ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

EMINE KEKILLI GUNGOR

HYDROGEN ENRICHED BIODIESEL USAGE IN COMPRESSION IGNITION ENGINE

DEPARTMENT OF AUTOMOTIVE ENGINEERING

ADANA, 2019

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We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on 23/07/2019.

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ABSTRACT

MSc THESIS

HYDROGEN ENRICHED BIODIESEL USAGE IN COMPRESSION IGNITION ENGINE

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DEPARTMENT OF AUTOMOTIVE ENGINEERING

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In this study, Biodiesel production has been acquired with using waste oil. Following this, pure hydrogen has been added 4 liter/min, 8 liter/min and 12 liter/min to the test fuels which are 100% Biodiesel, 100% Diesel, 90% Diesel + 10% Biodiesel and 80% Diesel + 20% Biodiesel. Brake thermal efficiency is higher in diesel fuels than WOB + Diesel fuels. Higher brake thermal efficiency has been obtained more than diesel fuels using with hydrogen in WOB+ Diesel fuels. BSFC increased using with WOB usage while decreased by addition of Hydrogen. Using with Hydrogen and Waste Oil Biodiesel usage together, CO emissions were decreased comparing to pure Diesel. In Biodiesel fuels, CO_2 and NO_x emission values were acquired more than Diesel fuels. CO_2emissions have been decreased with hydrogen enrichment. However, NO_x emissions have been increased with hydrogen enrichment.

Keywords: Biodiesel, Hydrogen, Performance, Emission, Waste Oil

ÖZ

YÜKSEK LİSANS TEZİ

ATIK YAĞLARDAN ELDE EDILEN BIYODIZEL YAKITLARIN HIDROJENLE ZENGINLEŞTIRILIPDIZEL MOTORLARDA KULLANILMASI

Emine KEKILLI GUNGOR

ÇUKUROVA ÜNİVERSİTESİ
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Bu çalışmada öncelikli olarak atık yağlar kullanılarak Biyodizel yakıt üretimi gerçekleştirilmiştir. Daha sonra saf Hidrojen dakikada 4 lt, 8 lt ve 12 lt oranları ile100% Biyodizel, 90% Dizel + 10% Biyodizel, 80% Dizel + 20%Biyodizel, 100%Dizel yakıtlarına eklenmiştir.Fren ısıl verimi, Dizel yakıtlarda WOB +dizel karışımlarına göre daha yüksektir.WOB + dizel karışımlarında hidrojen kullanılmasıyla, dizel yakıtlara göre daha yüksek fren ısıl verimi elde edilmiştir. Özgül yakıt tüketimi WOB kullanımıyla artarken, hidrojenin eklenmesiyle düşmektedir.WOB ve Hidrojenin birlikte kullanımıyla,CO emisyonu saf dizele göre azalmıştır. Biyodizel yakıtlarda, CO_2 ve NO_x emisyon değerlerinin dizel yakıtlara oranla daha yüksek oranlara sahip olduğu görülmüştür.CO_2 emisyonu hidrojen zenginleştirilmesiyle düşmektedir. Ancak NO_x emisyonu hidrojen zenginleştirilmesiyle artmaktadır.

Anahtar Kelimeler: Biyodizel, Hidrojen, Performans, Emisyon, Atık yağ

GENİŞLETİLMİŞ ÖZET

Petroleum is one of the most current fossil resources in order to obtain energy such as coal and natural gases. Wide range of using petroleum products affects prices of crude oil, environmental unfriendly, increment exhaust emissions etc.

Diesel engines give more mileage as compared to petrol engines. So, with the same amount of fuel tank capacity, diesel cars can travel longer distances. Diesel engines have excellent torque output at lower engine speeds compared to petrol engines. In simple terms, diesel vehicles can move heavy load from standstill more efficiently as compared to petrol cars.

On the other hand, Diesel engines tend to be noisier and harsher as compared to petrol engines. Diesel engines emit a lot of soot. It generally requires more after-treatment emission system than petrol engines. The end customer might not be directly affected or care about this soot emission, but it has consequences for the immediate environment. Diesel engine vehicles are generally expensive than petrol engine ones.

For that reasons, as an alternative fuel which non-edible biodiesel is the most promising fuel to fossil fuel. Another reason of using biodiesel is produced using with renewable resources such as waste cooking oils and decreasing exhaust emissions.

In all the tests, Waste Oil biodiesel is obtained and mixed 10% (B10) and 20% (B20) with diesel fuel by volume part, also pure diesel has been observed by the emission characteristics and engine performance addition of Hydrogen enrichment.

Hydrogen enriched diesel fuel was tested with hydrogen flow rates of4l/ min (H4), 8 l / min (H8) and 12 l / min (H12).

According to these enrichment, Pure hydrogen addition to biodiesel fuel is carried out to evaluate the emission characteristics and engine performance of a compression ignition (CI) engine with Hydrogen which has different flow rates as stated above.

Experimental studies have been carried out using with an engine (Kirloskar Oil Engines - 240) which has the compression ratio was set as 18:1, at 1500 rpm and operated with no load.

During all the operations, engine was stable for 5 minutes in order to reach the operating conditions. In the experiments, as performance data; carbon monoxide (CO), carbon dioxide (CO_x) and nitrogen oxides (NO_x) values were obtained and the results were investigated in terms of emission results and brake specific fuel consumption (BSFC).

Using of biodiesel fuel has some significant problems such as lower engine performance, higher BSFC and higher NO_x emissions.

Addition of Hydrogen to the test fuels was decreased brake specific fuel consumption (BSFC) and increased brake thermal efficiency (BTHE). The reason of lack of Carbon atoms in the Hydrogen causes decreasing of CO_2 and CO emissions, whereas rising in cylinder temperature caused increment of NO_x emissions.

Intake air gas which is enriched with pure hydrogen increased engine power and torque outputs in quiet.

H_2+Biodiesel-diesel fuel is considerably reduced brake specific fuel consumptions comparing with Biodiesel-Diesel and Diesel fuel results.

However, NO_x emissions are found raised with addition of H_2.

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Lastly, I want to dedicate this thesis my daughter, Lena GÜNGÖR,my husband, Orkun GUNGOR and my parents, Esma KEKILLI, Hamza KEKILLI. I wouldn't have succeeded my thesis without their support and encouragement.

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LIST OF ABBREVIATIONS AND NOMENCLATURE

CO	: Carbon Monoxide
CO_2	: Carbon Dioxide
NO_x	: Nitrogen Oxides
Lt/min	: Liter / Minute
CI Engine	: Compression Ignition Engine
DI Engine	: Diesel Engine
WOB	: Waste Oil Biodiesel
D100	: Pure Diesel Fuel
B10	: 90% Diesel + 10% Waste Oil Biodiesel
B20	: 80% Diesel + 20% Waste Oil Biodiesel
B100	: Pure Biodiesel Fuel
H4	: Hydrogen enrichment rate (4 liter/min flow rate)
H8	: Hydrogen enrichment rate (8 liter/min flow rate)
H12	: Hydrogen enrichment rate (12 liter/min flow rate)
RPM	: Revolution per minute
BSFC	: Brake Specific Fuel Consumptions
BSEC	: Brake Specific Energy Consumptions
BTHE	: Brake Thermal Efficiency
PPME	: Pongamia Pinnata Methyl Ester

1 INTRODUCTION

Petroleum, natural gases and coals are main raw materials in order to supply energy to the engines in the worldwide. However, environmental disadvantages of these suppliers cause new investigations in order to obtain for alternative energy sources which are sustainable and renewable. Especially, the internal combustion engine and automotive industry have been affected such as raised fuel cost and emission ordinance.

Hereby, renewable resources have been interested because of increment on the air pollutions and global warming especially petroleum product prices. On the other hand, decreasing on the fossil fuel raw materials has caused increment required sustainable energy.

Earth's energy resources are rapidly depleted. For that reason, as an alternative fuel which non-edible biodiesel is the most promising fuel to fossil fuel. (Awad et al., 2014). Biodiesel fuel has much more advantages compare to petroleum products as stated below (Al-Kofahi A, 2017):

Renewable Resources are used: Biodiesel is a renewable energy source which is produced using by waste cooking oil, animal and vegetable oil.

Diesel Engines are compatible with biodiesel: No or little modification is required in diesel engines. Also, blend of biodiesel and diesel mixture improve engine lubrication and engine life because of lack of Sulphur content.

Gas Emissions are less: In fossil fuels, after completion of burnt, carbon dioxide temperature raises in the atmosphere and global warming has been occurred. However, using with biodiesel in diesel fuels decreases emissions significantly.

Production and Distribution are Usable: After a certain time, current fuels which are fossil and natural gas will be danger of extinction. Biodiesel will be an alternative fuel in order to serve the purposes of fuel requirement. Biodiesel production is very usual and suitable for internal local refineries instead of buying fossil oil from other countries.

Biofuel Refineries are cleaner than Diesel: Diesel fuels have to be refined from crude form and this form causes release of chemical compounds to the environment and these chemicals (benzene, butadiene) are dangerous for all life. Biodiesel refineries have fewer toxic chemicals.

Fuel Economy is less than Diesel: Obtaining bio diesel is more economic than diesel fuels. This makes usable to the diesel fuel, significantly.

Dependence of Foreign Oil reduced: Using of biodiesels causes less usage of fossil fuels. So that, dependence to the foreign countries have been reduced.

More Health Benefits: Biodiesel produces fewer toxic pollutants than other petroleum products. Air pollution causes more deaths and diseases than other pollutions. Thousands of people get sick every year from smog which is caused by gasoline engines.

On the other hand, biodiesel fuel has disadvantages compare to petroleum products as stated below (Al-Kofahi A, 2017):

Quality Variation: Biodiesel quality can vary for biofuel crops. Producing power of fuels are not same as vegetable oils.

