SUDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
COLLOGE OF GRADUATE STUDIES

Performance and Emission Characteristic of A Diesel Engine Using Diesel and Ethanol Blends

خصائص الأداء وانبعاثات محرك الديزيل باستخدام مزيج وقود

الديزيل الديزيل الحيوي الإيثانول

A Thesis Submitted in Partial Fulfillment of the Degree of M.Sc. in Mechanical Engineering (POWER)

By:
Balla Mohmmed Ahmed Mohmmed Ali

Supervisor:

Dr. Ali Mohammed Hamdan Adam

December 2015

الآية

{ اللَّهُ نُورُ السَّمَاوَاتِ وَالْأَرْضِ مَثَلُ نُورِهِ كَمِشْكَاةٍ فِيهَا مِصْبَاحٌ الْمِصْبَاحُ فِي زُجَاجَةٍ الزُّجَاجَةُ كَأَنَّهَا كَوْكَبٌ دُرِّيٌّ يُوقَدُ مِن شَجَرَةٍ مُّبَارَكَةٍ زَيْتُونِةٍ لَّا شَرْقِيَّةٍ وَلَا غَرْبِيَّةٍ يَكَادُ زَيْتُهَا يُضِيءُ وَلَوْ لَمْ تَمْسَسْهُ نَارٌ نُّورٌ عَلَى نُورٍ يَهْدِي اللَّهُ لِنُورِهِ مَن يَشَاءُ وَيَضْرِبُ اللَّهُ الْأَمْثَالَ لِلنَّاسِ وَاللَّهُ بِكُلِّ شَيْءٍ عَلِيمٌ}

الآية 35 النور

DEDICATION

I dedicate this research to my father, mother, sister, brother and my uncle Ahmed Ali.

My dedication extends to all those who tought me in primary and secondary schools and the university.

I also dedicate this research to all friends and colleagues who were with me in the different educational and business institutions.

ACKNOWLEDGEMENT

I am heartily thankful to my supervisor, Dr. Ali Mohammed Hamadan, whose help, guidance and patience during all stages of this study enabled me to finish my research with heartiness. Thanks to the staff of the college of Engineering, department of Mechanical Engineering school at Sudan University of Science and Technology, I am appreciative to the support of my colleagues in the M.Sc group. Thanks to all my friends who supported me in my research. My sincere thanks are also due to the technicians in the internal combustion engine workshop of the Faculty of Engineering Sudan University of Science and Technology.

Finally, I am extremely grateful to my family. Thanks to all the staff at the Faculty of Engineering, University of Sennar.

Lastly, I offer my regards and blessings to all those who supported me in any way to complete my project.

ABSTRACT

The present research is aimed to investigate experimentally the performance and exhaust emission characteristics of the diesel engine when operated with conventional diesel fuel with three blends of diesel-biodiesel-ethanol (DBE) fuel having 5%, 10% and 15% of ethanol and 85%, 80% and 75% of diesel respectively, with fixed 10% of biodiesel. Engine performance and exhaust emission results have shown the brake specific fuel consumption for the three fuel blends are higher than that of diesel fuel and increases with the increase of the ethanol concentration in the blend. The brake power and torque for the fuel blend of 5% ethanol concentration is close to that of diesel fuel and decreases with higher concentration. The CO emission decreased significantly with the higher percentage of ethanol in diesel-biodiesel-ethanol blended fuel. Sulfur dioxide for the three blends increased slightly at lower speeds but at medium and higher speeds it is less than for the diesel fuel.

المستخلص

يهدف هذا البحث إلي الوصول لنتائج عملية للتحقق من خصائص الأداء وإنبعاثات غازات العادم لمحرك ديزل يعمل على وقود الديزل التقليدي ثم ثلاثة خلطات من وقود الديزل، الديزل - الحيوي والإيثانول (DBE) بنسب مختلفة تحتوي على (5%، 10% و15%) إيثانول و (85%، 80% و75%) وقود ديزل على التوالي مع نسبة ثابتة من الإيثانول (10%). أظهرت النتائج أن استهلاك الوقود عندما يعمل المحرك بوقود الخليط أعلى من إستهلاكه بالنسبة لوقود الديزل التقليدي، وكلما زاد تركيز الإيثانول في الخليط زاد إستهلاك الوقود. قدرة المحرك وعزمه بالنسبة للخليط (D85B10E5) تقاربان القدرة والعزم للماكينة عندما تعمل بوقود الديزل التقليدي وتنخفض القدرة والعزم عند زيادة تركيز الإيثانول. تركيز أول أكسيد الكربون ينخفض بصورة ملحوظة مع رفع نسبة تركيز الإيثانول في الخليط. تركيز ثاني أكسيد الكبريت SO_2 بالنسبة للخلائط الثلاثة زاد قليلاً مع السرعات البطيئة ولكن في السرعات المتوسطة والعالية أقل مما كانت عليه في وقود الديزل التقليدي.

List of Contents

LIST OF TABLES

LIST OF FIGURES

Abbreviations

Abbreviation	Fuel
B10E5	85 Percent Diesel , 10 Percent Biodiesel and 5 percent Ethanol by Volume
B10E10	80 Percent Diesel , 10 Percent Biodiesel and 10 percent Ethanol by Volume
B10E15	75 Percent Diesel , 10 Percent Biodiesel and 15 percent Ethanol by Volume
ASTM	American Society for Testing and Materials
API	American Petroleum Institute
WPKO	Waste Palm Kernel Oil
WVOs	Waste Vegetable Oils
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
DI	Direct Injection
CI	Compression Ignition
CLSER	Central Laboratory for Science Environmental and Soil Research (Ministry of Electricity and Dams)
RCU	Remote Control Unit
GAU	Gas Analysis Unit
BSFC	Brake Specific Fuel Consumption

CHAPTER ONE

INTERODUCTION

1.1 Background:

Energy is very important for life quality and social development of people as well as economic growth. Fossil fuels have been an important conventional energy source for years. Energy demand around the world is increasing at a faster rate as a result of ongoing trends in industrialization and modernization. Most of the developing countries import fossil fuels for satisfying their energy demand. Consequently, these countries have to spend their export income to buy petroleum products [1]. The extinction issue of fossil fuel due to continuous usage becomes the focus attention for all the people in the world who depend this energy source in all their activities. The people attention is also increasingly focused on fossil fuel due to the fact that continuous usage of this fuel is believed to cause environmental problems i.e. air pollution and global warming. Hence, currently many researchers all over the world have been trying to look for a solution by exploring and using an alternative fuel which is environmental friendly and also of sustainable availability. The diesel engine is one of the internal combustion engines that can convert the chemical energy of fuel into mechanical work. The diesel engine has a higher thermal efficiency and produces higher power that can save more fuel compared to gasoline engine. Therefore, diesel engines are usually used on large buses, trucks, heavy duty equipment, agricultural equipment and industrial machinery. However, diesel engines also produce gaseous pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), sulfur oxides (SO_x), nitrogen oxides (NO_x), unburned hydrocarbons (HC), and particulate matter (PM). Until now diesel fuel is usually derived from fossil fuel. Therefore, alternative fuels are needed to replace fossil-based fuel, and used for both reducing the consumption of fossil-based fuels and pollutants in the exhaust gases [2]. The main fuel developed, as an alternative the bio-fuel has been found to be an increasingly important alternative to petroleum. It is biodegradable, and produces significantly less air pollution than petrol fuel. Petrol exhaust is a potential carcinogen, and the use of bio- fuel has been found to reduce risks of cancer because it reduces the production of cancer-causing compounds, such as carbon monoxide. Ethanol, biodiesel and to a lesser extent pure vegetable oils are recently considered as most promising bio-fuels. Bio-fuel also displaces production of greenhouse gases such as CO_2. When either bio-fuel or petroleum is burned, the carbon content of the fuel returns to the atmosphere as CO_2. Plants grown to make ethanol for bio-fuel draw CO_2 out of the atmosphere for photosynthesis, causing a recycling process that result in less accumulation of CO_2 in the atmosphere. Thus, bio-fuel does not contribute to global warming in the same way that petroleum does. The National Bio-fuel Board announced that bio-fuel can be produced in large commercial quantities by fermenting sugar cane, maize, grains, sugar beet, etc, so it is an environmentally friendly alternative to petroleum. Bio-fuel has a higher octane number than diesel fuel and almost no sulfur [3]. Biodiesel is a significant fuel which consists of alkyl esters of fatty acids derived from vegetable oils and animal fats. Physical characteristics of biodiesel are very similar to that of conventional diesel fuel. Biodiesel is non toxic and environmental friendly as it produces substantially less carbon monoxide and 100% less sulfur dioxide emissions with no un-burnt hydrocarbons and thus it is ideal fuel for heavily polluted cities. Biodiesel reduces serious air pollutants such as alternative particulates and air toxicity.

It can be stored just like the petroleum diesel fuel and hence does not require separate infrastructure. The use of bio-diesel in conventional diesel engines results in substantial reduction of un-burnt hydrocarbons, carbon monoxide and particulate matters. Its higher cetane number improves the ignition quality even when blended in the petroleum diesel [4]. Utilization of ethanol alcohol fermented from surplus sugar molasses in sugar industry as alternative bio-fuel in the Sudan may be very encouraging and promising. These alternative fuels have the potential to be a very large agriculture produced commodity. Given the non-renewable of petroleum and agricultural potentials of the Sudan it will be very necessary and attractive to acquire the knowhow of using ethanol alcohol as substitute to petroleum fuel [3]. Ethanol is one of the possible fuels for diesel replacement in Compression Ignition (CI) engines. It can be made from raw materials such as sugarcane, sorghum, and corn barley, sugar beets using already improved and demonstrated technologies. Besides being a biomass based renewable fuel, ethanol has clean burning characteristics and high octane rating. Ethanol is a prospective fuel for vehicles, which can be blended with diesel or be injected into cylinder directly. Studies on the use of ethanol in diesel engines have been continuing since the 1970s. The initial investigations were focused on reduction of the smoke and particulate matter in the exhaust gas. Ethanol addition to diesel fuel results in different physical-chemical changes in diesel fuel properties, particularly reductions in cetane number, viscosity and heating value. Ethanol is a promising oxygenated fuel. Pure ethanol with additives such as cetane improver can sharply reduce particulates. Since the late 1990s, ethanol blended diesel fuel has been used on heavy-duty and light duty diesel engines in order to modify their emission characteristics. Since ethanol is polar molecule and its solubility in diesel is prone to be affected by temperature and water content [5]. The application of ethanol as a supplementary compression-ignition fuel may reduce environmental pollution, strengthen agricultural economy, and reduce diesel fuel requirements. Biodiesel, ethanol and diesel blends are a more viable alternative and require little or no change in diesel engines. The use of Biodiesel, ethanol and diesel blends can significantly reduce the emission of toxic gases and particulate matters when compared to pure diesel [1].

