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PERFORMANCE AND EXHAUST EMISSION TESTS OF FUELS OBTAINED FROM WASTE LUBRICATION OIL BY PYROLITIC DISTILLATION

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Performance and Exhaust Emission Tests of Fuels Obtained from Waste Lubrication Oil by Pyrolitic Distillation

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Supervisor
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ABSTRACT

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In this study, production of engine fuels from waste lubrication oils (WLO) by pyrolitic distillation method and investigation effects of the produced fuels on engine performance and exhaust emission are proposed. The system is mainly consisted of a waste oil storage tank, filter, a reactor, a product storage tank, normal and hot oil pumps, variac, heaters, thermostats and control panel. Firstly, the WLO is purified from contaminants such as dust, heavy carbon soot, metal particles, gum-type materials and other impurities in the WLO. A mixture of the waste purified oil and additives named as sodium carbonate (Na_2CO_3), zeolite and lime (CaO) with ratio of % 2, % 4, % 6 % 8 and % 10 are treated to thermal degradation, and fuels are produced applying pyrolitic distillation. Characteristics and distillation tests of the fuels are performed using test equipments. The most important result is obtained that the sulfur in the oil decreases at the lowest value when the WLO was blended with a ratio of 2 % CaO. The fuel obtained as 80 percent of the total WLO is separated into two samples, which are light fuel with 20 % and heavy fuel with 60 % of the total WLO. Characteristic and distillation test results of both fuels are compared with those of standard diesel and gasoline fuel, and it is observed that the results resembles to those of standard gasoline and diesel fuels. Therefore, the light and heavy fuels are named as Gasoline-Like Fuels (GLF) and Diesel-Like Fuel (DLF), respectively. After producing the GLF and DLF, series of tests for determining effect of the GLF and the DLF on engine performance and exhaust emission are performed using the gasoline and Diesel test engines. Force, air and fuel mass flowrate to the engine, engine speed, exhaust temperature and emissions of CO, CO_2, O_2, NO_x and HC for each test are measured using the fuels. It is observed that the produced GLF and DLF can be used in gasoline and Diesel engines without any problem in terms of characteristics, distillation and performance tests. It is understood that the GLF and DLF increase torque, brake power, brake mean effective pressure and thermal efficiency but they decrease brake specific fuel consumption. According to the sulfur test results, it is decreased below to 420 ppm using hydrogen peroxide (H_2O_2) and formic acid. Costs of the GLF and DLF are obtained as 0.718 TL/liter and 1.032 TL/liter, respectively.

Key Words: Waste lubrication oil, recycling system, pyrolitic distillation, engine performance, exhaust emissions.

ÖZET

ATIK YAĞLAMA YAĞINDAN PİROLİTİK DİSTİLASYON İLE ELDE EDİLEN YAKITLARIN PERFORMANS VE EKSOZ EMİSYON TESTLERİ

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Bu çalışmada, pirolitik distilasyon yöntemi ile atık yağlama yağlarından motor yakıtlarının üretilmesi ve üretilen bu yakıtların motor performans ve eksoz emisyonları üzerindeki etkilerinin incelenmesi amaçlanmıştır. Bu üretim sistemi temel olarak atık yağ tankı, filtre, reaktör, ürün depolama tankı, normal ve kızgın yağ pompası, varyak, ısıtıcılar, termostat ve kontrol panelinden oluşmaktadır. Öncelikle atık yağ, içerisinde bulunan toz, karbon ve ağır metal partiküllerden, yapışkan ve diğer maddelerden arıtılmıştır. Arıtılan yağ sodyum karbonat (Na_2CO_3), zeolit ve kireç (CaO) gibi katkı maddeleriyle % 2, % 4, % 6 % 8 ve % 10 oranlarında katılarak, karışımlar ısıl bozulma işlemine tabi tutulmuş ve pirolitik distilasyon yöntemi ile yakıtlar üretilmiştir. Bu yakıtların karakteristik ve distilasyon testleri yapılmıştır. Bu testlerin sonucunda en önemli bulgu ise atık motor yağına kütlesel olarak % 2 CaO katıldığında, kükürt miktarının en aza düştüğü görülmüştür. Yapılan inceleme sonucunda % 80 oranında elde edilen yakıtın, % 60'ı ağır, % 20'si ise hafif yakıt olmak üzere iki kısma ayrılmıştır. Her iki yakıt bileşeninin özellikleri standart benzin ve motorinin aynı özellikleriyle karşılaştırılmış, hafif olan bileşenin benzine, ağır olan bileşeni ise dizel yakıtına benzer özellikler gösterdiği gözlenmiştir. Bu yüzden bu yakıtlar Benzin Benzeri Yakıt (BBY) ve Dizel Benzeri Yakıt (DBY) olarak adlandırılmıştır. BBY ve DBY üretildikten sonra, bu yakıtların motor performans ve emisyon testleri üzerindeki etkilerinin belirlenmesi için test motorları ile bir dizi testler gerçekleştirilmiştir. Testler sırasında motor şaftına uygulanan kuvvet, hava ve yakıt debileri, motor hızı, eksoz sıcaklığı ve emisyonlardan CO, CO_2, O_2, NO_x ve HC miktarları ölçülmüştür. Yapılan karakteristik, distilasyon ve performans testlerine göre BBY ve DBY'nin motorlarda problemsiz olarak kullanılabileceği gözlenmiştir. Yapılan hesaplar sonucunda GLF ve DBY motorun torkunu, gücünü, ortalama efektif basıncını ve ısıl verimini artırdığı, fakat özgül yakıt tüketimini ise düşürdüğü anlaşılmıştır. Kükürt testlerine göre ise, yakıta hidrojen peroksit (H_2O_2) ve formik asit katıldığında kükürt miktarı yaklaşık olarak 420 ppm'e düşürülmüştür. Yapılan maliyet hesaplamalarında BBY ve DBY'nin maliyetleri sırasıyla 0.718 TL/litre ve 1.032 TL/litre olarak tespit edilmiştir.