Food Shortage: Using vegetable and animal fats to obtain biofuels may cause increment product prices of these foods.

Using Fertilizer increment: To grown up biofuel raw materials, more fertilizer is used, and this causes soil erosion and land pollution.

Clogging in the Engine: Biodiesel remains steady clean of engine. However, this dirt is collected and clogged in the fuel filter.

To Produce Diesel using of Petroleum: Raw material is diesel fuel to produce biodiesel. The energy required for planting, fertilizing and harvesting is required more than producing biodiesel fuel.

Increment in Nitrogen Oxide Emissions: Biodiesel has more Nitrogen Oxide emission than other petroleum products. When this emission is dissolved in atmospheric moisture, cause acid rain.

Also, Hydrogen usage is one of the most important alternatives to decrease fossil fuel dependence.

The reasons of usage Hydrogen have been stated and described as below;

1. high diffusivity,
2. low ignition energy,
3. lower heating value,
4. high flame speed,
5. small quenching distance and
6. wide flammability range.

Experiments are carried out to observe exhaust gas emission results of CO, CO_2, NO_x values in terms of engine performance, BSFC and BTHE. With regards to test results, except CO emission values CO_2, NO_x emission values are reduced. Following Hydrogen enrichment of test fuels, emission parameters have been reduced except NO_x emissions.

In this regard, new alternative fuels have been researched referring to fossil fuels are rapidly extinguished. Also, on the worldwide, emission values of vehicles are restricted. So that, new alternatives have been tested to have less emission values, more engine performance. The purpose of this experimental tests, independent alternative fuels can be used in Diesel engines with less effort, cheaper investment. Emission values can be reduced using with Hydrogen gases enrichment on this alternative fuel.

Because of the wide flammability limits of hydrogen, lean operating conditions of the rotary engine can be extended. By leaning out the air-fuel mixture improved fuel consumption without compromising performance due to high energy content of hydrogen. Wide flammability limit of the hydrogen fuel also provides more stable engine operation, lower engine noise and vibrations. The hydrogen existence can make a remarkable improvement in performance parameters. Due to high calorific value, flame speed and diffusivity functions of the hydrogen, better pre-mixed fuel and more complete combustion can be achieved in hydrogen fueled rotary engine. More complete combustion provided by hydrogen addition decreases the emission productions. Small quenching distance of the hydrogen helps to obtain more complete combustion and increasing the combustion efficiency which is poor in gasoline operation caused by the long shape of rotor housing. The carbonless structure of the hydrogen helps to cut down CO, CO_2 and HC emissions. Hydrogen combustion increases the cylinder temperature under stoichiometric conditions, so NO_x emission rises. However, the lean operation provides lower NO_x emission due to minimizing combustion temperature (Özcanlı et al., 2018).

Despite of advantages of hydrogen, it has very high self-ignition temperature (585 °C) and cannot be used only in spark plug or glow plug. So that, hydrogen gas improves quality of combustions when it mixed with fuel. Better premixed fuel can be obtained using with hydrogen gas and its high diffusivity property. Due to higher heating value of H_2 higher power output can be achieved without comprising from lower emission values. Carbon based emissions are applicable lower due to carbonless atomic structure of Hydrogen. Also, combustion duration can be reduced due to the high flame speed. (Özcanlı et al., 2018).

Hydrogen should be produced by other available compounds such as hydrogen, natural gas, oil, coal and water. Hydrogen is an energy source that requires external energy to produce fossil fuels: nuclear and renewable energy such as gasoline, diesel, ethanol, methanol, biodiesel, LPG, solar, wind, CNG, hydropower and geothermal.

In order to produce Hydrogen 3 mainly ways are conducted: natural gas reforming, electrolysis and gasification (McAllister et al., 2011). Consumption of Hydrogen causes independence to fossil fuels in internal combustion engines.

However, in recent years, about 95% of the total hydrogen production is made from fossil fuels used and only a small proportion of renewable and clean sources such as solar energy, wind, geothermal and biomass. Therefore, hydrogen production is still a costly and highly polluting process. The main problem is whether hydrogen can be produced economically and to a large content by clean and renewable sources. (Dimitriou et al., 2017).

2 PRELIMINARY WORK

Scientists have been searched for new alternatives for fuel consumption technologies. There have been lots of alternative investigations to decrease emissions and increase energy efficiencies in last decades. (Tosun et al, 2017; Çalık, 2017).

2.1 Biodiesel Preliminary Works

Biodiesel (fatty acid methyl esters) is derived from triglycerides by transesterification method with methanol. It has a significantly attention during the last decades as a nontoxic, biodegradable and renewable fuel. So that, using of biofuels are beneficial environmentally. In compression ignition engines, there is no need or little modifications. These properties of biofuels have set off the scientists to make researches about production methods of biodiesel. (Özcanli, 2009).

The petroleum fuel alternative which is biodiesel fuel has been carried out by scientists on their studies (Çanakçı, 2003; Çanakçı et al., 2007; Keskin et al., 2013; Serin et al., 2013; Usta et al., 2005; Chongkhong et al., 2007; Serin et al., 2014; Özcanlı et al., 2011).

Biodiesel fuel production has been utilized of waste vegetable oils (palm oil) in diesel engines and ran their test fuels using in one-cylinder, direct injection diesel engine at 1000, 1200, 1450 and 1800 rpm. Also, exhaust emission values such as carbon monoxide, carbon dioxide, sulfur dioxide, unburned hydrocarbons and smoke were measured in this study. According to result of this study, engine performance has the best values using with B100 and B75 while exhaust emissions have the best results using with B50. (Widyan et al., 2002).

Engine performance and emission characteristics of diesel engine using with pongamia pinnata methyl ester (ppme) and its blends have been studied. In this study, besides CO, CO_2, HC, NO_x emissions, brake specific energy consumption (bsec) and brake specific fuel consumption (bsfc) values have been evaluated. According to this test results in various diesel proportions, engine performance and emission characteristics have better results with blends of ppme with diesel up to 40% by volume of Biodiesel (Sureshkumar et al., 2008).

Biodiesel is produced from various energy sources such as woody essential oil (Choa et al., 2018), hazelnut oil (Efe et al., 2018), cooking oil (Trabelsi et al., 2018), groundnut acid oil (Deivajothi et al., 2017), Pithecellobium dulce seed oil (Sekhar et al., 2018), neem oil (Hasan Ali et al., 2013), tea seed oil (Serin et al., 2017a) etc. vegetable oils.

Engine Performance and emission characteristics have been studied in four-cylinder, four-stroke and direct injection diesel engine using with tea seed (Camellia sinensis) oil biodiesel. In this study, tea seeds oil has been obtained by using the soxhlet extraction apparatus, following this biodiesel was produced by transesterification of tea seed oil with methanol in the presence of a catalyst (NaOH) and mixed with biodiesel content at the volumetric ratios ofB10, B20 and B100 were tested in a direct injection diesel engine at full load condition. As a result of this study, increment in Biodiesel content causes decrement in power output. Also, increment in amount of Biodiesel causes Brake Specific fuel consumption (BSFC) increment in the test fuels. While NO_x emissions were increased, CO and CO_2 emissions were reduced with increasing Biodiesel fuel. These tests showed us up to 20% volumetric content of tea seed and biodiesel mixture could be used to provide reduction in diesel fuel usage (Serin et al., 2014).

2.2 Hydrogen (Alternative Fuels) Preliminary Works

Hydrogen usage (Özcanlı et al., 2016a; Özcanlı et al., 2016b; Özcanlı et al., 2016c; Saravananet al., 2010; Premkartikkumaret al., 2014) in experimental studies have been implemented in order to decrease fuel consumptions in internal combustions engines.

Hydrogen has high flame speed, wide flammability interval, low ignition energy, high diffusivity, lower heating value etc. (Uludamar et al., 2017). Also, carbonless structure of hydrogen gives rise to lower emission values which have Carbon based emissions (Açıkgöz et al., 2015; Ghazal, 2013). Though, hydrogen has 585 °C self-ignition temperature and for this reason, hydrogen cannot be used only for itself without any spark or glow plug in a compression ignition engine (An et al., 2013). For compression ignition engines, hydrogen is unsuitable fuel as only using itself, so that mixing a fuel using with hydrogen gas can make complete combustion and improve the combustions quality. Better premixed fuel is obtained with using hydrogen because of high diffusivity property into the cylinders (Özcanlı et al., 2017).

Higher power output can be obtained because of more heating value ofH_2without including from lower emission values. Moreover, combustion duration can be shortened because of high speed of flame reproduction of hydrogen (Hamdan et al., 2015).

Hamdan et al. (2015) observed hydrogen enrichment in brake thermal efficiency in diesel fueled engine. As a result, on the engine efficiency with hydrogen enrichment is more significant in partial loading and low engine speed. However, hydrogen enhance increased NO_x emissions because of increasing of combustion temperature. Yang et al. (2015) studied for found out the hydrogen addition in which ratio for the best diesel engine performance. Their results showed that Hydrogen enrichment causes decreasing PM emissions with using 17% volume fraction of H_2 addition. Uludamar et al. (2016) studied on various biodiesels, hydrogen addition to investigate noise and vibration of engine. These studies showed that using hydrogen enrichment biodiesel in diesel engines slightly decreased sound level and vibration of engine. Aldhaidhawi et al. (2017) showed that the reason of high ignition temperature of the Hydrogen, ignition delay has not observed remarkably in the hydrogen enriched Diesel and B20 fuels experimental and numerical study. Biodiesel is usable fuel which can be produced using without fossil fuels, also it reduces the emissions. On the other hand, dependence of fossil fuels can eliminate by using diesel fuels (Uludamar et al., 2017). However, high viscosity and lower calorific value of hydrogen have some negative test results in accordance with power output in the engine. Lower power output has been observed in compression ignition engine because of atomization of liquid fuel making corruption. Moreover, emission of NO_x is higher in biodiesel fuel engine than pure diesel fuel (Serin et al., 2017b). Also, it is possible to obtain biodiesel from vegetable oils, waste oil (Adewaleet al., 2015; Gharehghaniet al., 2017; Behçet, 2011; Gürü et al., 2010; Behçet et al., 2014; Awad et al., 2014) or animal fats (Ozcanlı et al., 2017; Wyatt et al., 2005; Lin et al., 2009; Barrios et al., 2014; Reye set al., 2006; Behçet et al., 2015; Godiganur et al., 2010; Sakthivel et al., 2014; Mikulski et al., 2016; Kumar et al., 2005).Besides, biodiesel which is produced from waste oils have advantages such as lower costs and environment friendly compare to non-edible waste oils(Yıldızhan et al., 2017). Because of these experiments, it is studied on improving engine performance and characteristics of emissions with addition of hydrogen and evaluated some of above parameters with experimental results in compression ignition engines.