1.2 The Problem Statement:

The rising petroleum prices and the growing concern on environmental pollution by the extensive use of conventional fossil fuels have led to search for more environmental friendly and renewable fuels. This problem of environmental pollution is caused by internal combustion engines emissions, particularly the diesel engine. Bio-fuels are potential alternatives to secure a future substitute for the conventional fuels.

1.3 Objectives:

The purpose of this study work is to investigate Biodiesel, ethanol and diesel blends as alternative fuels for Compression Ignition (CI) engines. This shall be achieved as follows:

- To investigate the physical properties of various Biodiesel, ethanol and diesel blends. 85% diesel, 10%biodiesel and 5% ethanol (D85B10E5), 80% diesel, 10% biodiesel and 10% ethanol (D80B10E10), and 75% diesel, 10% biodiesel and 15% ethanol (D75B10E15) shall be prepared for used and comparison with pure diesel fuel.
- To investigate the effect of those blends on the performance of diesel engine and on the exhaust gas emissions.

1.4 Methodology:

This research is an experimental study, so it will try to follow the following steps to achieve good results:

- Collect the literature related to the topic.
- To get ethanol from Kenana Sugar Company (Sudan).
- To blend biodiesel and ethanol with diesel fuel i.e. (D85B10E5), (D80B10E10), and (D75B10E15)
- To measure the performance (brake specific fuel consumption, power output and torque...etc) of the diesel engine tested by using pure diesel fuel.

- To measuring performance of diesel engine tested by using different percentages of diesel-biodiesel, ethanol blends.
- Determine exhaust emissions by testing the engine using the three blended fuels.
- Analyses and display the results drawn from testing the diesel engine using the four types of fuels i.e. the conventional diesel fuel and the three blended fuels.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background on Biodiesel:

2.1.1 Definition:

In 1895, Rudolf Diesel developed a new engine with the intention that it could use a variety of fuels, including vegetable oil. When he showed it to the public at the 1900 Paris World's fair, he had the engine run on peanut oil. As the diesel engine became more widely adopted in subsequent years, however, petroleum-based diesel fuel proved to be less expensive and became the fuel of choice [6]. Biodiesel's definition has been open while work in progress. Since the early 1900s, biodiesel has been defined as an alternative form of diesel fuel made from vegetable oils or animal fats and alcohol [7]. The definition of biodiesel was neither legally definable nor defensible in the United States for about a century. This changed when biodiesel was registered with the U.S. Environmental Protection Agency (EPA) as a fuel and a fuel additive under section 211(b) of the Clean Air Act [8]. With help from the American Society of Testing & Materials (ASTM), subsequent legislation such as the Energy Policy Act (Epact) helped further define biodiesel. In December 2001, the ASTM issued defined physical/chemical constraints for biodiesel and subsequently for mixtures of biodiesel with diesel fuel [9].

2.1.2 Manufacture:

Biodiesel is derived from biological sources, such as vegetable oils or fats, and alcohol [7]. Commonly used feed stocks are shown in Table 2.1.

Table 2.1: Feedstock Used for Biodiesel Manufacture

Vegetable Oil	Animal Fats	Other Sources
Soybeans	Lard	Recycled Restaurant Cooking Oil
Rapeseed	Tallow	
Canola Oil (a modified version of rapeseed)	Poultry Fat	
Safflower Oil		
Sunflower Seeds		
Yellow Mustard Seed		

Most commercial biodiesel is made by a chemical process called transesterification. This involves mixing the feedstock oil with an alcohol typically methanol or ethanol in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide. The reaction produces methyl esters (if methanol is used) or ethyl esters (if ethanol is used) which comprises the biodiesel fuel and glycerin [10]. Methanol is typically used for economic reasons, as the physical and chemical properties between methyl esters and ethyl esters are, according to a University of Idaho study, “comparable” Europe has been using biodiesel more extensively than the United States. Europe commonly uses rapeseed methyl ester. The predominant biodiesel used in the U.S. is soy methyl ester [11].

2.2 Ethanol:

Bio-ethanol is ethyl alcohol, grain alcohol, or chemically C_2H_5OH. Bio-ethanol and bio-ethanol/gasoline blends have a long history as alternative transportation fuels. It has been used in Germany and France as early as 1894 by the then incipient industry of internal combustion (IC) engines .Brazil has utilized bio-ethanol as a transportation fuel since 1925. The use of bio-ethanol for fuel was widespread in Europe and the United States until the early 1900s. Because it became more expensive to produce than petroleum-based fuel, especially after World War II, bio-ethanol’s potential was largely ignored until the oil crisis of the 1970s .Since the 1980s, there has been an increased interest in the use of bio-ethanol as an alternative transportation fuel. Bio-ethanol has a higher octane number, broader flammability limits, higher flame speeds and higher heats of vaporization. These properties allow for a higher compression ratio and shorter burn time. Bio-ethanol is an oxygenated fuel that contains 35% oxygen, which reduces particulate and nitrogen oxides (NOx) emissions from combustion [12]. Ethanol fuel, which can be produced from vegetable materials, such as corn, sugar cane, sugar beets, sorghum, barley and cassava, and it has higher miscibility with diesel fuel. The use of ethanol in diesel engines has received considerable Attention. It is regarded as one of the promising alternative fuels or an oxygen additive in diesel engines with its advantages of low price and high oxygen fraction [13]. Ethanol derived from sugar cane is an efficient and renewable bio-fuel that appears as a solution to the problems of rural development, diversification of energy sources, and fossil fuel-saving, as well as contributing to the reduction of local pollutants from vehicle exhausts and net reductions in greenhouse gas (GHG) emissions. Ethanol is a prospective fuel for vehicle; it can be blended with diesel in varying quantities up to pure ethanol (E100), and most Compression Ignition (CI) engines operate well with mixtures of 20% ethanol (E20).

2.2.1 Ethanol Production Worldwide:

Global production of bio-ethanol increased from 17.25 billion liters in 2000 to over 46 billion liters in 2007. With all of the new government programs in America, Asia, and Europe in place, total global fuel bio-ethanol demand could grow to exceed 125 billion liters by 2020. In 2007, bio-ethanol production represented about 4% of the 1300 billion liters of gasoline consumed globally. Bio-ethanol is a fuel derived from biomass sources of feedstock; typically plants such as wheat, sugar beet, corn, straw, and wood. Bio-ethanol is currently made by large-scale yeast fermentation of sugars that are extracted or prepared from crops followed by separation of the bio-ethanol by distillation. World Ethanol Production between 2007 and 2013 is presented in Table 2.2. Brazil, USA, China, EU-27 and Canada were considered as major producing country of Bio-ethanol fuel in 2007 with approximately 11.7 hectare or 2.2% of their arable lands allocated for Bio-ethanol biomass. Bio-ethanol from sugar cane represented 60% of total Bio-ethanol production worldwide while the other 40% comes from other crops. It is noteworthy that Brazil is biggest producer of sugar cane with about 27% of global production. During the period 2006–2007, 6.45 million hectares of sugar cane crops were cultivated and around three million hectares were dedicated to bio-ethanol production, which represents more than 5% of Brazil's arable land. Furthermore, Brazil was expected to produce a record 27.8 billion liters of ethanol in the 2009-2010 seasons. It began its bio-fuel program 30 years ago and now mandates a minimum 20 percent of ethanol in gasoline .In Asia (India, Thailand, and Philippines) sugar cane is produced on small fields owned by small farmers. For example India has around seven million small farmers with an average of around 0.25 ha sugar cane fields. In North America, USA produces Bio-ethanol from starchy feed-stock specifically from corn and wheat. In Canada, some efforts have been exerted but in smallscale plants for Bio-ethanol productions from corn, wheat and lignocelluloses feedstock which is from agricultural residues [12].

Table 2.2: World fuel Ethanol Production 2007-2013 by Country Millions of Gallons/Year.

Country	2007	2008	2009	2010	2011	2012	2013
Brazil	5019.0	6472.2	6577.89	6921.54	5573.2	5577	6,267
U.S.	6498.6	9000.0	10,600.00	-	-	-	13,300
China	468.0	501.9	541.55	-	554.76	555.0	696
India	52.8	66.0	91.67	-	-	-	545
Canada	211.0	237.7	290.59	356.63	462.30	4490.0	523
European	570.3	733.6	1039.52	1208.58	1167.64	1,139	1,371
Thailand	79.2	89.8	435.20	-	-	-	-
Colombia	74.9	79.29	83.21	-	-	-	-
Central America	39.6	-	-	13,720.99	14,401.34	13,768	-

2.2.2 Ethanol Production in Sudan:

Sudan is rich of fertile land, water for irrigation and wide range of climates which lead to different crops. This is helpful to produce ethanol. The most important crop for producing manufacturing plant will be the focus of ethanol production. An increase in production capacity in the Sudan together with the production capacity of the White Nile sugar factory and the existing production capacities of the other cane sugar production factories like Assalaya, Sennar, El-Guneid and Halfa 100 million liters would be considered a possible ethanol production capacity. Table 2.3 shows the existing sugar capacities for Sudanese sugar factories [14].

Table 2.3: Existing Sugar Capacities

Project	Estimated ethanol capacity (liter)
Kenana sugar company	65,000,000
Sudanese sugar company	40,000,000
White Nile sugar company	40,000,000
Subtotal	145,000,000

2.3 Diesel Fuels:

Diesel fuel is one of the petroleum products, which is used in all kinds of compression ignition engine as a fuel. It is produced from crude oil by various refining processes, which come out from the oil wells. It is estimated that the source of crude oil would be ruined in future, as the demand of petroleum products is growing at a faster rate day by day [15]. Diesel fuel is used in medium and heavy vehicles, as well as in rail and marine engines. Typical diesel fuel is also a mixture of hydrocarbons from refined crude oil, but it is composed of a blend of fuels with a higher boiling point range than that of gasoline [16]. Diesel engines provide important transportation power sources which are receiving additional attention due to their superior fuel economy and lower green house gas emissions. However, diesel engines have the problem of emitting more amount of particulate matter (PM) due to its heterogeneous combustion. Diesel emission control is a function of combustion improvement, fuel formulation and after treatment devices Combination of fuel formulation and additive is effective for control of emissions from in-use diesel engines [17].