Anahtar Kelimeler: Atık yağlama yağı, geri dönüşüm sistemi, pirolitik distilasyon, motor performansı, eksoz emisyonu.

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LIST OF SYMBOLS

Bmeb	brake mean effective pressure
Bsfc	brake specific fuel consumption
DLF	diesel like fuel
EGT	exhaust gas temperature
GLF	gasoline like fuel
HDS	hydrodesulfurization
LSDLF	low sulfur diesel like fuel
m_f	fuel mass flow rate
n_r	number of crank revolutions
ODS	Oxidative desulfurization
Pb	brake power
Q_{LHV}	lower heating value of the fuel
T	brake torque
V	volt
Vd	total volume of engine cylinders
WLO	waste lubrication oil

Greek Symbols

η_{bt}	brake thermal efficiency
ω	brake angular speed

CHAPTER 1

1. INTRODUCTION

Fuel is known as a considerably crucial energy resource in many countries and Turkey as well. The scientists have been driven to research new alternative and renewable energy sources due to the depletion in fossil based energy sources and especially in petroleum resources, also clustered energy sources in certain region of the world. Recycling of the waste oil has considerably been a new research area for serving them to human society. In this respect, in our country and in all over the world, waste oil has become an important energy sources not to be despised since lubricant oil which is 97 percent petroleum based is increasingly being used in different industries. The lubricant oil is become vitally dangerous for environment when they are left in the environment. In our country, about 500.000 tons of lubricant oil is being used, yearly. Since, one litter of waste lubricant oil can contaminate 800.000 litters of water, and 5.000.000 drinking water, the recycling of the waste lubricant oil has become very crucial. Environment can be prevented from this pollutant by recycling. 500.000 tons of usable waste lubricant oil can be converted 300.000 tons to diesel fuel, 100.000 tons to gasoline. It is highly important for environmental protection to convert this lubricant oil. Petroleum based wastes are either converted to fuel by various processes or converted to different chemical components in order to reduce poisonous effects of them. However, because of their sulfur, nitrogenclorine and bromine contents waste lubricant oils are difficultly converted to engine fuel. The sulfur of waste lubricant oils reacts with the zinc oxide (ZnO), ferric oxide (Fe_2O_3) and or with copper oxide (CuO) content of the oil resulting lower sulfur content in the oil. Waste oils can be chemically destructed by heating in oxygen-free conditions. The main advantage of this method is that not polluting environment. On the contrary, as the pyrolyzed oil contains a great deal of unsaturated hydrocarbon it can be repolymerized [2].

The wastes of many industries pollute environment depending on rapid development. These wastes should be recycled to reduce their harmful effects on environment. Due to their high energy potential, the idea of using petroleum based plastics and mineral oils as energy resource has been developed.

It can be seen from Table 1.1 that used motor oil has a high energy potential, but it can not be used as fuel before removing some dangerous materials. Because waste motor oil contains sulfur, heavy metals and chlorine and these materials are very dangerous for environment when they burned. There remains a need for improvement within the art of converting used motor oil to a high quality energy source.