Addition of Hydrogen outlines are listed below in previous researches:

- H_2 calorific value is much more than diesel fuel.
- Hydrogen has a self-ignition temperature of 585°C. Because of this, it is not possible to use Hydrogen only in a Compression Ignition (CI) engines without any glow or spark plug. So that, Hydrogen is unsuitable fuel as only for CI engines (Saravanan et al., 2007).
- In terms of its high diffusivity function, using small value of hydrogen injection to the cylinder makes better premixed fuel.

- Likewise, hydrogen reduces the combustion time because of high speed of the flame diffusing (Szwaja et al., 2009).

3 MATERIAL AND METHOD

3.1 Material

3.2 Materials for Bio Diesel Production

3.2.1 Waste Oil

Waste oil is any synthetic oil which has become unsuitable through contamination for its original purpose because of the losing original properties or availability of impurities.1500 ml waste oil is used for biodiesel production. After filtering the oil, heated up to 60°C (Figure 3.1).

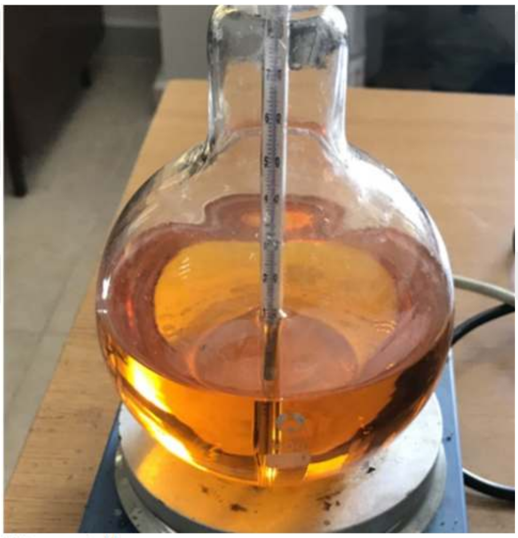

Figure 3.1. Filtered Waste Oil

3.2.2 Methanol

Methanol is a colorless, flammable liquid used in the manufacture of formaldehyde and acetic acid, in chemical synthesis, solvent, and as an antifreeze. Uptake of methanol is toxic and may cause blindness (Figure 3.2).

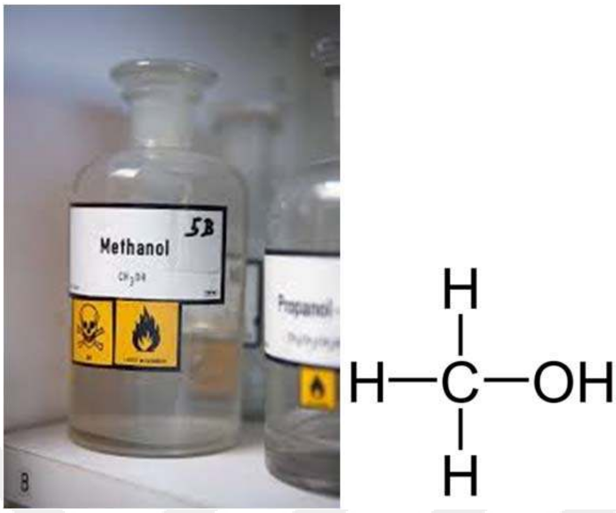

Figure 3.2. Methanol

3.2.3 Sodium Hydroxide

Sodium hydroxide is a highly caustic substance that is used to make sodium salts and neutralize acids. Sodium hydroxide is used to explosives, paper, petroleum products and manufacture soaps (Figure 3.3).

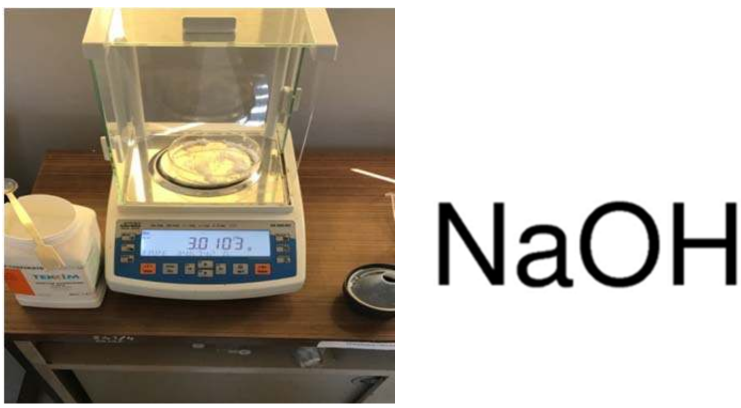

Figure 3.3. Sodium Hydroxide

3.2.4 Magnetic Stirrer

A laboratory equipment which produces a rotating magnetic field, so that a magnetic stir bar will automatically stir for chemical solutions. They often incorporate an electric heating plate (Figure 3.4).

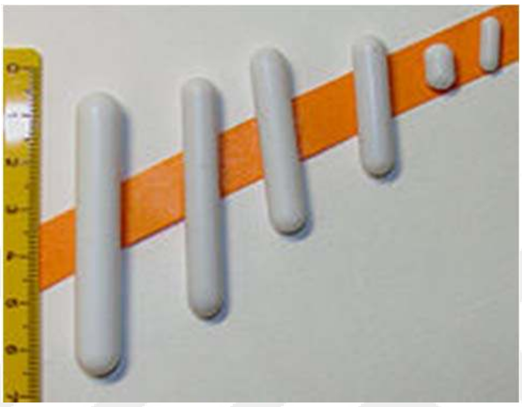

Figure 3.4. Magnetic Stirrer

3.2.5 Paper Filters

Filter papers have wide range usages in laboratory experiments across many different fields; for instance, from biology to chemistry. The type of used filters changes according to the purpose of the procedure and the chemicals involved. Usually, filter papers are used with laboratory techniques as a vacuum filtration and cleanliness of products.

Figure 3.5. Paper Filters

3.2.6 Crude Glycerin and Methyl Ester

The solution in the reactor which is methoxide and filtered-heated waste oil is transferred to the waiting and rinsing tank and kept still for 6 hours. After this period, the crude methyl ester and the crude glycerin are separated because of the density difference, and glycerin is taken away from the tank.

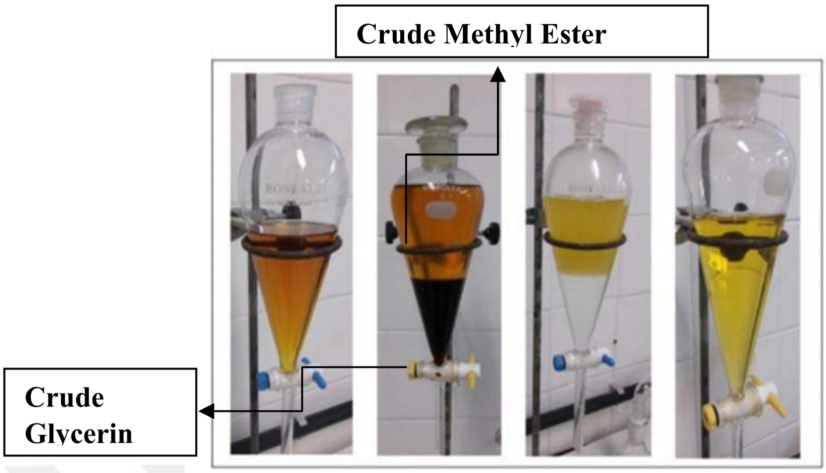

Figure 3.6. Crude Glycerin and Methyl Ester

3.3 Materials for Experimentation

3.3.1 Engine

Multi-fuel research engine which consists four stroke, single cylinder is connected to eddy current type dynamometer for loading. From Petrol to Diesel or from Diesel to Petrol changes in the engine can be achieved using by some necessary changes. In these two modes, compression ratio can be changed without stopping the engine and altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. Spark point and injection point can be varied for experimental tests. Setup is provided with necessary instruments for Diesel line pressure, crank-angle and combustion pressure measurements. For pressure crank angle diagrams, the signals are interfaced with the computer. Load, temperatures, airflow and fuel flow measurements are interfaced providing by instruments. The setup has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for fuel and airflow measurements, hardware interface and process indicator. Cooling water and calorimeter water flow measurements are provided by Rota meters. In order to engine electric start arrangement, a starter, battery and battery charger is provided.

The setup facilitates study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, BTHE, BSFC, Mechanical efficiency, indicated thermal efficiency, Volumetric efficiency, A/F ratio, heat balance and combustion analysis.

"Engine soft" provides on line performance evaluation software package based on Engine Performance Analysis in order to based on lab view. (Kirloskar Oil Engines Instruction Manual, 2010).