2.4 Diesel Blends:

The alternative diesel fuels must be technically acceptable, economically competitive, environmentally of ethanol, methanol, hexanol, and jatropha oil, waste oil and vegetable oils, such as palm, soya bean, sun flower, peanut and olive oils as alternative fuels for diesel engines which dates back to almost nine decades .Due to the rapid decline acceptable and easily available. Oil blending is simple idea; started when global a warming occurs to remove the small particles of metal and other contaminants blends with diesel fuel. Many of the research have indicated the successful use in crude oil reserves, the use of vegetable oils as diesel fuels is again promoted in many countries. It can be mixed with diesel fuels to reduce imported petroleum and modify their emissions and save a gallon of diesel fuel for each gallon of oil blended, where there is no cost for disposing of the waste oil [18].

2.5 Ethanol-Diesel Blends:

The use of ethanol blended with diesel was a subject of research in the 1980s and it was shown that ethanol–diesel blends were technically acceptable for existing diesel engines. The relatively high cost of ethanol production at that time meant that the fuel could only be considered in cases of fuel shortages. Recently the economics have become much more favorable in the production of ethanol and it is able to compete with standard diesel. Consequently there has been renewed interest in the ethanol–diesel blends with particular emphasis on emissions reductions. An additional factor that makes ethanol attractive as a fuel extender or substitute is that it is a renewable resource [19]. In general, it has been recognized that the addition of oxygenated blend components to diesel fuel will result in lower particulate emissions under many operating conditions. Since ethanol (35% of oxygen content) is widely available oxygenate with long history of use in gasoline blends it has also been considered as a potential oxygenate with diesel fuel. The particulate matter reduction appeared to be related to the amount of oxygen content in the fuel blends. Mixing up to 15% (vol) of ethanol with diesel is the easiest method to use ethanol in diesel engines [17]. But the ethanol solubility in diesel is one of the difficulties of using ethanol in them. Solubility can be increased by adding co-solvent or emulsifier to produce a homogeneous blend's suitable emulsifier diesel and alcohol. Such chemical structures can be found in biodiesel**.** Biodiesel is used because of their similarity to diesel oil, which allows the use of biodiesel-diesel blends in any proportion. The biodiesel allows the addition of more ethanol-blended fuel, keeps the mixture stable and improves the tolerance of the blend to water, so that it can be stored for a long period. The large Cetane number of the biodiesel offsets the reduction of Cetane number from addition of ethanol to diesel, thus improving the engine ignition. The addition of biodiesel increases the oxygen level in the blend. Also biodiesel have lubricating properties that benefit the engine. Biodiesel, ethanol and diesel blends are new renewable alternative energy sources with environmentally friendly characteristics comparable to fossil fuels. Recent research has shown that the use of diesel-ethanol-biodiesel blends can substantially reduce emissions of CO, total hydrocarbons (HC), and particulate matters (PM) [1]. In an experimental study, carried out by G. Venkata Subbaiah et al (2010).Investigated experimentally the performance and exhaust emission characteristics of a direct injection (DI) diesel engine when fuelled with conventional diesel fuel, rice bran oil biodiesel, a blend of diesel and rice bran oil biodiesel and three blends of diesel-biodiesel-ethanol over the entire range of load on the engine. The experimental results showed that the highest brake thermal efficiency was observed with 15% ethanol in diesel-biodiesel-ethanol blends. The exhaust gas temperature and the sound intensity from the engine reduced with the increase of ethanol percentage in diesel-biodiesel-ethanol blends. The Carbon monoxide and smoke emissions reduced significantly with higher percentage of ethanol in diesel-biodiesel-ethanol blends. The unused oxygen with 5% ethanol in diesel-biodiesel-ethanol blend was lower than that of diesel fuel. The Hydrocarbons, Oxides of nitrogen and carbon dioxide emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends but the hydrocarbon emissions were still lower than that of diesel fuel [1].

V. Arul Mozhi Selvan et al (2009).Investigated experimentally the effects of cerium oxide nanoparticles addition in diesel and diesel-biodiesel- ethanol blends on the performance and emission characteristics of a CI engine. The results of the Experiments revealed that, the Brake Specific Fuel Consumption (BSFC) is higher for the diesel-biodiesel-ethanol blends than neat diesel at all the brake mean effective pressures. The brake thermal efficiency of neat diesel is higher than diesel-biodiesel-ethanol blends at all the loads and a small improvement is observed with the addition of cerium oxide with diesel ethanol blends; the peak pressure increases with the addition of cerium oxide and ethanol in diesel. The heat release rate increases with the addition of ethanol in diesel. The addition of cerium oxide accelerates earlier initiation of combustion and cause for the lower heat release rate when comparing with diesel-biodiesel-ethanol blend; the carbon monoxide (CO) emission decreases with the use of cerium oxide nanoparticles in diesel-biodiesel-ethanol blends and neat diesel. The addition of cerium oxide decreases the hydrocarbons (HC) emission when comparing with neat diesel and diesel-biodiesel-ethanol blends .The oxides of nitrogen (NO_x) emission is lower for the neat diesel than the oxygenated blends. The smoke decreases with the fuel blends with oxygenated additive. The addition of cerium oxide nanoparticles in neat diesel and diesel-biodiesel-ethanol blends decreases the smoke further [20].

M. Al - Hassan a et al (2012).Investigated experimentally the Solubility of a diesel-ethanol blend and on the Performance of a diesel engine fueled with diesel-biodiesel ethanol blends. The engine was operated with DBE blends having 5, 10, 15 and 20% ethanol with fixed 10% biodiesel on a volume basis, as well as on diesel fuel alone at constant load and at engine speed ranges from 800 to 1600 rpm for each run. The experimental results of the phase stability revealed that the DE blends is not stable and separated after 2, 5, 24 and 80 hours, for 20%, 15%, 10% and 5% ethanol concentrations, respectively. Whereas for DBE blends the separation time is longer than of the first system and reached 1, 3 and 9 days for 20%, 15%, 10% ethanol concentrations, respectively. The blend of DBE5 was of the best stability with very little separation. The experimental results of the engine performance indicated that the equivalence air-fuel ratio and the brake specific fuel consumption for the fuel blends are higher than that of diesel fuel and increases with the increase of the ethanol concentration in the blends. The brake power for the fuel blend of 5% ethanol concentration is close to that of diesel fuel and decreases with higher concentrations. The brake thermal efficiency was increased with fuel blends of 5 and 10% ethanol concentration and decreases with a higher ethanol proportion in the blends [21].

Shyam Pandey et al (2012).Investigated the physical stability of ethanol-diesel blends using Jatropha oil methyl esters and enerdiesel emulsifier as additives, subsequently analysis of physic-chemical properties. Furthermore, experimental tests were carried out to study the performance and emissions of Direct Injection (DI) engine fuelled with the various blends compared with those fuelled by diesel. The blends used for this study were B0D95E5, B0D90E10, B15D70E15 and B20D60E20. It is revealed from the observations that the test fuel blends are physically and thermally stable up to 17 days at room temperature. The physic-chemical properties of the all blends show good resemblance with that of diesel except the flash point. The performance results show that B0D95E5 fuel blend has maximum brake thermal efficiency and minimum Brake Specific Fuel Consumption at higher loads. Similarly, the overall emission characteristics are found to be best for the case of B0D90E10 over the entire range of engine operations [22].

Jincheng Huang et al (2009). Investigated experimentally the engine performance and exhaust emissions of diesel engine fuelled with ethanol–diesel blends, the test results show that it is feasible and applicable for the blends with n-butanol to replace pure diesel as the fuel for diesel engine; the thermal efficiencies of the engine fuelled by the blends were comparable with that fuelled by diesel, with some increase of fuel consumptions, which is due to the lower heating value of ethanol. The characteristics of the emissions were also studied. Fuelled by the blends, it is found that the smoke emissions from the engine fuelled by the blends were all lower than that fuelled by diesel; the carbon monoxide (CO) were reduced when the engine ran at and above its half loads, but were increased at low loads and low speed; the hydrocarbon (HC) emissions were all higher except for the top loads at high speed; the nitrogen oxides (NO_x) emissions were different for different speeds, loads and blends [23].

E. Mensah et al (2013).Investigated the engine performance using biodiesel blends from waste palm kernel oil (WPKO) and mixed waste vegetable oils (WVOs), and diesel fuel which were compared with diesel fuel in a four stroke single cylinder diesel engine. The diesel blends with (WPKO) 5%, 10% and 20% by volume also the diesel mixed with (WVOs) 5%, 10% and 20% by volume. The results indicated that BM10 (90% diesel + 10% mixed WVO biodiesel) and BM5 (95% diesel + 5% mixed WVO biodiesel) blends showed the least sulphur content compared for diesel fuel. For cetane index, both biodiesel blends of WPKO and mixed WVOs gave higher values than diesel fuel. In terms of engine performance, BPK10 (90% diesel+10% waste palm kernel oil) and BPK20 (80% diesel+20% waste palm kernel oil) indicated higher brake power, higher thermal efficiency but lower exhaust temperatures at all engine loading conditions. Brake specific fuel consumption was lower in most cases for BPK10 and BPK20 blends than the rest of the other blends. Therefore, it can be concluded that 10% and 20% blends of waste palm kernel oils (BPK10 and BPK20) can be used as an alternative fuel in diesel engine without any significant modification of the engine and that the viscosity of BPK20 was similar to that of diesel fuel [24].

