IIT, Chennai
3.	**AMIE**	**:**	Degree in Mechanical Engineering Institution of Engineers (India)

EXPERIENCE

15 years of teaching experience in various engineering institutes including University of Petroleum and Energy Studies, Dehradun. One-year experience in industry.

RESEARCH CONTRIBUTION

1. FEM Analysis of cracked Rotating Timoshenko Beam
2. Design, Analysis and development of linear Fresnel Solar thermal concentrators.

PUBLICATIONS

1. Singh Yashvir, Singla Amneesh, Kumar Deepak and Kumar Ajay, Friction and wear characteristics of Jatropha oil based biodiesel blended lubricant at different load; Energy Sources, Taylor & Francis; Accepted for Publication.
2. Kumar Deepak, Garg Rajnish and Tripathi R K, Experimental investigation on emissions of direct injection diesel engine operating on dual fuel mode with Polanga based biodiesel and Ethanol. International Journal of Scientific and Engineering Research; December 2014; 05(12): 1641-51.

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