Four stroke cycle engines

In four stroke cycle, two revolution of the crankshaft or four strokes of the piston operations completion is carried out in two revolutions of the crankshaft or four strokes of the piston. A cycle consists of 7200 of crankshaft rotation which has four stroke rotation consists 1800 in equal.

An ideal four-stroke engine series operations are stated below:

1. **Intake stroke:** The inlet valve is opened, and after the piston travels down the cylinder, air is inserted.
2. **Compression stroke:** The inlet valve closes, the piston moves up, and compresses the air mixture, heating it up. Fuel (dark blue) is injected into the hot gas through the central fuel injection valve and spontaneously ignites.
3. **Combustion stroke:** The third stroke will include combustion. When the air is compressed too much, it starts to heat up. The fuel injectors will spray diesel fuel into the combustion chamber. The fuel will immediately ignite as soon as it comes into contact with this compressed air. The result of this ignition is the heat energy that generates the power required to move the vehicle.
4. **Exhaust stroke:** When the exhaust valve remains open steadily, the piston moves towards the cylinder and the remaining gases are ejected. When the

exhaust valve closes, exhaust gas waste will be diluted with the next charge.

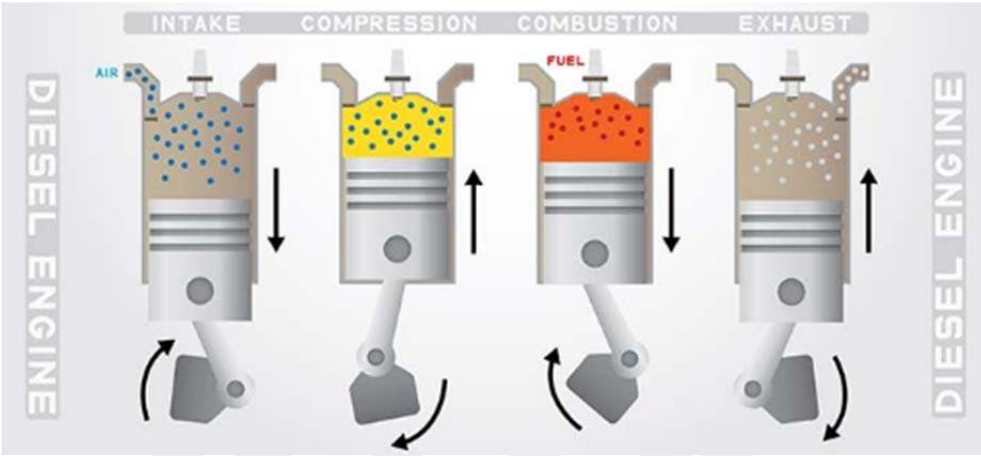

Figure 3.7. Diesel Engine Operations

Experimental tests were implemented using with water cooled, single cylinder, four stroke and naturally aspirated Kirloskar Oil Engine (CI Engine).
All the technical properties of the engine are shown in Table 3.1.

Table 3.1. Technical properties of the Diesel (DI) Engine

Brand	Kirloskar Oil Engines-240
Type	Single cylinder, Four stroke
Displacement	661 cc
Cooling type	Cooling water
Minimum / Maximum Operation Speed	1200 / 1800 rpm
Power	3,5 Kw@ 1500 rpm
Stroke	110 mm
Bore	87.5 mm
CR Range	12:1 18:1
Injection Variation	0-25 Deg BTDC
Lubrication System	Forced Feed System
Weight	160 kg

Figure 3.8. Kirloskar Oil Engines-240

3.3.2 Dynamometer

Testing of the engines up to 400kW (536 hp), the AG Series eddy current dynamometers designed and this dynamometer may be used with various control systems.

The shaft mounted finger type rotor runs in a dry gap. The dynamometer is bi-directional. Cooling system which type is closed circuit permits for a sump. Dynamometer load measurement is made from a strain gauge load cell and speed measurement is made from a shaft mounted 360 PPR rotary encoder.

System was connected to AG Series Eddy current dynamometer. These dynamometers are designed for testing of the engines up to 400kW (536hp) and it is possible to use with various control systems.

Table 3.2. Technical properties of the Diesel Engine

Brand	AG10 Eddy current dynamometer.
Model	AG10
Make	Saj Test Plant Pvt. Ltd.
Load	3.5 kg
Bolt size	M12 x 1.75
Weight	130 kg
End flanges both side	Cardon Shaft Model 1260 type A
Water inlet	1.6 bar
Minimum kPa	160
Pressure lbf/in^2	23
Hot coil voltage max.	60
Torque Nm	11.5
Air gap mm	0.77 / 0.63
Cold resistance ohms	9.8
Continuous current amps	5.0
Speed max.	10000 rpm

Figure 3.9 : Eddy Current Dynamometer

3.3.3 Gas analyzer

Exhaust gas emission values were measured using with MRU Delta 1600 V gas analyzer. This equipment was connected to the computer and used software of MRU Gas Analyzer. Including sample conditioner with:

- Gas cooler, gas sampling pump, gas filter, condensate pump
- Flexible gas sampling probe
- Protective nylon transport case
- Integrated rechargeable batteries

Table 3.3. Technical properties of the Gas Analyzer

Brand	MRU Delta 1600 V Gas Analyzer
Model	Delta 1600 V
Dimensions	530x490x310 mm
Weight	6,5 kg
Power supply: Mains	90 ... 264 V/50Hz
Power supply: Vehicle Battery	12 V dc
Probe	Length 400 mm, flexible
Sample gas line	5 m Viton
Filtering	Pre and Fine-filter
Exhaust Gas Temperature	Max. 650 ºC
Ambient Temperature	+5° - +45°C
Lambda	0-9,99
Accuracy	acc. to OIML-class 1
PC-Interface	RS 232
Data Storage	7.500 measurements
AUX-connector (only for RPM	1
Measurement of CO	0-10%
Measurement of CO_2	0-20,0%
Measurement of HC	0-20.000 ppm
Measurement of O_2	0-22%
Measurement of NO	0-4.000 ppm
Measurement of NO_2	0-1.000 ppm

Figure 3.10 : MRU Delta 1600 V

3.3.4 Computer

Host computer and data will be obtained with specific software of MRU.

Table 3.4. Technical properties of the Host Computer

Brand	HP
CPU	Pentium 300 GHz
RAM	Min. 2GB or higher
Monitor	Colored
Microsoft Office	2007/ more version
OS	Windows XP + SP2
Monitor Screen Resolution	1280 x 1024
Other properties	DVD ROM drive, USB Port

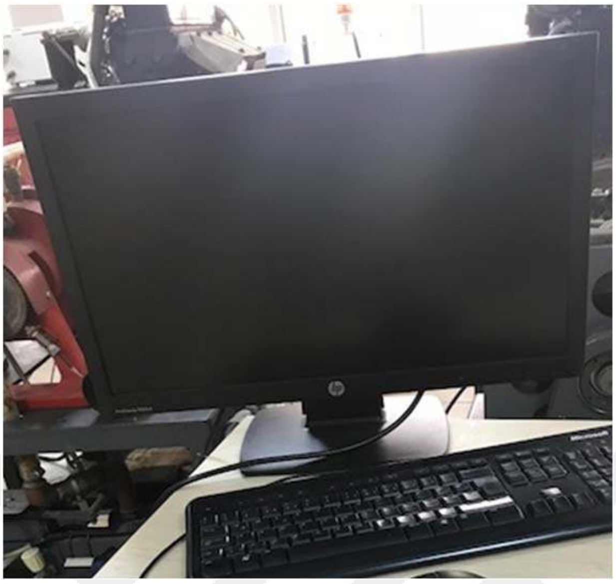

Figure 3.11 : HP Host Computer

3.3.5 Air Filter

Air filter was used in order to improve quality of the air in the CI engine.

Figure 3.12 : Air Filter

3.3.6 Mixing Chamber

Hydrogen and Biodiesel+ Diesel Fuel get into the mixing chamber.

Figure 3.13 : Mixing Chamber of DI Engine.

3.3.7 Needle Vane

Needle vane controls flow rate of Hydrogen through to the system.

Figure 3.14 : Needle Vane

3.3.8 Flow meter

Before mixing chamber and after in-cylinder, Alicat volumetric flow meters are located after gas flows measurement.

Figure 3.15 : ALICAT Flow meter

3.3.9 Hydrogen Regulator

In order to set flow of Hydrogen gas, Hydrogen regulator was used. For the test results obtaining effectively, Hydrogen fuel amount which is supplying to engine was adjusted by using this regulator.

Figure 3.16 : Hydrogen Regulator

3.3.10 Hydrogen Tank

The tank was filled out with 99.99% Hydrogen (170 bar pressurized).

Figure 3.17 : Hydrogen Tank

3.3.11 Data Logger

This equipment outputs were transferred to HP Host computer system.

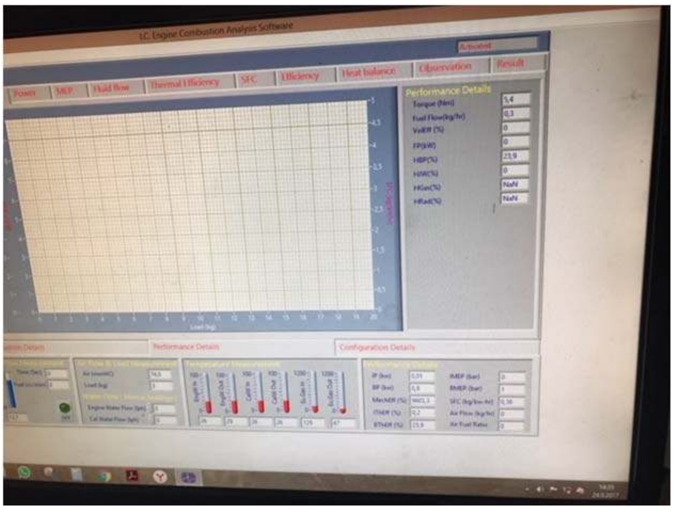

Figure 3.18 : Data logger

3.3.12 Fuel Tank

Biodiesel and Diesel mixture were used in order to obtain results of experiment.