R. Senthil Kumar et al (2013).Studied the performance and emission characteristics of the diesel engine using ethanol diesel blend with varying inlet air temperature on a single cylinder, four stroke, and DI diesel engine. Experimental applications were carried out with the blends containing 10%, 15%, 20%, 25%, 30% Ethanol and preheating the inlet air to 40ºC, 50ºC and 60ºC. Experimental results showed that The Total fuel consumption and SFC of ethanol diesel blended fuels increased for the reason that the low heating value of ethanol is about 2/3 of that of diesel, and it is increasing with increasing concentration of ethanol in blend. The Brake thermal efficiency of ethanol diesel blend is lower without pre heating condition, but at 40ºC and 50ºC inlet air condition, for 10% ethanol diesel blends gives the much better BTE compare to the neat diesel fuel. On emission characteristics CO and HC emission is increasing. Addition of ethanol will lead to complete combustion so that HC and CO emission should reduce, but here the introduction of ethanol in diesel fuel, HC emission increased at various load condition. CO and HC emission is higher for the pre heated condition compare to without pre heating condition. The NO_X emissions were reduces; smoke is increased as load increases. Without pre heating condition produces less smoke compare with the Pre heating conditions for ethanol diesel blends [25].

Dr. Hiregoudar Yerrennagoudaru et al (2014). Investigated experimentally the engine Performance and emission of C I engine using diesel and ethanol blended with Jatropha Oil in four stroke twin cylinder diesel engine. Performance tests were conducted to study Brake Thermal Efficiency (BTHE) and Specific Fuel Consumption (SFC). Exhaust emissions were also investigated for Carbon monoxide (CO), Particulate matter and UN burnt hydro carbon (HC). Experimental results showed that the (SFC) of Bio fuel (90%jatropa oil+10%ethanol) is more than the diesel. The (BTHE) as load increases is also increases for diesel as well as Bio fuel. Particulate Matter emission increases with increase in load. Diesel has higher Particulate Matter level when compared to Bio fuel. When using Bio fuel as fuel in diesel engine the HC and CO is lower than the diesel fuel [26]. Ajith K et al (2013).

Investigated experimentally the engine performance characteristics of Single cylinder four stroke diesel engines with ethanol and diesel blends, and diesel blended with ethanol 5%, 10%, 15%, 20%, 25% and 30% by volume. Experimental results showed that the brake specific fuel consumption is decreased with the blends and the brake thermal efficiency increased with all blends when compared to the conventional diesel fuel [27]. Prommes Kwanchareon et al. [2006] studied solubility of a diesel-biodiesel- ethanol blend, its properties and its emission characteristics from diesel engine. They found that the blended fuel properties were close to the standard diesel except flash point. It was also found that CO and HC emissions reduced significantly at high engine load, whereas NO_x emissions increased compared to those of diesel [28]. The above studies showed that the diesel-biodiesel-ethanol blends reduce CO, HC, PM, Smoke emissions and increase NO_x emissions compared with the diesel fuel.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction:

Fuel properties experiments were carried out in Central Laboratory for Science, Environment and Soil Researches (CLSER), Ministry of Electricity and Dams (Sudanese Company for Electricity Distribution). Laboratory tests were carried out using ASTM tests standards to determine the following properties; API gravity, density, cloud and flash point, kinematic viscosity and calorific value. While engine performance and emissions tests were carried out at a diesel engine in Sudan University of Science and Technology, Faculty of Engineering internal combustion engine workshop.

3.2 Materials:

Diesel, biodiesel and ethanol were used as the materials to form the fuel blends. Ethanol was purchased from Kenana Sugar Company and was analyzed and found to have a purity of 99.35%**.** Detailed description of Kenana ethanol is presented in the table 3.1. Biodiesel fuel was produced from jatropha oil by transesterification process using methanol as the alcohol and sodium hydroxide (NaOH) as the catalyst. The procedures as follows: jatropha oil was heated to 110 °C to evaporate possibly existed water in the oil and then filtered. Then the oil was poured in to (preheated to 70 °C) vessel placed on, a temperature-controlled, hotplate magnetic stirrer. With the oil stirred and heated to a temperature of 50 °C, a solution of methanol and sodium hydroxide was added into the vessel taking this moment as time zero of the reaction. After a 30 minutes reaction time, the mixture was transfer red to a separating flask and allowed to settle for overnight to produce two distinct liquid phases (i.e. methyl ester-upper layer and glycerin - lower layer). After separation of the two phases by sedimentation, the methyl esters were purified by distilling the residual methanol at 80 °C. The residual catalyst was extracted by the successive washing of the methyl ester with warm distilled water at a temperature of 50°C until the wash water becomes clear, Then the water present was removed by heating at 110 °C and the final product, biodiesel, would be obtained as a clear, light yellow liquid. The properties of biodiesel are presented in table 3.2.

Table 3.1: Properties of kenana Ethanol alcohol

Property	**Value**
Density @ 15^0C	0.79287 g/ cm^3
Kinematic Viscosity	1.19 mm^2/s at 40°C
Appearance	Clear, bright, free of suspended or settle material
Sulfur	10 mg/kg, max
Total acidity (As Acetic Acid)	0.007 % WT, max
Water content, V/V	0.3 % WT, max

Source: Copyright 2013 © Kenana Sugar Company.

Table 3.2: Biodiesel Fuel properties

NO	Property	Value
1	Density @ 15°C	0.8841 g/ cm^3
2	Viscosity @40°C	4.729 mm^2/sec
3	Flash point	154.8°C
4	Cloud point	12°C
5	Calorific Value	44.0714 MJ/kg

3.3 Equipment of Blends Properties Tests:

The samples properties were inspected at Central laboratory for Science, Environmental and Soil Research (Sudanese Company for Electricity Distribution/ Ministry Of Electricity And Dams).

3.3.1 Viscometer Device Test:

The viscometer is used to determine the viscosity of diesel, biodiesel and ethanol blends. Kinematic viscosity is a measure of the resistance to flow of a fluid under gravity, it is important to note that viscosity critically depends on temperature and numerical value of viscosity has no significance or meaning unless the temperature of the test is specified. So in determining any viscosity of fuel the temperature during the test must always be stated. ASTM D445 is a standard test procedure for determining the kinematic viscosity of liquids. It provides a measure of the time required for a volume of liquid to flow under gravity through a calibrated glass capillary tube. The kinematic viscosity is then equal to the product of this time and a calibration constant for the tube. (See fig 3.1).

3.3.2 Density Meter Device:

The density meter was used to measure the density of blends at central laboratory. The test method covers the determination of the density or relative density of crude oils, petroleum distillates and viscous oils that can be handled in a normal fashion as liquids at test temperatures between 15 and 35°C (See fig 3.2).

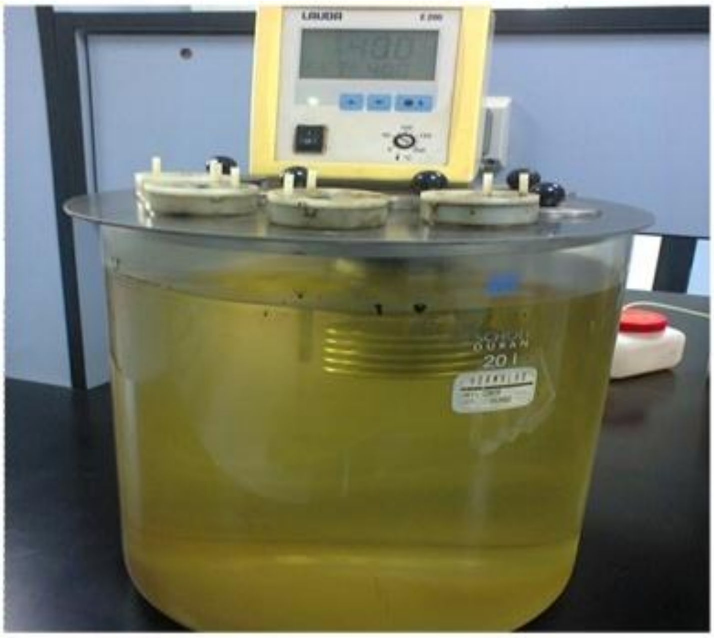

Figure 3.1: Viscometer Device Test

Figure 3.2: Density Meter Device Test

3.3.3 Cloud Point Device Test:

For petroleum products and biodiesel fuels, cloud point of a petroleum product is an index of the lowest temperature of their utility for certain applications. This test method covers only petroleum products and biodiesel fuels that are transparent in layers 40 mm in thickness, and with a cloud point below 49°C.

Figure 3.3: Cloud Point Test Tube Device

3.3.4 Flash Point Device Test:

The flash point of a volatile material is the lowest temperature at which it can vaporize to form an ignitable mixture in air. Measuring a flash point requires an ignition source. At the flash point, the vapor may cease to burn when the source of ignition is removed. The flash point of the blends was measured by Pensky-Martens Flash Point.

Figure 3.4: Flash Point Device

3.4 Tests Equipment:

3.4.1 Gas Analyzer Unit (Eco- Line Device):

EcoLine 6000 Portable industrial flue gas analyzer was used to measure the concentration of NO, NOx, SO2, CO and the smoke opacity was measured using Smoke meter. EcoLine 6000 consists of two functional parts: the gas analysis unit and the remote control unit (RCU).Communication between the two devices are via standard RS232. All data collected by the analysis unit can be sent to the RCU as to be viewed, stored and printed. Gas analysis unit is a true, portable, flue gas laboratory. It includes: aspiration pump, filters, condensate drain with peristaltic pump, cells and electronics. Gas analysis unit can be positioned beside of the stack sampling point and can works, after programming, as a standalone unit (black-box).

The operator can survey the overall inspection at distance by using the Remote Control Unit. RCU is used to send operative instructions to the unit, to display and memory store the analysis data, to printout data, and to transfer data to a Personal Computer. Flue gas sampling probes with different length shape and max. Operating temperature (800°C and 1000°C) is available to match the requirement of different applications Figure 3.5.

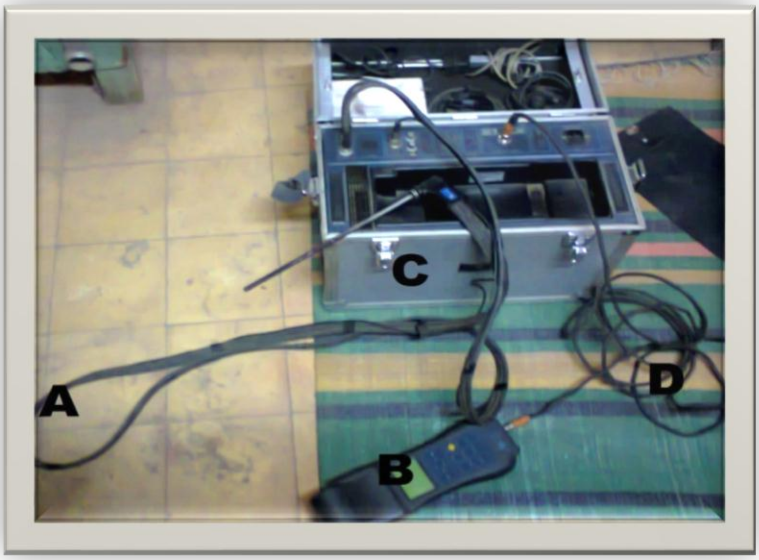

Figure 3.5: EcoLine Device: [(A) Gas sampling probe (B) Remote control unit (RCU) (C) Gas analysis unit (D) Data transfer cable.]