Fuel	**Heating Value (kj/kg)**
Coal	8,303 - 29,806
Natural Gas	31,736
Raw Petrol	42,622
Used motor oil	43,070

Table 1.1 Lower heating values of some fuels.

According to petder 2008 activity report the waste oil collection in Turkey from the years of 2004 to 2008 is given in Figure 1.2. It can be seen from this figure that the oil collection is in a large amount. Lubrication oils lost their chemical and physical properties, after they have been used a time period. Therefore used oil should be collected and recycled.

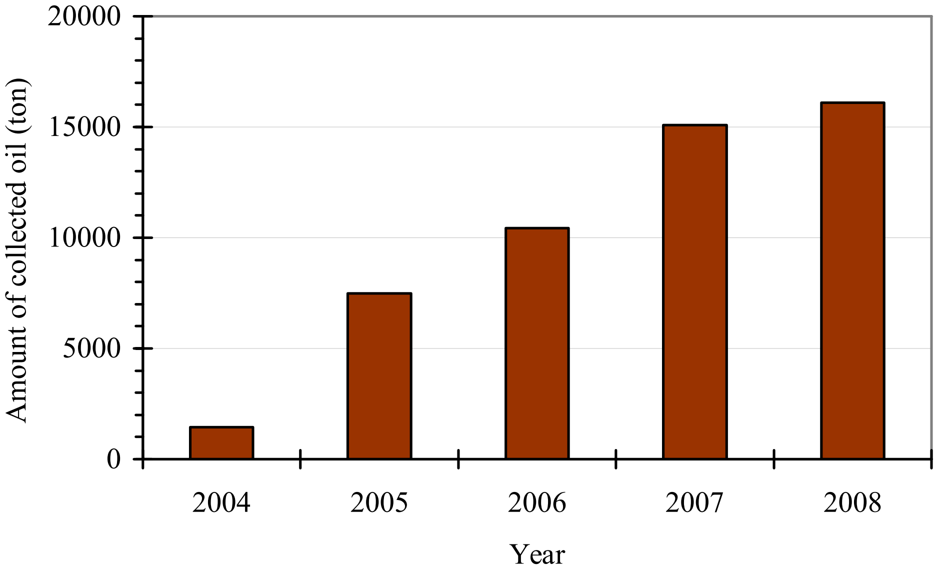

Figure 1.1Total used oil collection between 2004–2008

With the utilization of the waste engine oil and lubricants as diesel oil by applying filtration process, protection of environment, and economical value are supplied. After the engine oils are used during a definite time period, they transform into waste oil which is very detrimental to the environment. According to 2008 activity report of PETDER waste oil has the following hazards:

a) Waste oil pollutes the environment; it has a harmful effect on the living organism. Therefore it should not be discharge into the soil or water.

b) It should not be burnt in ovens because heavy metals and chlorine components will be discharged to the atmosphere as result it pollutes the air and it has harmful effect for human health.

c) One liter waste oil makes 800,000 liters drinking water unusable.

These wastes can be very harmful to environment when used without any modification or conversion. The lubricant oil which is used in industrial and transport sectors after being used for a certain period are becoming poisonous for environment. In our country, a legal regulation has recently been brought arrange collecting and controlling waste lubricant oil from engines. According to the Law No. 4856 on establishment and Duties of the Ministry of Environment and Forestry and the By-law on Control of Waste Oils discharge waste oils and residues resulting from processing of waste oils into internal surface waters, ground waters, coastal waters, drainage systems and soil, using waste oils causing air pollution which exceeds the level prescribed by existing provisions and mixing waste oils with water, solvents, toxic and hazardous substances have been prohibited.

In this study fuel from waste lubrication engine oils by pyrolitic distillation method, which can be used in engines has been investigated experimentally. Chapter 2 presents the literature survey on this subject. Literature review has been classified as pyrolysis of waste lubrication oil, engine performance and exhaust parameters, and desulfurization process.

The third chapter represents fuel production system from waste lubrication oil. Design of fuel production system and its components which were used in this study are explained and technical specifications of each component were given. A purifying and distillation system was designed and manufactured to purify waste lubricant oil from hazardous materials and reutilize the waste lubricating engine oil. For this purpose, control and measurement elements were installed on the system. The system was installed in the Motor Laboratory, Department of Mechanical Engineering, University of Gaziantep. To investigate the effects of catalysts on the yields of distillation the purified oil samples were blended as mass basis of 2 %, 4 % 6 %, 8 % and 10 % with catalysts known as sodium carbonate, zeolite and lime.