Figure 3.19 : Fuel Tank

3.3.13 Fuel Pump

The pump is of self-priming version. It fills approximately 300ml.water into the body during installation, after this shut the filler cap tightly. Following the pump switching on, during the first operation, it will have to remove the air in the suction pipe. This operation will take minimum 2 minutes before flowing of the water. During sequential operations you will get water immediately on switching the pump.

Table 3.5. Technical properties of the Fuel Pump

Brand	Kirloskar
Model	MINI-18SM
Supply	230 VAC, Single phase
Total Head Max.	6-18 meter
Discharge	1650-720 Lph
Connection	20 x 20mm
Water Seal	Mechanical
Pump Unit	CI.
Power Rating	0.18Kw/0.25hp
Type of Motor	Capacitor starts and run
Insulation	‘B’ class
Rating	Continuous
Shaft	Carbon steel
Delivery casing	Cast Iron
Motor Body	Cast Iron
Impeller	H.T. Brass

Figure 3.20 : Kirloskar Fuel Pump

3.4 Methods

In Fig. 3.21, Experimental Set-up Schematic diagram is shown and all the materials which are used in these tests are listed as below:

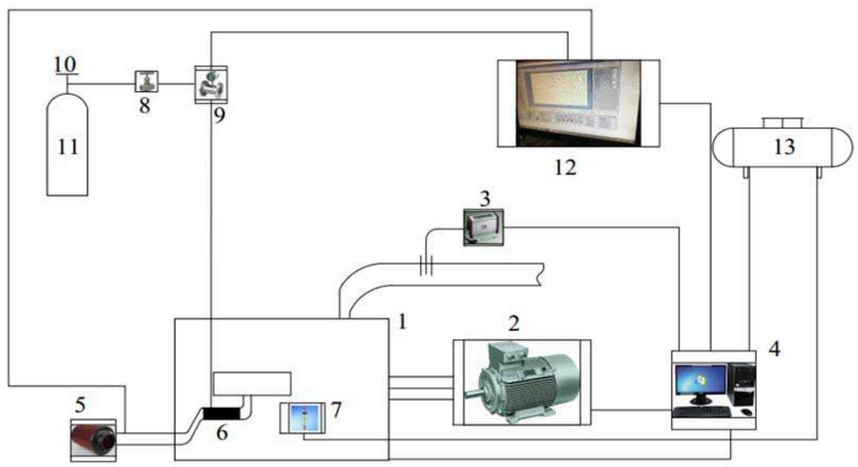

Figure 3.21 : Schematic Diagram of experimental set-up

3.4.1 Raw Materials for Biodiesel

Vegetable oils, waste oils and animal fats are used for biodiesel production as raw materials.

In the worldwide, biodiesel production has been carried out mostly oils which are vegetable oils are main component for United States of America biodiesel production as one of the major countries. Soybean oils have been used in USA and Argentina. Palm oils have been used in Asian and Central American countries. Sunflower, peanut, linseed, safflower, vegetable oils and animal fats are used for biodiesel production in many countries (Romano et al., 2011).

Main reason of the using biodiesel fuels production is its costs and for this reason non-edible vegetable oils are used to make studies properly recently. Since lower costs of non-edible vegetable oils, it is preferred to be used. Besides its lower cost, there is no need to use foodstuffs to produce biodiesel, it can be produced by using non-edible oils which costs are not high values compare to other oils. So that, it cannot be denied that advantage of using non-edible oils for biodiesel production to produce fuel (Romano et al., 2006). All these reasons, biodiesel production trials which are made using with Tung, cotton, jojoba, castor oil and jatropha have become well-liked in some countries. Animal fats are alternatives in biodiesel production where has significantly resources. Although they need to execute preliminary treatment when they are solid. Also, pork, poultry, cattle and fish can be used producing for highly acidic grease. An important alternative is microalgae for future biodiesel production because of microalgae's have very high oil yield. However, it must be considered only some species of microalgae are useful for production of bio-fuels. While the properties of oils and fats of biodiesels used as raw materials can change, according to the international standards requirements, biodiesel properties must be the same (Romano et al., 2011).

Methanol is the most frequently used alcohol while ethanol can also be used.

While making biodiesel fuel, transesterification process component is required, and methanol is the key component of this process. The transesterification process is defined as below:

1. The first thing is to mix the methanol and the catalyst, as Sodium Hydroxide.

   $CH_3OH + Na^+ + {}^-OH \longrightarrow Na^+ + {}^-OCH_3 + H_2O$

2. In transesterification reaction components are defined as RCOOR' indicates an ester, R"OH an alcohol, R'OH another alcohol (glycerol), RCOOR" an ester mixture and $NaOH^-$ a catalyst:
   RCOOR' (ester) + R''OH (alcohol) $\xleftrightarrow{NaOH^-}$ R'OH (glycerol) + RCOOR''(ester)

3. The triglyceride will react with 3 moles of methanol, so excess methanol must be used in the reaction to entrench complete reaction. The three attached carbons with hydrogen react with OH^- ions and form glycerin, while the CH_3 group reacts with the free fatty acid to form the fatty acid methyl ester (Figure 3.21).

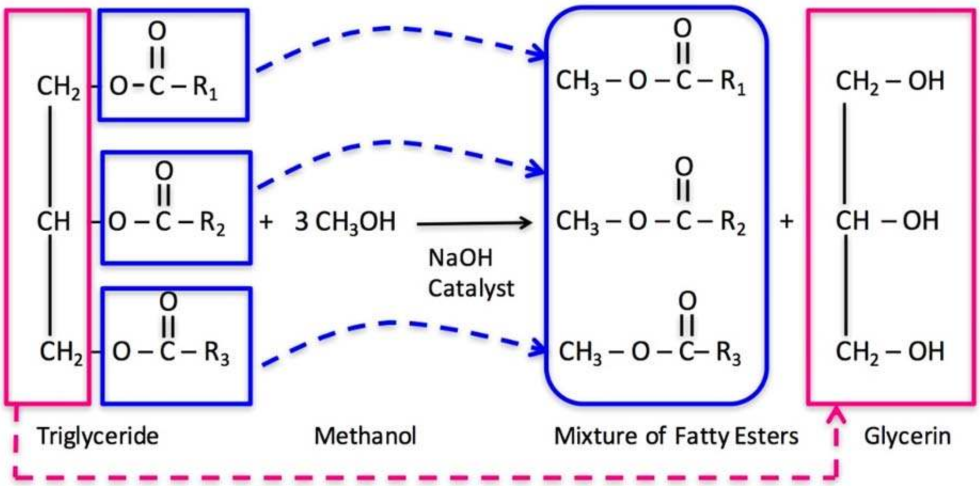

Figure 3.22 : Chemical formula of Biodiesel Production

Triglyceride +Methanol $\longrightarrow$ Ester + Glycerin

3.4.2 Production of Bio Diesel

All tests were implemented at Automotive Engineering Department of Çukurova University, Adana, TURKEY.

Waste oil biodiesels (WOB) were prepared with transesterification reaction as defined in below equation:

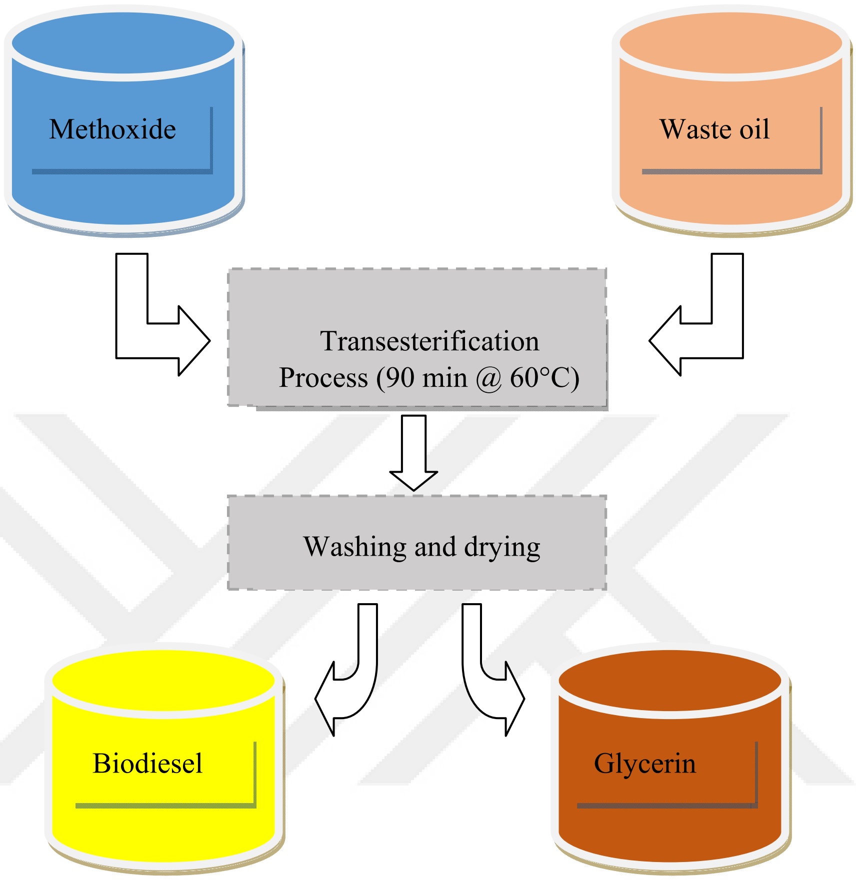

Figure 3.23 : Processes of biodiesel production from waste oil.