3.4.2 Electronic Display Board Device:

An electronic display device includes a housing having a sliding slot and engine speed recorder unit, load and discharge load engine recorder unit.

Figure 3.6: Electronic Display Board.

3.4.3 Engine Experimental Test:

Diesel engine type Mitsubishi, model 4D56 JG3553, Turbocharger TD04, Compression ratio 21:1, it was coupled with dynamometer.

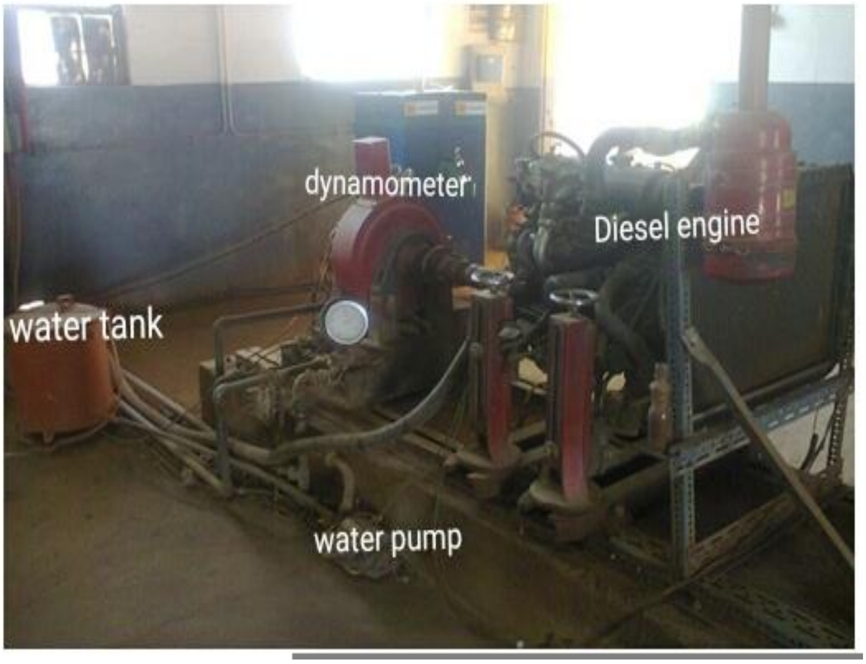

Figure 3.7: Diesel Engine Test

3.4.4 Test Engine Specifications:

The test engine Mitsubishi cyclone motor model 4D56_JG3553.The 4D5 engine is a range of four-cylinder belt-driven overhead camshaft diesel engines. However, production of the 4D5 (4D56) continued throughout the 1990s as a lower-cost option than the more modern power plants. Until now it is still in production, but made into a modern power plant by putting a common rail direct injection fuel system into the engine. The specification for the engine is shows in table 3.3.

Table 3.3: Engine Specifications

Engine name	**Mitsubishi cyclone motor Intercooled Turbo (TD04 water cooled Turbo)**
Model	4D56, JG3553
Displacement	2.5 L (2,476 cc)
Bore	91.1 mm
Stroke	95.0 mm
Fuel type	Diesel
Power	78 kW (104 hp) at 4,300 rpm
Torque	240 N.m (177 lb·ft) at 2,000 rpm
Engine type	Inline 4-cylinder
Rocker arm	Roller Follower type
Fuel system	Distribution type jet pump (indirect injection)
Combustion chamber	Swirl type
Bore x Stroke	91.1mm x 95mm
Compression ratio	21:1
Lubrication System	Pressure feed, full flow filtration
Intercooler Type	Aluminum Air to Air, Top-mounted
Turbocharger	Mitsubishi TD04-09B

3.5 Methods:

3.5.1 Blends Preparation:

The blends samples are prepared by test tube that capacity one litter at internal combustion engines workshop at Sudan University. The first sample of blend composed 850 mL litters diesel + 100 mL litters biodiesel +50 mL ethanol (D85%B10%E5%), second sample 800 mL litters diesel + 100 mL litters biodiesel +100 mL litters ethanol (D80%B10%E10%) and third sample 750 mL litters diesel + 100 mL litters biodiesel +150 Ml litters ethanol (D75%B10%E15%). . In this experiment, four types of fuel have been individually tested on the test engine. One of them was pure diesel or B0 E0 and it had been experienced for comparison purpose.

Table 3.4 presents the tested fuel blends.

No	Fuel	Symbol
1	100% diesel (reference fuel)	Diesel(B0E0)
2	85% diesel + 10% biodiesel+5% ethanol	D85B10E5
3	80% diesel+ 10% biodiesel+10% ethanol	D80B10E10
4	75% diesel + 10% biodiesel+15% ethanol	D75B10E15

3.5.2 Test Procedure:

The experiments were carried out using diesel, biodiesel and Kenana ethanol blends.4-cylinder compression ignition diesel engine with specifications as shown in table (3.3). The experiment procedure were listed below

1. The amount of fuel level was checked in outer tank where the amount of the sample was found to be one litters, check engine cooling water, check engine lubrication and check the dynamometer water.
2. The data stored in the RCU was removed

3. The engine was operated without load. The speed was gradually increased to 1000 rpm where the weight of fuel sample was recorded in kg. Another weight for the sample was recorded 30 seconds later, for purpose of knowing the fuel consumption in 30 seconds. The Gas sampling probe was fixed to the outlet of the engines exhaust for 30 seconds. The data then was stored in the memory of RCU. The components of the exhaust fumes (NO, NO_X, CO, SO_2) in 30 seconds were recorded.
4. Step no.3 was then repeated at speeds 1000, 1500, 2000 rpm for three fuel samples. (D85%B10%E5%, D80%B10%E10%and D75%B10%E15%).
5. The engine was loaded at the speed of 1000 rpm till the engine was about to stop. Fuel consumption during 30 seconds was recorded together with the data of the components of the exhaust fumes in the 30 seconds. The torque on the engine was also recorded.
6. Step (5) was repeated at the speed 1500and 2000 rpm for the three fuel samples.

CHAPTER FOUR

RESULTS AND DISCUSSION

Results for engine performance parameters such as brake power output and brake specific fuel consumption and exhaust emission parameters such as carbon monoxides, carbon dioxide, oxides of nitrogen and sulfur dioxide with different engine speeds for (DBE) blends and pure diesel fuel are presented and discussed below:

4.1 Fuel Properties (Diesel, Biodiesel and Ethanol Blend):

Standard methods (ASTM Test) were used to determine the properties of the diesel, biodiesel and ethanol blends at the Central laboratory for Science, Environment and Soil Research (Sudanese Company for Electricity Distribution/Ministry of Electricity and Dams). Summary of chemical and physical properties of the blends (B10%E5%, B10%E10%, B10%E15%) were provided in Tables 4.1.

Table 4.1 Chemical and Physical Properties of the Tested Fuels:

Properties	Diesel	Biodiesel	Ethanol	DBE5	DBE10	DBE15
Density at 15 °C (Kg/m3)	829	884.1	792.87	825.2	823.1	820.7
Kinematic Viscosity @ 40°C(mm2/s)	2.480	4.729	1.190	2.483	2.560	2.830
Flash Point (°C)	40	154.8	14.3	47	56	73
Cloud Point (°C)	-34	12	-	7	8	6
Colorific Value (MJ/kg)	46.000	44.0714	27.400	45.58	44.83	44.10

4.2 Engine Performance:

Engine performance test results of diesel, biodiesel and ethanol blends were presented on Appendix A.

4.2.1 Fuel Consumption Rate without Load (Kg/hr):

The first parameter for investigating the engine performance when operating without load is the Specific fuel consumption. The variation of specific fuel consumption for various fuels (diesel, biodiesel and ethanol blend) with the rotating speed of the engine is presented in Figure 4.1 and table A.3 (Appendix A). The fuel consumption rate increased by 13.04%, 26.09% and 34.78% from that of the conventional diesel fuel with the addition of 5%, 10% and 15% of ethanol in the diesel-biodiesel-ethanol blend respectively. Ultimately increases in fuel consumption are mainly due to the reduction in calorific value of the blends with high contents of ethanol.

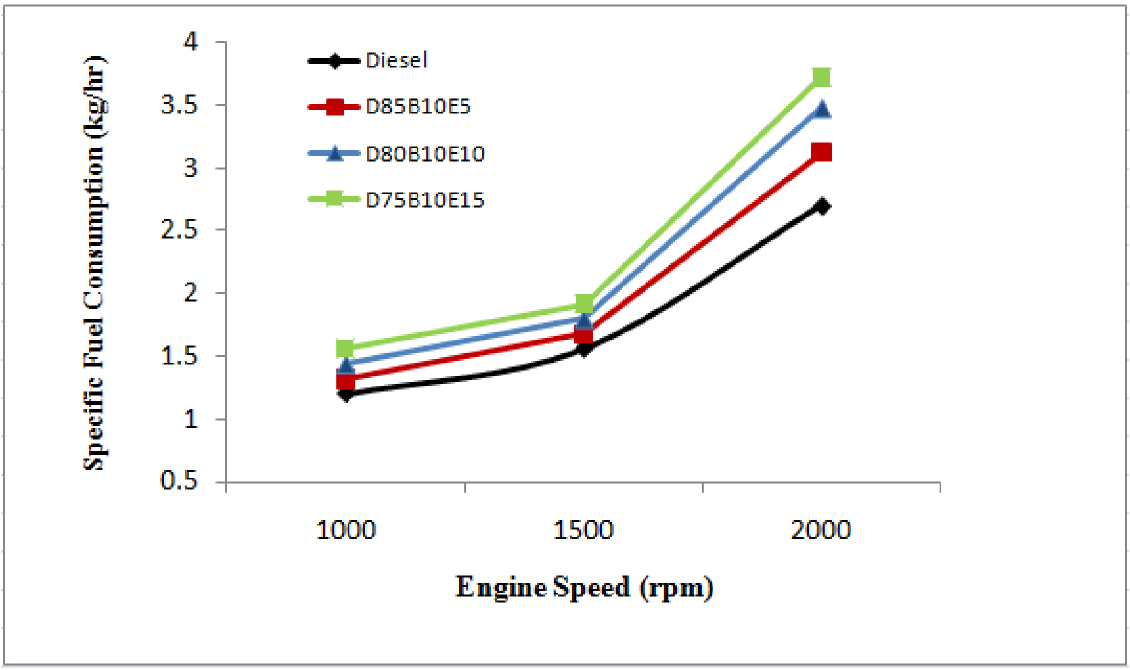

Figure 4.1: Variation of Fuel Consumption (without engine load).