Thermal and physical properties of the purified waste oils such as kinematical viscosity, density, flash point, and sulfur content and distillation tests were determined. From these results, lime has the highest effect on decreasing of sulfur content of the waste engine oil. It is observed that distillation curves obtained by blending of 2 % zeolite and lime in to the engine oil indicates similar behavior with distillation curve of a diesel fuel for exceeding of 30 percent of the sample.

Characteristics, performance and exhaust emissions tests of the produced DLF are subject of Chapter 4. The characteristic tests such as density, viscosity, flash point, heating value, sulfur content and distillation of the DLF sample are performed utilizing test equipments presented in motor laboratory of Mechanical Engineering Department, University of Gaziantep, Turkey. Performance and exhaust emission tests for the DLF are performed using diesel test engine. It is observed from the test results that about 60 cc out of each 100 cc of the waste oil are converted into the DLF. Characteristics and distillation temperatures of the DLF are close to those values of a typical diesel fuel sample. It is observed that the produced DLF can be used in diesel engines without any problem in terms of engine performance. The DLF increases torque, brake mean effective pressure, brake thermal efficiency and decreases brake specific fuel consumption of the engine for full power of operation.

It is observed that amount of sulfur in DLF is higher than standard value and it should be decreased to protect environmental pollution, via chemical methods. Oxidative desulfurization method (ODS) was used to remove sulfur from DLF and sulfur level decreased from 3500 ppm to 420 ppm. After desulfurization process new fuel which is named as Low Sulfur Diesel Like Fuel (LSDLF) was obtained in chapter 5. Thermo physical properties of LSDLF such as density, flash point, viscosity, lower heating value, and distillation curve were investigated. Engine performance and exhaust tests of LSDLF are shows that performance and exhaust emission parameters of LSDLF lower than those of LSDLF.

The light fuel named as gasoline-like fuel (GLF) and gasoline samples are used to investigate the effect of the GLF on performance and emissions of a 1300 cc engine manufactured by Fiat in Chapter 6. The experimental results showed that the GLF had a positive effect on brake power, thermal efficiency, mean effective pressure and specific fuel consumption. The GLF also raised CO emission and exhaust temperature, but it decreased hydrocarbon (HC) in the exhaust.

Chapter 7 presents results of experimental investigation on engine performance and exhaust emission of a gasoline (SI) engine fueled by GLF, and blends of GLF and turpentine. The GLF was obtained from waste lubrication oil via pyrolitic distillation method. Characteristics of the pure GLF and its mixture with turpentine with amount of 10 %, 20 %, and 30 % such as density, flash points, kinematic viscosity, heating value and distilled temperatures were tested by using measurement equipments. Engine performance and exhaust emission parameters were measured by using the fuel samples in the Fiat 1300 cc SI test engine. The results indicate that torque, brake mean effective pressure and thermal efficiency increase but Brake specific fuel consumption decreases with increasing amount of turpentine in the GLF sample. The maximum engine torque for blend of the GLF and 30 % of the turpentine is obtained at the engine speed of 2500 rpm. The main effect of 10 %, 20 %, and 30 % turpentine additions to GLF on pollutant formation is that the NO_x ratio increases but that of CO decreases. It is observed that the GLF and blends of the GLF and turpentine with the ratio of 10 %, 20 %, and 30 % can be used as a fuel in the SI engines without any problems according to the test results.

In chapter 8 cost analyses has been done. At all stages of fuel production from waste lubrication oil process, unit cost of raw materials, chemicals, and used energy were determined.

A literature review has been carried out on the recycle of waste engine oil and it has been understood that there are few studies in this topic. In these few studies, the physical properties, engine performance, and exhaust emission parameters of the fuel obtained after recycling process have not been investigated. That waste engine oil have high energy capacity (43070 kj/kg), and minimizing its harmful effects on environment have been the motivation behind the study. Therefore, it has been aimed to obtain fuel from waste lubrication oil which can be used in engines and to investigate the effects of this fuel on engine performance and exhaust emission.

In this study the oil samples with the additives were heated in the reactor and exposed to pyrolitic distillation separately. They were exposed to thermal and pyrolitic treatment in order to convert them into a diesel-like fuel during the heating process. After that process, typical characteristics of the fuel, such as density, viscosity, flash and fire point, sulfur content, heating value and distillation temperatures were tested. 80 % of the total waste lubrication oil was converted into useful fuel, and its remaining part about 20% was rejected as residue. The produced fuel was separated into two fuels according to characteristics and distillation test results. These fuels are named as gasoline-like fuel (GLF) and diesel-like fuel (DLF). It was necessary to separate the light and heavy samples from each other to eliminate lighter amount of the fuel sample or detrimental effects of the fuel on an engine. Since, first 25 percent of the produced fuel is lighter than diesel fuel. Light and heavy fuels named as GLF and DLF were obtained approximately 25 % and 75 % of the produced fuel respectively.