For transesterification reaction, Methanol was used 6 methanol to 1 oil with molar ratios. Sodium Hydroxide was used 0.5% (by weight of oil) as catalyst.

Methanol and Sodium Hydroxide had mixed to obtain methoxide, before transesterification reaction.

Waste oil was filtered before reaction and following this oil heated up to 60 °C. On the other hand, methanol and sodium hydroxide were blended in order to obtain methoxide. Following this, heated oil and methoxide were mixed and kept 90 min by stirring at 60 °C temperature.

After this reaction, the crude methyl ester was put and waited for 8 hours a separating funnel. Following that, methyl ester was disaggregated from crude glycerin.

The crude methyl ester was washed with warm water until the water was clear. Following this, it dried at 110 °C for an hour. Furthermore, methyl ester which is washed and dried went through a filter. Finally, this waste oil biodiesel is ready to use it in WOB blends. All processes of Biodiesel production are shown in Figure 3.16. Euro-Diesel, the second liquid fuel, was supplied from petroleum station.

3.4.3 Addition of Bio Diesel-Diesel Mixture

In these experiments, blends ware listed as below:

1. 0% Bio Diesel + 100% Diesel(D100),
2. 10% Bio Diesel +90% Diesel (B10),
3. 20% Bio Diesel +80% Diesel (B20).

3.4.4 Addition of Hydrogen to Bio Diesel-Diesel Mixture

Furthermore, for each test, effects of hydrogen addition with flow rates which are listed, test is carried out and results are considered:

1. 4 liter/min Hydrogen (H4),
2. 8 liter/min Hydrogen (H8),
3. 12 liter/min Hydrogen(H12).

It is important that before starting to test, system was hold on 10 min at least and 3 times experiments were performed to obtain certain results. The CI test engine was performed at 1500 rpm and there was no dynamometer load for every experiment. After all the tests; emission values and BSFC, BTHE results were obtained.

Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with the fluid mass density like:

$\nu = \mu / \rho$ where

ν = kinematic viscosity (m^2/s)

μ = absolute or dynamic viscosity ($N\ s/m^2$)

ρ = density (kg/m3)

3.4.5 Experimental Procedures

Engine performance and emission measurement experiments were performed with one compression ratio (18:1) and 1500 rpm. During the experiments, engine was under no load. At first, D100, B10 and B20 blends are evaluated. In addition, hydrogen was blended through the intake manifold with flow rates of 4 lit/min (H4), 8 lit/min (H8) and 12 lit/min (H12) to enhance combustion of VCR engine.

Before experimental measurements engine was run 5 minutes to attain stable operation conditions. “Engine soft” software was used for logging experimental data. This software logs for 60 seconds when logging starts and at the end of this period gives the average values of experimental data.

As a result of these experiments, brake thermal efficiency (BTHE), specific fuel consumption (BSFC), brake specific emissions of; carbon monoxide (CO), carbon dioxide (CO_2) and nitric oxides (NO_X) were obtained to evaluate effects of applied methods on performance and emission characteristics of a four stroke, naturally aspirated, water-cooled and spark ignited test engine.

4 RESULTS AND DISCUSSIONS

4.1 Fuel Properties

Some important physical fuel properties test fuels were measured. The fuel properties of the diesel were given in Table 4.1.

According to fuel properties results, density of waste oil biodiesel is higher than pure diesel fuel in Figure 4.1. Also, tests showed that density of B10, B20 and B100 was higher than the diesel fuel, but the values were within the biodiesel standards EN 14214.

The tests showed that WOB biodiesel has a higher kinematic viscosity than diesel fuel. High viscosity can damage fuel pump but, the viscosity of WOB biodiesel and B20 were within the standards and it can be used directly without any modification. Heating value of the WOB biodiesel and B20 was slightly lower than diesel fuel. Flash point of the WOB biodiesel was over 120 ^{o} C which is safer compared to diesel fuel. Also, blending WOB biodiesel with diesel fuel increased the flash point value of the diesel fuel which is an important criterion for storage of the fuel. Cold filter plugging point of the WOB was measured higher than diesel fuel.

Table 4.1. Fuel Properties of Diesel Test Fuels (Data derived from (Yıldızhan et al., 2017)

Fuel Properties	Diesel	EN 590	EN 14214
Density (20 °C) kg/m^3	834	820-845	860-900
Cetane Number	59,47	Min. 51	Min. 51
CFPP °C	-11	-	Summer<4 Winter<1
Heating Value, cal/kg	11044	-	-
Kinematic Viscosity (40 °C) mm^2 /s	2.759	2.0-4.5	3.5-5.0
Flash Point °C	79.5	Min. 55	Min. 120

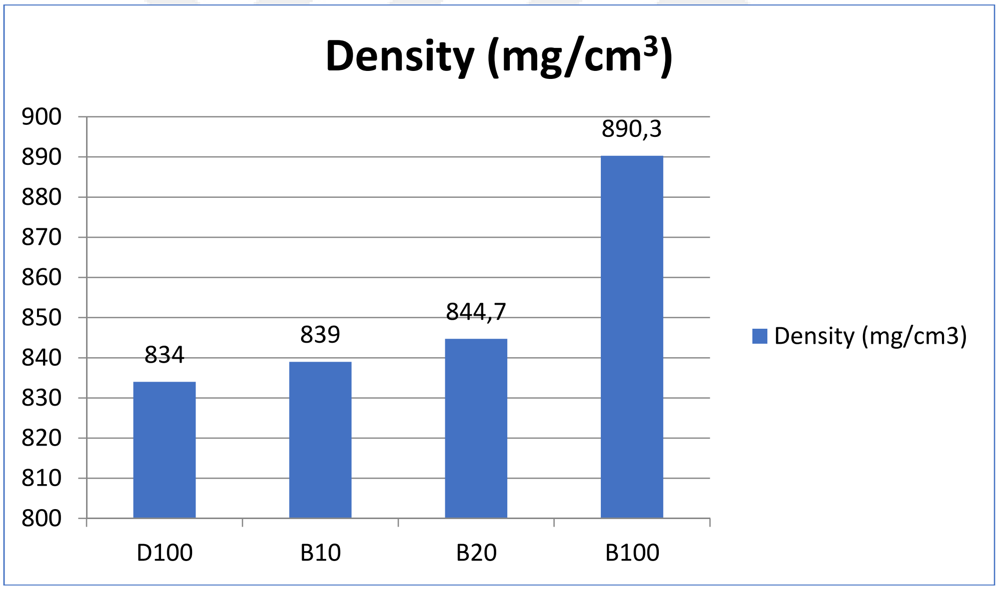

Figure 4.1 : Fuel Properties of D100, B10, B20 and B100(Density)

According to test results, kinematic **viscosity** of waste oil biodiesel is higher than pure diesel fuel (D100), B10 and B20.

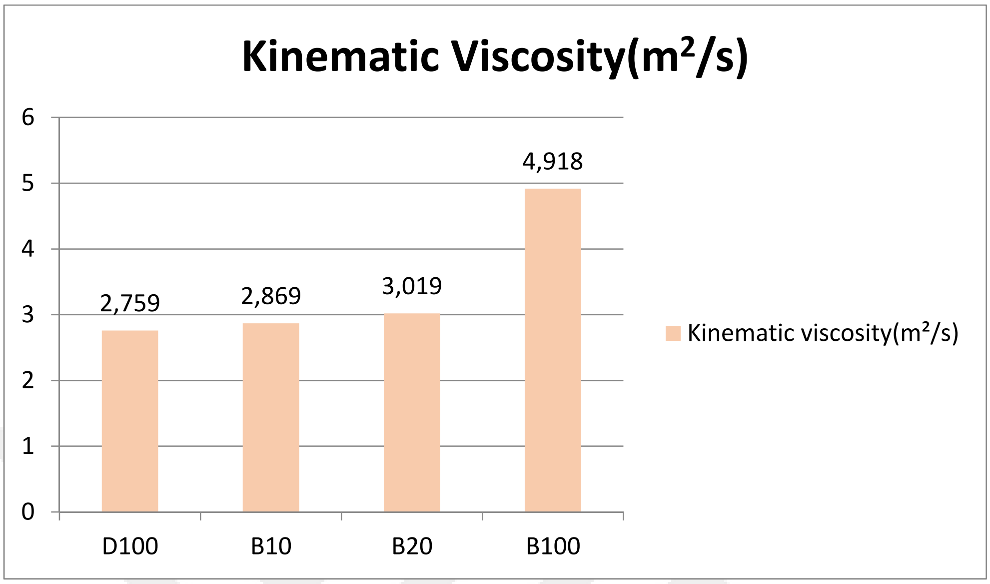

Figure 4.2 : Fuel Properties of D100, B10, B20 and B100 (Kinematic Viscosity)

The **heating value** is the amount of heat produced by combustion a unit quantity of a fuel. According to fuel properties results, heating value of waste oil biodiesel is lower than pure diesel fuel (D100), B10 and B20.