4.2.2 Fuel Consumption Rate Under-Load (Kg/hr):

Figure 4.2 and table A.4 (Appendix A) represent engine fuel consumption for various diesels, biodiesel and ethanol blends with the angular speed. The engine fuels consumption under load increases with increasing of engine speed for all fuel tested. In addition, it can be seen that the SFC of fuel blends are higher than that of diesel fuel, and increased by 1.16%, 2.89% and 15.22% with the increasing of ethanol concentration in the diesel-biodiesel-ethanol blends for BE5,BE10 and BE15 respectively at all loading conditions of the engine. It is due to the lower heating values of biodiesel and ethanol compared with diesel fuel.

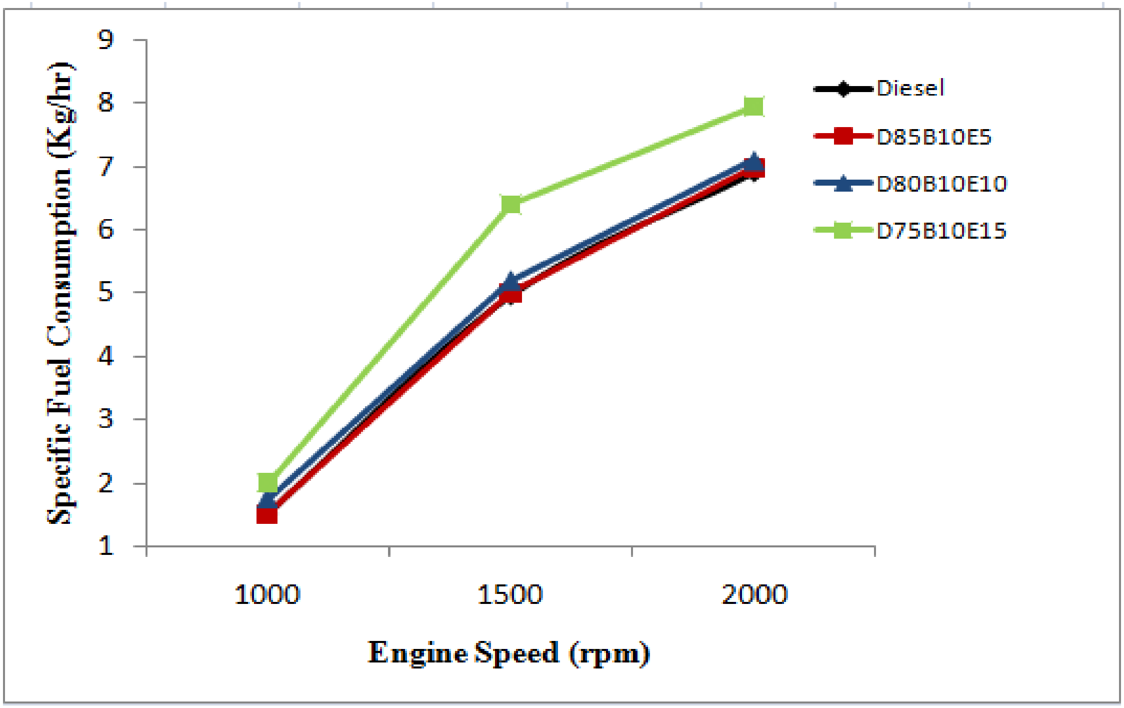

Figure 4.2: Variation of Fuel Consumption with Engine Loaded.

4.2.3 Brake Specific Fuel Consumption (g/kW hr):

Brake Specific Fuel Consumption (B.S.F.C.) is the fuel consumed by the engine per unit of power output or produced. Figure 4.3 and Table A-5 (Appendix A) represent engine brake specific fuel consumption variation of the tested fuels at various engine speeds. It is obvious that the BSFC increased by 2.87%, 14.54% and 37.35% with increasing of ethanol concentration in the diesel-biodiesel-ethanol blends for BE5, BE10 and BE15 respectively, comparing with diesel fuel at all loading conditions of the engine speeds. In addition, it can be seen that the BSFC of fuel blends are higher than that of diesel fuel and decreases when engine speed increase. The best specific fuel consumption was achieved for BE5 and BE10 compared to those values when utilized pure diesel in test engine.

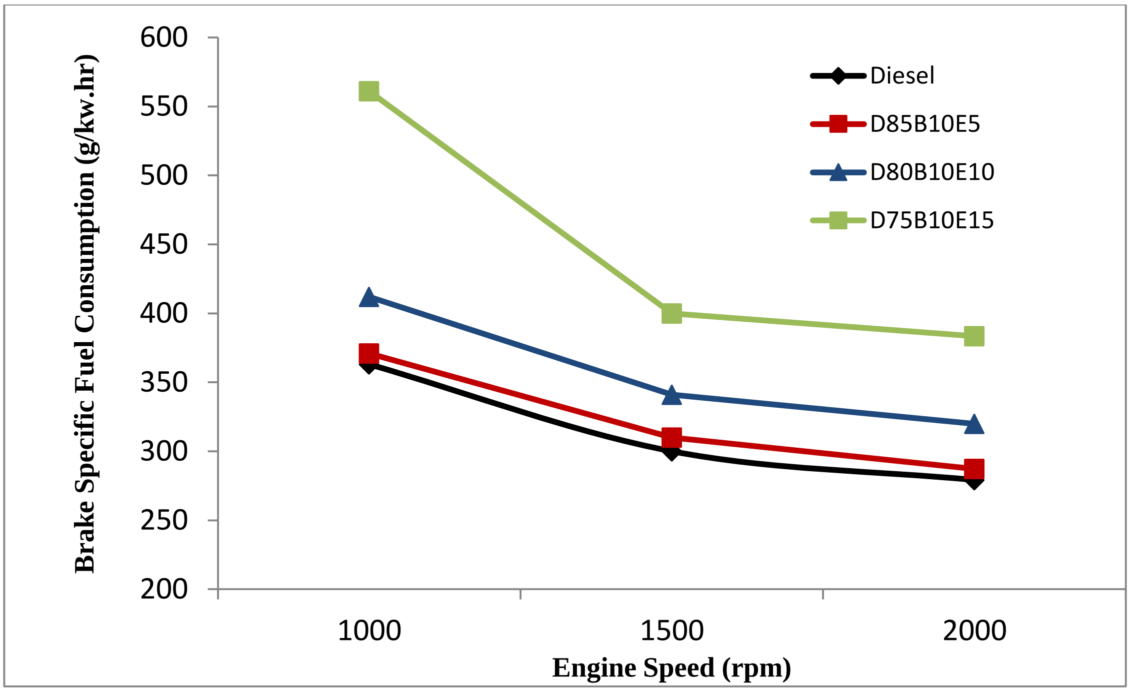

Figure 4.3: Variation of Brake Fuel Consumption with Engine Loaded.

4.2.4 Engine Torque:

Figure 4.4 and Table A-2 (Appendix A) represents engine torque curves comparing various diesel-biodiesel-ethanol blends. The engine torque output decreased slightly by 1.69%, 10.17%, and 16.10% with increasing ethanol percentage for BE5, BE10, and B E15, respectively, comparing with diesel fuel at 2000rpm.

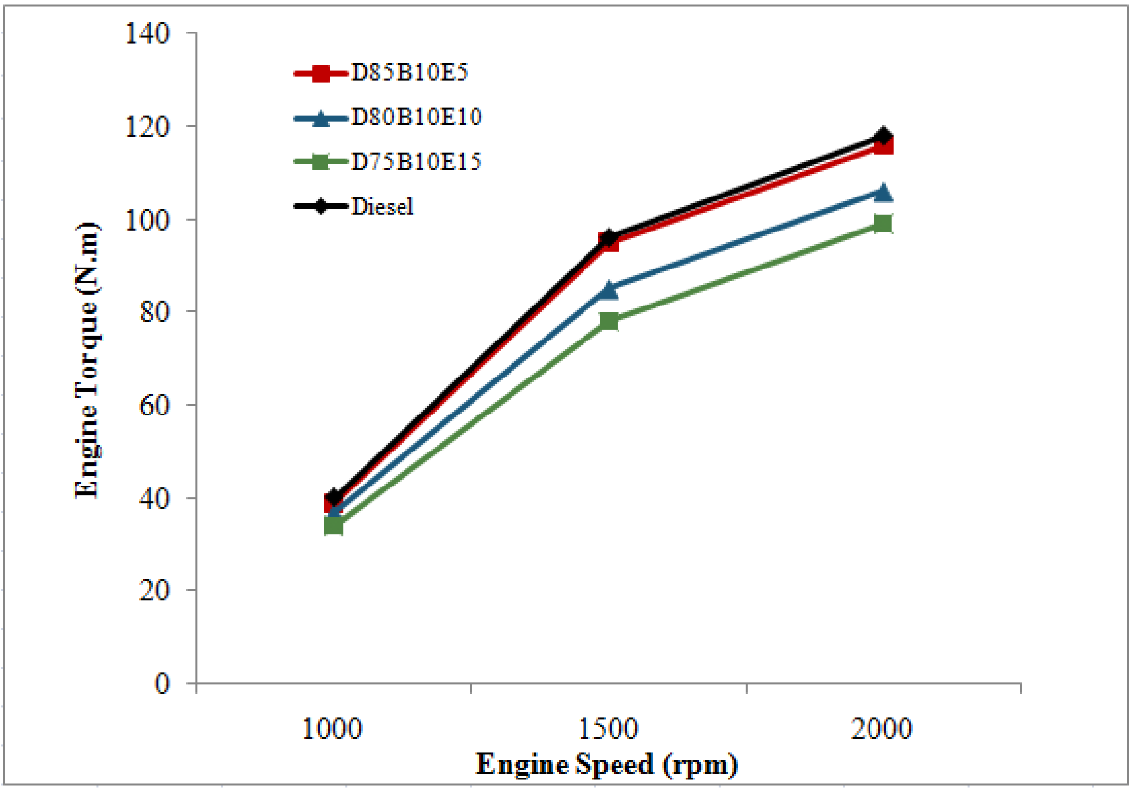

Figure 4.4: Variation of Engine Torque with Engine Speed.