Three main tests, which are characteristics, performance and exhaust emission tests, were performed in this study. Characteristics of the fuel samples used in the SI test engine such as density, flash point, lower heating value (LHV), and distillation tests were examined. Engine speed, torque, air and fuel consumption, exhaust gas temperature and emissions tests were done.

CHAPTER 2

2. LITERATURE SURVEY

2.1 Introduction

In this chapter previous study about recycling of waste engine oil, desulfurization methods of fuels, engine performance and exhaust reviewed. A literature review has been carried out on the recycling of waste engine oil and it has been understood that there are few studies on this topic.

The present literature was classified in three groups as recycling of waste engine oil, engine performance and exhaust emissions, and desulfurization studies.

2.2 Recycling of Waste Engine Oil

As known fossil energy sources have been exhausted rapidly nowadays, it is predicted that fossil fuel sources will be depleted in the near future [1]. According to some studies, it is estimated that crude oil will last only for roughly 80 more years, gaseous fuels for about 150 years, and coal for 230 years. Therefore, scientists and researchers all over the world are now working hard to discover new sources of energy for the future, and also try to develop new technologies that allow recycling or reusing waste material as a source of energy [3]. Many research works addressed the utilization of waste oils that are of lubricating oils originated from crude oil [3] and biomass origin waste oils for the case of diesel engine applications [4-6] as sources of energy. Mineral waste lubricating oil sources, particularly engine oils have attracted much attention as an alternative energy source. It is renewable, available everywhere and proved to be cleaner fuel and more environment friendly than fossil sources. The lubricating oils can be recycled as lubricating oil, and re-used as fuel or made into diesel-like fuel.

Production of diesel-like fuel from waste oils such as industrial and engine waste oils, wood pyrolysis oils, fresh and waste fats and vegetable oils is an excellent way for producing alternative fuel sources. Industrial and engine waste oils [7], wood pyrolysis oils [8], fresh and waste fats and vegetable oils [9] have been proposed as pyrolysis raw material to produce gasoline and diesel-like fuels. There is plenty of the waste engine oil in the world. Abundant amounts of used engine lubricating oils are produced worldwide every year [10]. Annually, about 40 million metric tones are produced, and around 60 percent of the production becomes waste [11]. Less than 45 % of available waste oil was collected worldwide in 1995, and the remaining 55 % was either misused or discarded by the end user in the environment [12]. It should be collected and re-used in order to decrease detrimental effects on environment, and underground and surface waters, since it pollutes the atmospheric air as a result of burning, and has negative effects on living organisms, underground and surface waters when it is discharged into soil or water. Conversion of the waste engine oils into diesel-like fuel by using pyrolitic distillation, and by utilization of the product as a diesel fuel has positive effects on environment and atmospheric air, and also has economical value.

Recycling and utilizing of waste oils have received significant attention all over the world, since waste lubricant oils are considered toxic and hazardous because of the presence of metal particles remaining from the additives such as phenols, compounds of zinc, chlorine and phosphorus, chlorinated compounds, polycyclic aromatic hydrocarbons and other residues [10]. Waste materials of petroleum are exposed to various processes and then used as fuel or they are converted into various chemicals in order to minimize the harmful effects of these wastes [13]. However, materials, such as sulfur, nitrogen chlorine, and bromine found in waste oils are the most important factors making it difficult to recycle waste oils for various purposes including the production of fuel [14]. The sulfur found in waste oils precipitates by undergoing a chemical reaction with metal oxide powders, such as zinc oxide (ZnO), iron oxide (Fe_2O_3), and copper oxide (CuO) in a certain temperature, so sulfuric acid can be decomposed from the oil [15-16]. Waste oils can be reconstructed chemically by being heated in an oxygen-free environment [13]. The most important advantage of this method is that it does not pollute the environment when carried out in an appropriate way.

The use of lubricating oils in various applications is increasing due to its importance. Petroleum derived base oils currently account for about 97 % of the total lubricant production. The thermal and catalytic treatment of waste lubricant oil into fuel oil or chemical feedstock is one of the best methods protecting the environment from toxic and hazardous chemical present in waste lubricant oil. However, the presence of heteroatoms such as sulfur, nitrogen, chlorine, and bromine in waste lubricant oil poses serious problems for secondary use as a fuel or any other application [15].