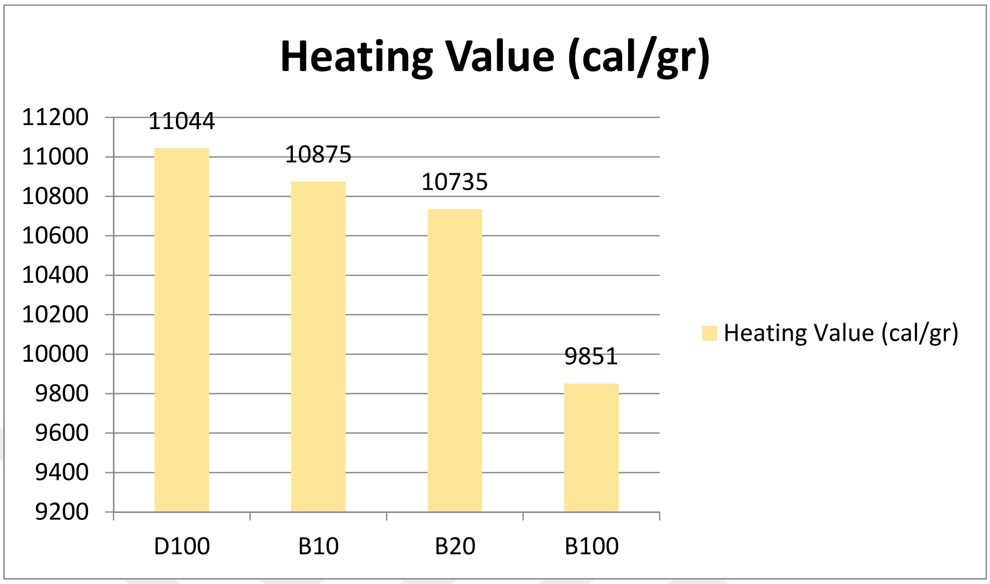

Figure 4.3 : Fuel Properties of D100, B10, B20 and B100 (Heating Value)

Cetane is a colorless, liquid hydrocarbon that ignites easily under compression. For this reason, it was given a base rating of 100 and is used as the standard measure of the performance of compression ignition fuels, such as diesel fuel and biodiesel. All the sundry hydrocarbon constituents of diesel fuel are measured and indexed to cetane's base 100 rating.

A high cetane number of the fuel means it combusts or “burns "quicker than say fuel of a lower cetane number.

Cetane number is an indicator that shows combustion speed of a diesel fuel and increase the ignition quality. For a diesel fuel, if cetane number is too high, combustion will not be mixed of air and fuel properly, as a result incomplete combustion will be implemented. Also, cetane number is very low, incomplete combustion will be implemented, too.

Higher cetane number fuels are more desirable for running high speed diesel engines found in automotive diesel transport vehicles (cars and light trucks) while lower speed applications tend to prefer lower cetane number fuels which are also typically cheaper to buy.

As it can be seen on Figure 4.4, in diesel fuel cetane number is 54,037 and by increasing Biodiesel mixture cetane number will drop to 53,002, 51,995 and 44,03 for B10, B20 and B100 respectively.

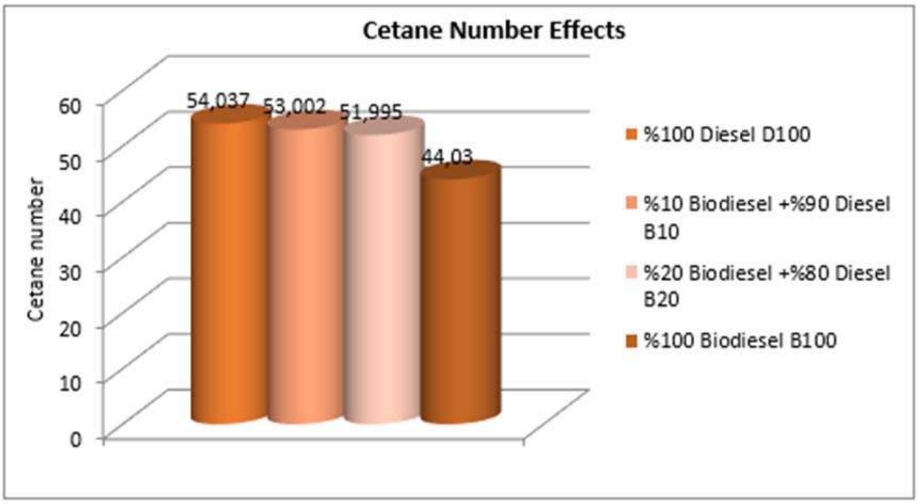

Figure 4.4 : Cetane Number Effects on D100, B10, B20 and B100

Theoretically, the cetane number is defined in the range of 15-100; the limits are given by the two reference fuels used in the experimental determination of the cetane number.

According to the test results of Cetane number values, B10 andB20 test fuels was found as 53.002 and 51.995, respectively so that they comply with the American and European Biodiesel Standards. Furthermore, all test fuels met the standards in terms of copper strip corrosion test.

Table 4.2. US and EU Biodiesel Specifications

Fuel Properties	Diesel	EN 590	EN 14214
Cetane Number	59,47	Min. 51	Min. 51

4.2 Performance

4.2.1 Brake Thermal Efficiency (BTHE)

Brake thermal efficiency is the ratio of energy in the brake power to the fuel energy. Brake thermal efficiency (BTHE) is defined as break power of a heat engine as a function of the thermal input from the fuel.

It is used to evaluate how well an engine converts the heat from a fuel to mechanical energy. BTHE values are shown in Figure 4.5. According to test results, BTHE of the test engine is dropped with addition of the Waste oil Biodiesel usage.

When B10 was used, BTHE is decreasing from 31.9% to 31.7%and B20 was tested, BTHE is decreasing from 31.9%to31.3%comparing to the pure diesel (D100) usage.

The higher density and viscosity values are the main reason of the Waste oil Biodiesels have poor atomization, extended ignition delay, following this incomplete combustion is carried out. Despite WOB usage decreased the BTHE, in the engine using of hydrogen increased BTHE for all the tested fuels which are D100, B10 and B20. After these results, Hydrogen volumes were increased in order to see effects on the BTHE. It was seen that amount of the Hydrogen addition to the Waste oil Biodiesels can be eliminated negative effects of the WOB usage. Because, hydrogen has high flame speed, high diffusivity and low quenching distance and these reasons provides more complete combustion. In the tests, B10 (10% Biodiesel + 90% Diesel) + H12 test results of BTHE were slightly higher than Pure Diesel (D). BTHE values are obtained as 31.9% and 32%, respectively.

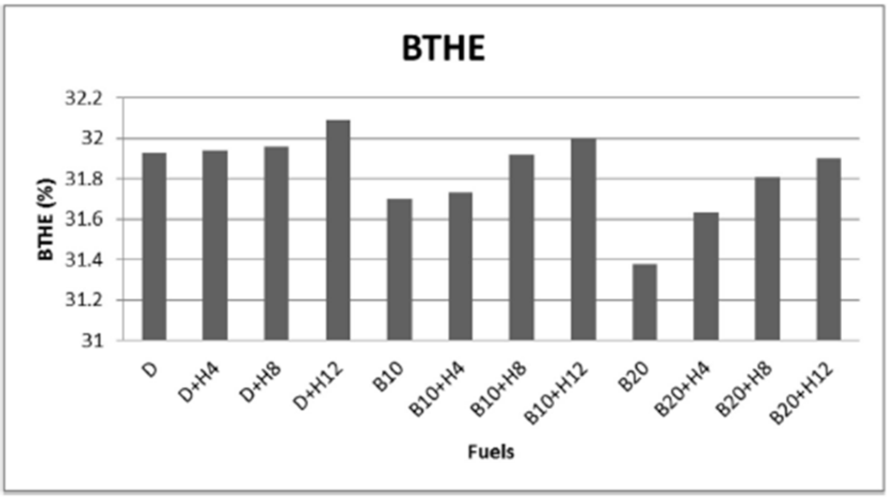

Figure 4.5 : BTHE Values of Test Fuels

4.2.2 Brake Specific Consumption (BSFC)

In order to evaluate fuel economy, Brake specific fuel consumption (BSFC) is one of the most important characteristic performance parameters. In Figure 4.6, BSFC values of the test fuels were shown. As mentioned on above of the BTHE values of the tested fuels are related with BSFC. An increment on the BTHE values, it affects to the BSFC values, vice versa. Also, heating value of fuel is another determinant which affects to the BSFC significantly. Using with biodiesel in the fuels, BSFC increased when it compares to the diesel fuels. BSFC increased 3.8% for B10, while BSFC increased for B20 4.9%. WOB fuel was enriched with Hydrogen and it was seen that considerably increment were observed.

BSFC was decreased in D100+H12, D100+H8 and D100+H4 to 0.50%, 0.26% and 0.11% compare to pure diesel, respectively. However, decrement of the BSFC was not as effective as Hydrogen effect on the BTHE. The use of hydrogen at this rate was not enough to reduce BSFC which increased with the use of biodiesel. BSFC was decreased in B10+H12, B10+H8 and B10+H4to 2.26%, 0.67% and 0.33% compare to B10 blend, respectively.

BSFC was decreased in B20+H12, B20+H8 and B20+H4to 1.66%, 0.41% and 0.22% compare to B20 blend, respectively.

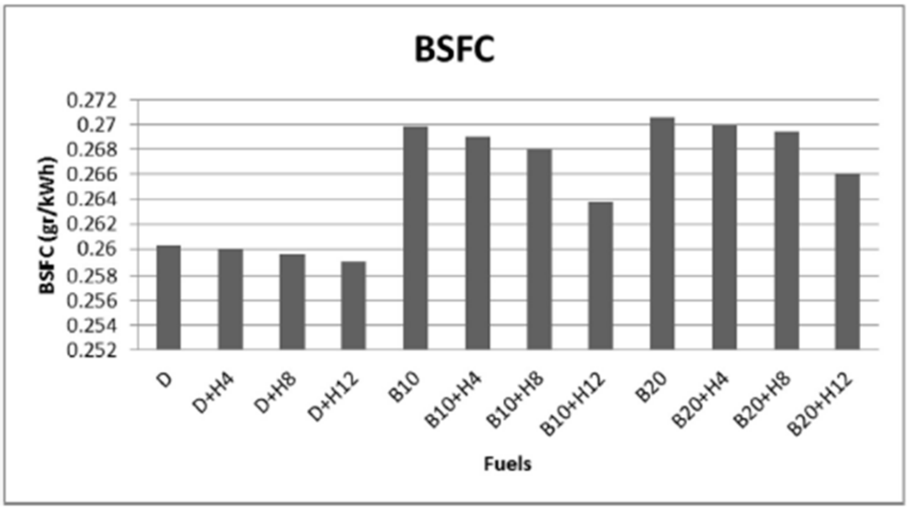

Figure 4.6 : BSFC Values of Test Fuels

4.3 Emissions

4.3.1 Carbon monoxide emissions

In Figure 4.7, Carbon Monoxide (CO) emission results were demonstrated of the test fuels. According to the test results, both WOB and hydrogen usage decreased CO emission. Because of Oxygen content of the WOB causes the CO reduction in the blend.