4.2.5 Brake Power of Diesel, Biodiesel Ethanol Blends:

The variation of the engine brake power obtained with different fuel blends at various engine speeds is shown in Figure (4.5) and table A.1. As the figure shows the engine brake power increases with the increasing of the engine speed for all fuels. Comparing with diesel fuel, the blend including 5% ethanol (DBE5) gives the same engine power. However, as the ethanol concentration increases above 5% the engine power decreases.

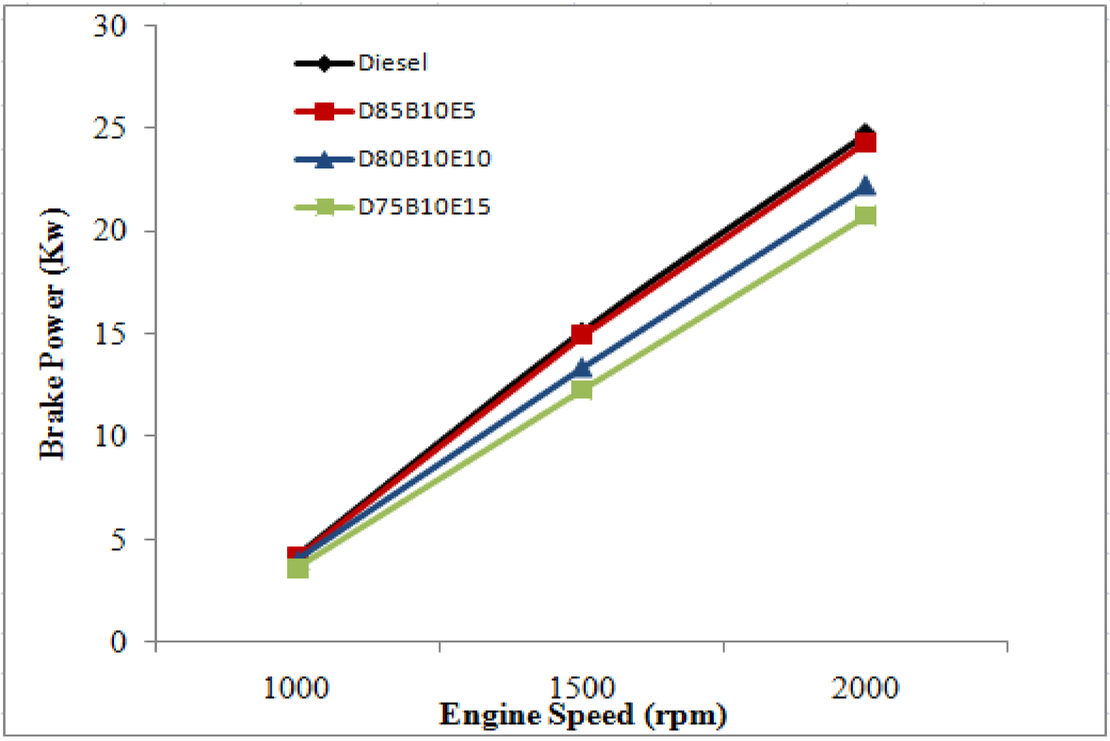

Figure 4.5: Variation of Brake Power with Engine Speed.

4.3 Analysis of Exhaust Gas Emissions:

Exhaust gases were analyzed for blend diesel, biodiesel and ethanol to identify the impact of the following cases:

1. The engine running without load
2. The engine running under load

4.3.1 Emissions of Engine Running without Load:

4.3.1.1 Carbon Monoxide Emissions (CO):

The relation between CO values and angular speed of engine is presented in Figure 4.5 and table A.6 (Appendix A) the CO emissions of these blends decreased significantly, when compared with those of conventional diesel at full load of the engine. This is due to the higher amount of oxygen with the ethanol and biodiesel addition, which will promote the further oxidation of CO during the engine exhaust process. The results showed that the CO emissions reduced with increase of ethanol percentage in the diesel-biodiesel-ethanol blend.

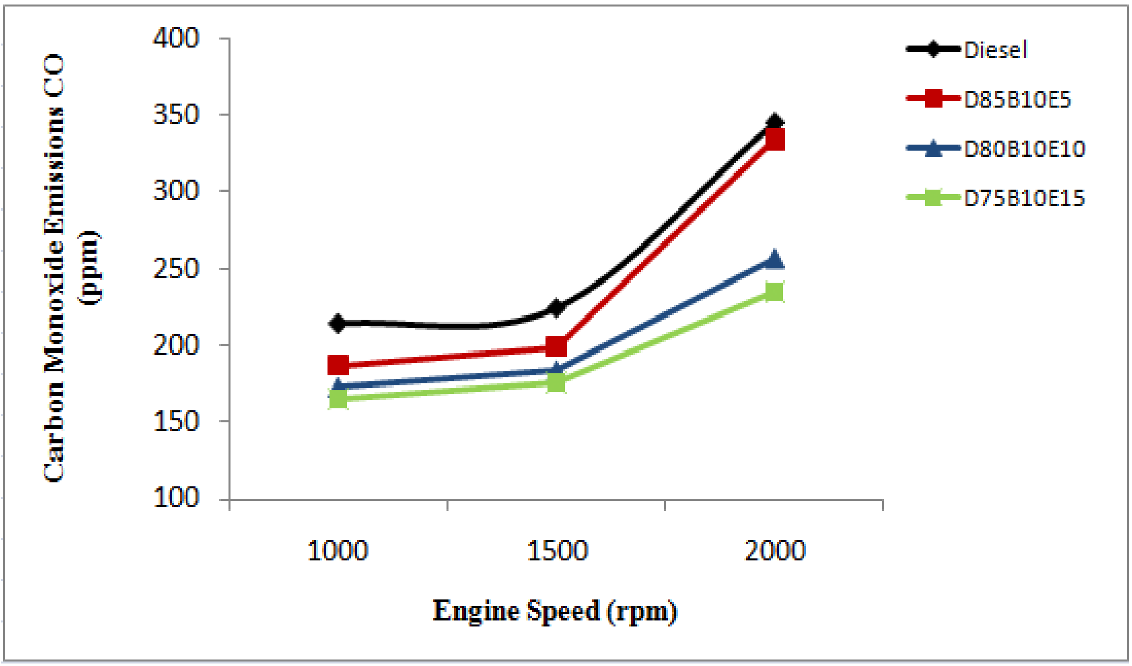

Figure 4.6: Variation of Carbon Monoxide Emission (CO) With Engine Speed.

4.3.2 Emissions of Engine Running Under Load:

4.3.2.1 Carbon Monoxide Emission (CO):

Carbon monoxide (CO) is produced from incomplete combustion whenever any carbon fuel, such as gas, oil, kerosene, or charcoal is burned. Figure 4.7 and Table A-6 (Appendix A) represent the Carbon Monoxide variation of the tested fuels at various engine speeds. The CO emissions slightly increased at low and medium speed and increased significantly at higher speed with all the tested fuels. The CO emissions of the diesel-biodiesel-ethanol blends were not much different from that of conventional diesel at low and medium loads as shown in the figure. However, the CO emissions of these blends decreased significantly, when compared with those of conventional diesel at full load of the engine. This is due to the higher amount of oxygen with the ethanol and biodiesel addition, which will promote the further oxidation of CO during the engine exhaust process. The results showed that the CO emissions reduced with increase of ethanol percentage in the diesel-biodiesel-ethanol blend. The CO emissions reduced by 21.11%, 25.84% and 37.94% than the conventional diesel with the addition of 5%, 10% and 15% of ethanol in diesel-biodiesel-ethanol blends. Among the diesel-biodiesel-ethanol blends the blend of 75%diesel, 10%biodiesel and 15% ethanol produced the lowest amount of CO emissions at full load of the engine.

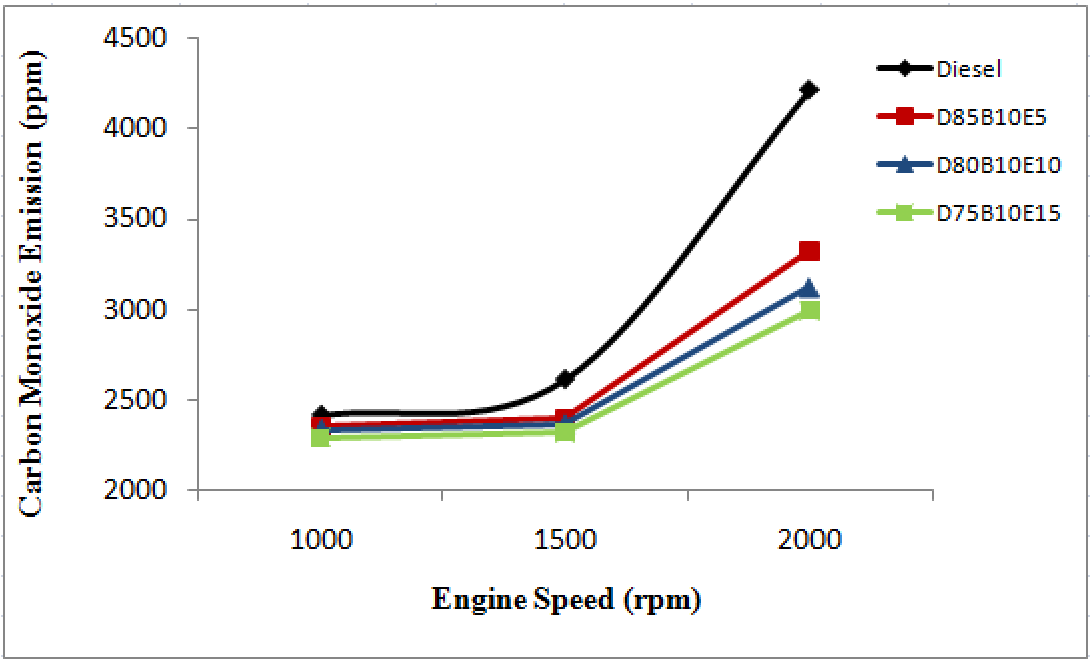

Figure 4.7: Variation of Carbon Monoxide Emission (CO) With Engine Speed.