The waste lubricant oil has become a serious problem for environment. Recently recycling of waste oils has received significant attention all over the world. Lubrication oils were discarded after use and ended up in landfills. Landfill is no longer an acceptable means for disposal of petroleum wastes due to serious environmental problems [26].

Animal studies have shown an increased incidence of skin tumors in mice after long-term skin exposures to used mineral-based crankcase oil from gasoline-powered cars, with more tumors observed in mice exposed to oil from cars driven the longest distances. The increase in carcinogenicity was attributed to accumulation of PAHs (Polycyclic aromatic hydrocarbons) in the oils, given the correlation between tumor incidence and the PAH content of the oil (Agency for Toxic Substances and Disease Registry, 1997). In support of this hypothesis, McKee and Plutnick reported no tumors in mice exposed to new motor oil [24].

A large amount of used mineral-based crankcase oil is generated each year when motor oil is changed. It is usually discarded into the environment or recycled, but some other uses for it exist. Some industries mix used mineral-based crankcase oil with other oils to produce cutting oils or other lubricating oils. Used mineral-based crankcase oil can also be burned. It burns at about 300-400 °C, depending on the mixture of chemicals in the used mineral-based crankcase oil. It has been used as a fuel in oil burners in homes, as well as in industrial steam boilers, municipal incinerators, and rotary cement kilns. It is also used in producing asphalt. In the past, used mineral-based crankcase oil was also used on dirt roads to control dust. However, most states currently restrict this use [28].

Bhaskar et al. [15] studied the thermal and catalytic treatment of waste lubricant oil with silica, silica–alumina, and alumina supported iron oxide catalysts was performed at 400 °C at atmospheric pressure. It has been reported that Fe/SiO_2

catalyst decreased the sulfur content from 1640 to 90 ppm and produced low molecular weight hydrocarbons by cracking the high molecular weight hydrocarbons. Fe_2O_3 crystalline size was found to be smaller in Fe/SiO_2 catalyst than Fe/Al_2O_3 and $Fe/SiO_2–Al_2O_3$ catalysts. The $Fe/SiO_2–Al_2O_3$ (86 %) and Fe/Alumina (90 %) catalysts could decrease the sulfur content, however, with the increase of reaction time, the desulfurization activity was found to decrease.

The kinetics of waste automobile lubricating oil have been studied experimentally and modeled mathematically by Kim and Kim [21]. Their experiments were carried out in the tubing bomb micro reactor at a temperature of 420–440 ^{o}C and reaction times of 5–50 min. The volume of the tubing reactor was 39 ml. A sample mass of 5 g was charged into the tubing reactors for all experimental runs. Molten salt bath, which has excellent heat transfer properties, was used for the pyrolysis of waste automobile lubricating oil. Eutectic salt of KNO_3 (59 wt %) 1 $Ca(NO_3)_2$ (41 wt %) has been used. They reported that the yields of gas (C1–C4) increased until 20 min of reaction time and thereafter decreased with a further increase in the reaction time at the experimental temperatures. The coke content of the products was 1–2 % and the yield of oil was 95–98 % at different residence times and temperatures.

Thermal decomposition of raw waste lubricant oils in helium atmosphere conditions and with different proportions of helium: oxygen was studied [11] to investigate effects of helium and helium-oxygen atmosphere. Primary thermal devolatilization of waste oils is independent of the presence of oxygen, and consists mainly in a vaporization process, as was confirmed analyzing the flue gas evolved from a pyrolysis process at 500 ^{o}C. This can be modeled satisfactorily assuming that the oil is formed by two independent fractions: a main one (92.6 %) which simply evaporates, and a second one which decomposes yielding gases. The volatile gases evolved under go through pyrocracking reactions at higher temperatures (850 ^{o}C), yielding light olefins (40 %), methane and aromatic compounds, and coke in typical incineration conditions. When air is present, these fuel gases formed during the pyrolysis are burnt.

As a consequence of the growing awareness of the need to protect the environment, a study was undertaken to investigate the impact of the use of recycled waste oils as an industrial fuel in relatively small industrial units. Combustion tests were carried out in a 240 kW experimental furnace with oils that had been subjected to pretreatment involving centrifugal separation of solids present. However, the analysis of the combustion gases demonstrated that the levels of principal contaminants such as lead and other heavy metals were still too high to meet the emission levels required by the European Union. It has been suggested that physical processes are inadequate to remove the contaminants present in waste oils [22].