Hydrogen enrichment also decreased emitted CO since its carbonless molecular structure. Moreover, CO was produced by incomplete combustion results and flame speed functions, high diffusivity provides more complete combustion.

B10 and B20 test fuels decreased CO emissions 2.5% for B10and 3.67% for B20 according to test results when comparing to the pure diesel fuel. Also, when Hydrogen and WOB combined with (B20 + H12), CO emission was decreased significantly 62.5 % compare to the pure diesel.

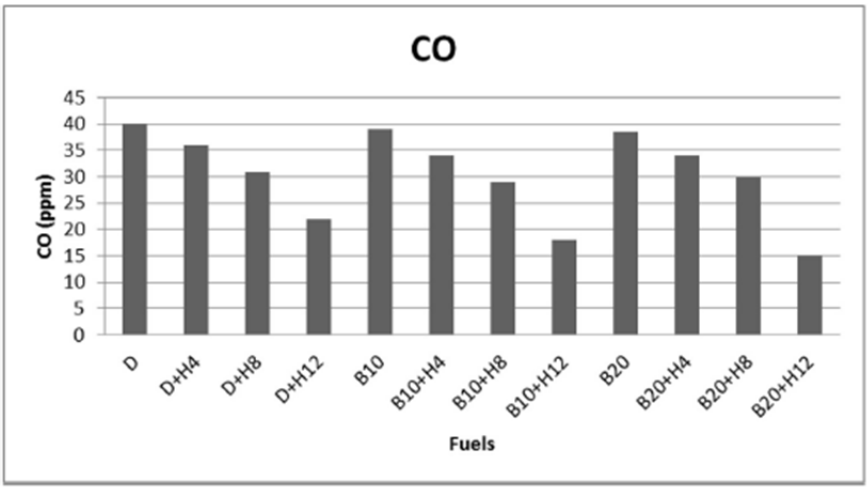

Figure 4.7 : CO Values of Test Fuels

Lower CO compared to diesel and biodiesel fuels emissions were measured. The most important reasons for the decrease in biodiesel fuel the presence of oxygen in the molecular structure and air during use in the engine the excess coefficients are higher than diesel fuel. These two factors are burning CO emissions during the oxidation of CO_2 was effective in the conversion. However, the higher Cetane numbers of biodiesel fuels, the less Sulfur content also had a decreasing effect (Dorado et al., 2003).

4.3.2 Carbon Dioxide emissions

Carbon Dioxide emission values of the test fuel were shown in Figure 4.8. According to the results, WOB blends cause increment in the CO_2 emissions. However, hydrogen addition to the fuels decreased the CO_2 emissions because of its carbonless molecular structural shape. Also, Hydrogen provided combustion more complete in order to convert CO to CO_2.

CO_2 emissions decreased in D+H4, D+H8 and D+H12 comparing to the pure Diesel with 2.61%, 2.83% and 3.33%, respectively.

CO_2 emissions decreased in B10+H4, B10+H8 and B10+H12 comparing to the B10 blend with 0.22%, 0.9% and 0.93%, respectively.

CO_2 emissions decreased in B20+H4, B20+H8 and B20+H12 comparing to the B20 blend with 1.42%, 2.88% and 5.35%, respectively.

CO_2emissions were decreased by addition of Hydrogen, however CO_2 pollutant increased in B20+H12 about 2.69 % comparing to the Pure Diesel fuel.

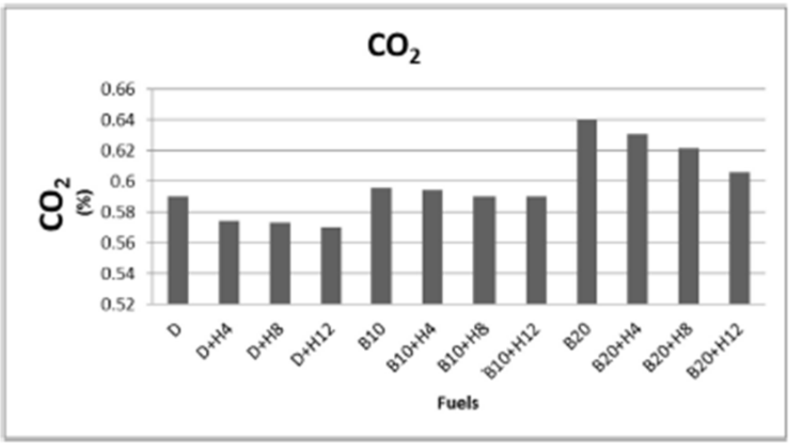

Figure 4.8 : CO_2 Values of Test Fuels

4.3.3 Nitrogen Oxide emissions

NO_x emission results of the test fuels were indicated in Figure 4.9. NO_x emissions were increased in Waste Oil Biodiesel blends. In WOB blends, combustion temperature is generally higher than D100 fuel. Higher cylinder temperatures expedite the formation of NO_x pollutants. Meanwhile, hydrogen NO_x emissions were increased addition with Hydrogen, too. Calorific value of hydrogen is greater than biodiesel calorific value fuel about four times and this value causes increment in cylinder temperature (Aldhaidhawi et al., 2017).

NO_x emissions increased in D+H4, D+H8 and D+H12 comparing to the pure Diesel with 8.03%, 16.06% and 23.36%, respectively.

NO_x emissions increased in B10+H4, B10+H8 and B10+H12 comparing to the B10 blend with 6.9%, 15.86% and 24.82%, respectively.

NO_x emissions increased in B20+H4, B20+H8 and B20+H12 comparing to the B20 blend with 2.75%, 15.17% and 35.17%, respectively.

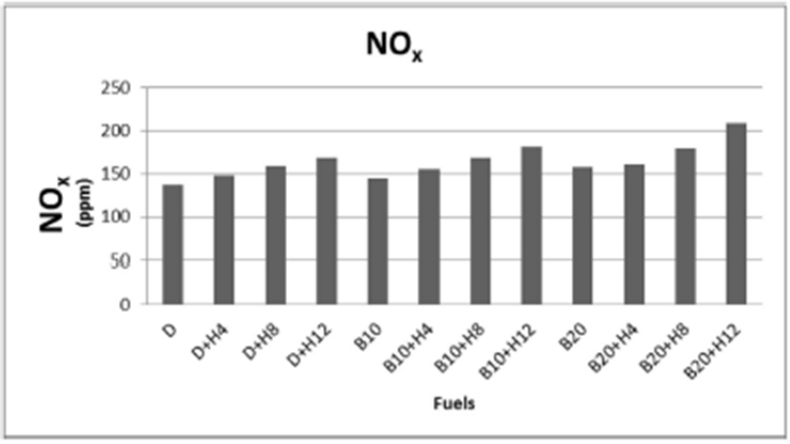

Figure 4.9 : NO_x Values of Test Fuels

Under normal conditions, nitrogen (N_2) with air does not react as a result of combustion. At high temperatures (above 1600 °C) in the combustion engine, nitrogen oxides are formed when the nitrogen contained in the air reacts with oxygen. Nitrogen oxides contain NO. After the exhaust gases are released to the atmosphere, some part of NO is converted into NO_2 and the other part becomes NO_X in contact with oxygen. As a result, nitrogen oxide formation nitrogen oxide increases rapidly as temperature increases (Reşitoğlu et al., 2010).

Nitrogen oxides combine with water in the atmosphere to cause nitric acid formation. As a result, acid rains occur in the atmosphere. Similarly, they combine with water vapor in the lungs, causing nitric acid and nitrous acid formation in the human body.

NO_X depending on the oxygen content of biodiesel fuels emissions may show increasing tendencies compared to diesel fuel values. Because oxygen increases the combustion efficiency and increases the end-combustion temperature nitrogen oxidation of NO_X into NO_X emissions. This NO_X emissions measured by biodiesel fuels increased compared to diesel fuel trends.

Nitrogen oxides generally contain NO as the main element. After the exhaust gases are released into the atmosphere, some of NO are converted to NO_2 and the other to NO_X.

5 CONCLUSIONS

During this study, WOB and hydrogen usage in diesel engine were tested and utilized in terms of emission parameters and engine performance. In this study, all sets of the engine were compression ratio is 18:1and 1500 rpm, also there was no load on the engine.

As a conclusion, all test results are listed below as follows:

- BTHE of the test engine is dropped with addition of the Waste oil Biodiesel and by the usage of hydrogen this reduction was tolerated. So that, 0.3% increment was obtained in BTHE for theB20+ H12 test fuels.

- Brake specific fuel consumptions of the test engine increased for WOB usage, however hydrogen addition decreased for 2.23% in BSFC was obtained for the test fuel B20 + H12.
- CO emission was decreased by using Waste Oil Biodiesel and Hydrogen together. CO emission values were seen minimum for B20 + H12 test fuel.
- WOB blends cause increment in the CO_2 emissions. However, hydrogen addition to the fuels decreased the CO_2 emissions slightly.
- Comparing to pure diesel, NO_x emissions raised up to 51.8% because of increment in the combustion temperatures of Hydrogen and Waste oil Biodiesel.

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