4.3.2.2 Sulfur Dioxide Emissions:

Most previous studies that tested fuel blend diesel, biodiesel and ethanol did not mention sulfur dioxide as one of the combustion products. Table 4.8 shows the variation of the sulfur dioxide emission with engine speed. Noted here the amount of SO2 is higher than diesel at low loading due to incomplete combustion resulting from lower cylinder temperature but SO2 at higher load is less than for the diesel fuel.

Table A.7: Sulfur Dioxide Emissions (SO2) Of Diesel, Biodiesel and Ethanol Blends Under-Load.

Speed (rpm)	**Sulfur Dioxide Emissions (ppm)**			
	Diesel	Blend.1 B10%E5%	Blend.2 B10%E10%	Blend.3 B10%E15%
1000	117	377	414	415
1500	568	394	400	389
2000	874	413	448	382

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion:

The effects of addition of ethanol to diesel fuel with a fixed amount of biodiesel, on the engine performance and emission characteristics of the four cylinder light duty diesel engine, have been investigated and compared with the baseline diesel fuel. The main effects can be detailed as follows:

1. The addition of ethanol to diesel fuel with a fixed amount of biodiesel changes the physicochemical parameters, properties such as the density, viscosity, flash point, cloud point and calorific value which have been successfully tested and determined.
2. The density of a fuel blend decreases with increased ethanol concentration in the blend.
3. The viscosity, flash point and cloud point of fuel blend increases with increased ethanol content in the blend.
4. The calorific value of fuel blend slightly decreases with increase of concentration of ethanol in the blend.
5. Engine performance and emission characteristics of conventional diesel and diesel-biodiesel-ethanol blends were investigated and successfully tested on 4-stroke, 4-cylinders and ID diesel engine.
6. The brake power and engine torque of a fuel blend of DBE5 are very close to that of diesel fuel, but for higher ethanol concentration they are slightly lower compared with diesel fuel.
7. The brake specific fuel consumptions of the engine using blended fuels are higher compared with pure diesel fuel. The higher the ethanol concentration in, the higher is the brake specific fuel consumption given.
8. The addition of ethanol to diesel fuel, together with a fixed amount of biodiesel (B10%), helps in lowering the carbon monoxide emissions from

the diesel engines. Minimum CO emission resulted from the use of the blend B10E15 which is well below that of the diesel fuel, but sulfur dioxide (SO_2) emission increased.

9. The sulfur dioxide (SO_2) emission decreased with an increase in ethanol percentage in the blend.

As the brake power and carbon monoxide can be reduced by the increase in ethanol percentage in the diesel-biodiesel-ethanol blend, the biodiesel can be used as an aid to mix higher percentages of ethanol in diesel-biodiesel-ethanol blends for a diesel engine enhanced performance.

5.2 Recommendations:

Based on the results obtained in this study work I would like to suggest:

1. Upgrade & intensify the research facilities necessary for more deep research to speed up commercialization of ethanol-diesel-biodiesel fuel blends use.
2. Comprehensive and extensive testing facilities for engine performance and emissions from diesel-biodiesel-ethanol blends to produce environment friendly fuels.

References

1. K. Raja Gopal, Syed Altaf Hussain, B. Durga Prasad & K. Tirupathi Reddy, Venkata Subbaiah, 2010. Rice bran oil biodiesel as an additive in diesel – ethanol blends for diesel engine, IJRRAS, 03.

2. Yanuandri Putrasaria, Arifin Nura &Aam Muharama, 2012. Performance and emission characteristic on a two cylinder DI diesel engine fuelled with ethanol-diesel blends, International Conference on Sustainable Energy Engineering and Application, 32.

3. Goering, C. E., and Schrader, 1988. *Effects of ethanol proof on engine performance*, Transactions of the ASAE , 31

4. Hanbey Hazar, 2010. *Cotton methyl ester usage in a diesel engine equipped with insulated combustion chamber*, 134-140, 87.

5. S. Gomasta, and S.K, 2012. An Experimental Investigation Ethanol Blended Diesel Fuel on Engine Performance and Emission of a Diesel Engine. International Journal on Emerging Technologies , (1): 74-79, 3.

6. Clean Alternative Fuels – Biodiesel, 2002. Environmental Protection Agency Fact Sheet, Document No. EPA420-F-00-032.

7. Granite State Clean Cities Coalition – Fuel Types, Granite State Clean Cities Coalition Web Sitehttp://www.granitestatecleancities.org/fueltypes.htm#biodiesel, Accessed on September 19, 2003.

8. Did You Know: Use of Biodiesel Fuel on International School Bus / International Truck and Engine Corporation Web Site, www.internationaldelivers.com/assets, Accessed on October, 2003.

9. Standards and Warranties/ National Biodiesel Board Web Page, http://www.biodiesel.org/resources/fuelfactsheets/standards_and_warranties.shtm, Accessed on November 3, 2003.

10. Murphy, Michael J., H. Norman Ketola and Phani K. Raj,1995. Summary and Assessment of the Safety, Health, Environmental and System Risks of

Alternative Fuels, U.S. Department of Transportation, Federal Transit Administration, Report No. FTA-MA-90-7007-95-1.

11. Production and Testing of Ethyl and Methyl Esters," University of Idaho, December 1994. Accessed at http://www.biodiesel.org/resources/reportsdatabase/reports/gen/19941201_gen-005.pdf on October 30, 2003.
12. Balat, M. & Balat, H. recent trends in global production and utilization of bio-ethanol fuel. Applied Energy, 86, 2273-2282.2009.
13. İsmet ÇELİKTEN, 2011. The Effect of Biodiesel, Ethanol and Diesel Fuel Blends on The Performance and Exhaust Emissions in A DI Diesel Engine / Gazi University Journal of Science/ 24(2):341-346.
14. JAAFER MUSA,2013. Fuel properties, Engine performance and Exhaust Emissions Ethanol-Gasoline Blends/ Department of agricultural and biological engineering, University of Khartoum.
15. R.A. Beg, M. R. Sarker, and M. R. Pervez, 2010 . Production of diesel fuel fuel from used engine oil. International Journal of Mechanical & Mechatronis Engineering IJMME-IJENS Vol:10 No:02.
16. Sara McAllister l Jyh-Yuan Chen A. Carlos Fernandez-Pello / Fundamentals of Combustion Processes/ For other volumes in this series, go to http://www.springer.com/series/1161.
17. T. Krishnaswamy and N. S. V. Moorthi, 2012. Performance Evaluation of Diesel Engine with oxygenated bio-Fuel blends, ARPN Journal of Engineering and Applied Sciences, ISSN 1819-6608.18.
18. Khalid Abdel rahim ,(2013) .performance and emission characteristics of diesel engine using ethanol diesel blend / Department of agricultural and biological engineering Vol:11 No:04.
19. A. C. Hansen, Q. Zhang and P. W.L. Lyne, 2005. Ethanol–diesel fuel blends—a review, Bioresource Technology, Vol. 96, pp 277–285.
20. V. Arul Mozhi Selvan, R. B. Anand And M,2009. Udayakumar Effects Of Cerium Oxide Nanoparticle Addition In Diesel And Diesel-Biodiesel-Ethanol

Blends On The Performance And Emission Characteristics Of A Ci Engine/ Arpn Journal Of Engineering And Applied Sciences/Vol.4,No.7.

21. M. Al-Hassana,* , H. Mujafeta and M. Al-Shannagb, 2012. An Experimental Study on the Solubility of a Diesel-Ethanol Blend and on the Performance of a Diesel Engine Fueled with Diesel-Biodiesel - Ethanol Blends. Jordan Journal of mechanical and Industrial Engineering, volume 6, Number 2.
22. Shyam Pandey, Amit Sharma, P. K. Sahoo,2012. Experimental investigation on the performance and emission characteristics of diesel engine fuelled with ethanol, diesel and jatropha based biodiesel blends. International Journal of Advances in Engineering & Technology, ISSN: 2231-1963.
23. Jincheng Huang a, Yaodong Wanga,b,*, Shuangding Li a, Anthony P. Roskilly b, Hongdong Yu a, Huifen Li a, 2009. Experimental investigation on the performance and emissions of a diesel engine fuelled with ethanol–diesel blends. journal homepage, Applied Thermal Engineering 29.2484-2490.
24. E. Mensah, G.Y. Obeng, E. Antwi,2013. Engine Performance Evaluation Using Biodiesel Blends From Waste Palm Kernel Oil, Mixed WVOs And Diesel Fuel. The International Journal Of Engineering And Science (IJES) ||Volume||2 ||Issue|| 9 ||Pages|| 19-25|| ISSN(e): 2319 – 1813 ISSN(p): 2319 – 1805.
25. R. Senthil Kumar1, R. Manimaran2 and V. Gopalakrishnan3,2013. Experimental investigation on D. I. diesel engine fuelled by ethanol diesel blend with varying inlet air temperature/Available online at www.pelagiaresearchlibrary.com/ Advances in Applied Science Research, 4(1):319-329.
26. Dr. Hiregoudar Yerrennagoudaru1, Manjunatha K2, Chandragowda M3, Basava Prakash,(2014). Performance & Emission of C I Engine Using Diesel & Ethanol Blended with Jatropha Oil. International Journal of Recent Development in Engineering and Technology/Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 2, Issue 6.
27. Ajith K1, Gavudhama Karunanidhi S2, Prince M G3, Subba Rao G4, (2013). Experimental Analysis of Single Cylinder Four Stroke Diesel Engine with

Ethanol & Diesel Blends/ International Journal of Science and Research (IJSR), India Online ISSN: 2319-7064/Volume 2 Issue 7.

28. Prommes Kwanchareon, Apanee Luengnaruemitchai, and Samai Jai-In, 2006.Solubility of a diesel-biodiesel ethanol blend, its properties and its emission characteristics from diesel engine", DOI: 10.1016/J. Fuel.09.034.