The pyrolysis and combustion of waste lubricant oil have been studied through a thermo gravimetric analysis in nitrogen atmosphere conditions and with different proportions of nitrogen: oxygen (pyrolysis with N_2, combustion with 4:1 and 9:1 ratios N_2:O_2 mixtures), different weights (1–5 mg) and different heating rates (5, 10 and 15 ^{o}C min^{-1}) in [10] to analysis the volatilization and thermal decomposition. The identification of the volatile and semi volatile compounds from pyrolysis and combustion was also carried out in a tubular reactor at 500 and 850 ^{o}C. The semi volatile compounds were detected in pyrolysis and combustion at the lowest temperature, 500 ^{o}C, these appear in small quantities, indicating that the waste oil undergoes small changes. As far as pyrolysis and combustion volatile compounds are concerned, the yields of pyrolysis at 500 ^{o}C were very small but significant yields of methane and ethane can be observed in combustion at 500 ^{o}C.

Used oil has been found to contain arsenic, barium, cadmium, chromium, lead, manganese, nickel, and zinc. The presence of these metals is due to the breakdown of lubricating oil additives (e.g., barium and zinc), wear from engine parts (e.g., arsenic, cadmium, chromium, nickel), or piston blow-by (e.g., lead in gasoline). Numerous other metals are present in used oils such as aluminum, copper, iron, magnesium, silicon and tin; however, they are generally not given much attention due to their low concentrations and low toxicities [23].

Kuen-Song et al. [25] investigated a waste engine oil catalytic gasification for generating high-purity hydrogen with 15 wt. % NiO/Al_2O_3 catalysts. In a lab-scale fixed-bed downdraft experimental approach, catalytic gasification of waste motor oil was accompanied by a substantial production of syngas at 760–900 K. They have been reported that Ni species in Ni/Al_2O_3 were highly dispersed. So, a complete oxidation of WMO occurred to form Ni on the catalyst surface and start to generate the production of hydrogen. The material and energy balances of the 10 tons per day gasifier system pointed out that 85 % (dry basis) of H_2 and CO were generated at 900 K and 46.2 atm, and in addition to the hydrogen generation, approximately 9.7 10^5 watts of thermal energy may be recovered.

Wansbrough et al. [27] developed a process for thermal cracking of waste motor oil into a diesel fuel product. Thermal cracking from 625 ^oF to 725 ^oF with ambient pressure to generate a column distilled fraction of diesel fuel mixed with light ends, the light ends being flashed off to produce a high quality no: 2 diesel fuels.

Engine lubricating oil does not ''wear out.'' A number of processes are available for purification and reprocessing of the lubricating oils. Recycling of the used lubricant is one option. At present, three methods are used for recycling: reprocessing, reclamation and re-refining. Reprocessing is used to make used oil suitable for combustion as burner fuel. Reclamation involves a higher degree of processing and is primarily used for industrial lubricants [29].

Lubricating oils mainly consists of two materials namely the base oil and the chemical additives. Various types of additives are blended with the base oil according to its grade and specific duty. These additives can be metallic detergents, ashless dispersants, zinc dithiophosphate, anti-oxidant/anti-wear, friction modifier, antifoam and pour point depressants because of the changes that occur during use, engine oils tend to differ in chemical and physical composition from virgin oil. In general recycled oils have: a much higher water and sediment levels than virgin oil; relatively higher concentrations of toxic organic compounds; and relatively higher levels of metals such as Fe, Cd, Cr, Pb, etc [30].

Lubricating oils are the most valuable constituents in crude oil. Used lubricating oils are by-products of oil used in vehicles and machinery. They must be replaced on a regular basis in all operating equipment due to the contamination from dirt, water, salt, metals, incomplete products of combustion, or other materials. The principal source of contamination during oil use is the chemical breakdown of additives and the subsequent interaction among the resultant components to produce corrosive acids and other undesired substances [31].

Some researchers [32] investigated the combustion of used engine lubrication oil in a diesel engine. Aim of their study is to develop the way to utilize WLO for diesel fuel at such a generator plant. Combustion characteristics of WLO are in detail investigated by observation of burning flames in a visual engine and by engine test run. As results of comparison between ULO and heavy fuel oil (HFO), WLO shows rather better ignition quality in the visual engine and lower smoke emission from the running test engine than HFO. However, as abnormally thick deposit of combustion products is found in the combustion chamber after a short time running, it is confirmed that some process to remove the additives from ULO before supplying to the engine is essential for the practical use.

In another work Bechtold and Lestz [33] also considered the combustion of WLO/fuel-oil mixture with different volume mixing ratios in a single cylinder diesel engine. They compared the emission results they obtained for the different fuel mixtures used with the results of a baseline case in which only the fuel oil is used. Based on their comparison it was concluded that there is no appreciable difference in smoke density or mass of emitted particulate matter as compared with the results of the baseline values. Further more, deposit formation is found to be higher when WLO/fuel-oil mixture is used.

Berry and McDonald [34] reported that 330000 gallons of used lubricating oil was burned as a portion of the total fuel requirement for a dry-process cement kiln which is located in Canada. The plant uses a dual four-stage preheater with a by-pass system. The oil was primarily composed of automotive crankcase draining and contained approximately 0.6 % lead, 0.15 % bromine, 0.1 % zinc and 0.1 % phosphorus. Lead, zinc and phosphorus emissions in the kiln exhaust gases were not found to be increased during waste-oil burning. A small reduction in particulate emissions was found during waste-oil burning.

The feasibility of using waste lubrication oil (WLO), as an energy source, was investigated in [3] experimentally. WLO was co-fired with LPG as a dual fuel. The study concludes that WLO is a very significant energy source and represents an energy management opportunity with great potential. Moreover, by co-firing even a small amount of WLO with gaseous fuels such as LPG the radiation form the gaseous fuels flames gets enhanced significantly. One major concern remaining is the impact of WLO combustion on the environment. It has been recommended that, further tests and analysis of the composition of WLO and the characteristics of the emission from its combustion are needed.

High temperature pyrolysis and cracking of waste thermoplastic polymers, such as polyolefines, polyethylene, polypropylene and polystyrene, are well-known and environmentally accepted methods of their utilization. This group of processes embraces thermal pyrolysis and cracking, catalytic cracking and hydro cracking in the presence of hydrogen. Pyrolysis is the typical chemical recycling process, enabling production of monomers, mainly ethylene, propane and butane from waste plastics. In case of cracking processes, their main products are fuels fractions, gaseous hydrocarbons and liquid mixtures of hydrocarbons boiling in the range of temperatures ~35–360 ^{o}C (gasoline and light gas oils) as well as the solid carbon residues, similar to coke [35]. Numerous papers present the results of application of various acidic catalysts, such as silica–alumina, zeolites or alkaline compounds such as ZnO, CaO and K_2O [36-39]. An interesting method of polymers utilization is cracking, similar to the visbreaking of vacuum residue or catalytic cracking of vacuum gas oil in the presence of various zeolites containing cracking catalysts [40]. Some inventors propose cracking of melted polymers together with petroleum and carbon derived fractions or biomass with using of typical commercial and laboratory prepared catalysts [39, 41].

2.3 Sulfur Removing Process

Recently sulfur removing process from hydrocarbon fuels is becoming an important subject for researchers. Environmental regulations in developed countries call for the production and use more environmental friendly fuels which have low sulfur.

The available regulations in European Union and the USA calls for a maximum sulfur level of 50 ppm in gasoline and diesel by 2005 and it has been aimed reduce sulfur level below 10 ppm by the year 2010 [42, 43].

Crude oil typically contains about 1 wt % of sulfur; during combustion of fuels, SOx, a major air pollutant, is emitted. Nevertheless, legislation should be in force by the year 2005, stipulating that diesel fuels cannot contain more than 0.05 wt % of sulfur. Due to increasingly restrictive legislation on the number of heteroatoms, especially sulfur, the production of “cleaner” distillate products is a major challenge for refiners [44].

Chan et. al [45] have tested $CoMoS/Al_2O_3$ catalysts containing different amounts of fluorine for the hydrodesulfurization of dibenzothiophene, methyldibenzothiophene, and dimethyldibenzothiophene. They have reported that fluorine addition enhances the catalytic activity due to the increase in the metal dispersion and the acidic sites, Fluorine addition increases the amounts of active phase, Co–Mo–O, in the catalyst possibly by enhanced metal dispersion, therefore promoting the hydrogenation pathway in the hydrodesulfurization mechanism.

Conventional hydrodesulfurization (HDS) with Mo, Ni or W-based catalysts are widely used to reduce sulfur content. This method requires high temperature and high pressure, making HDS a very costly option for deep desulfurization. Moreover, HDS is not effective for removing hetrocyclic sulfur compounds such as Dibenzothiophene (DBT) and its derivatives especially 4,6-dimethyldibenzothiophene (4,6-DMDBT). There are many research and development efforts both on the conventional hydrodesulfurization and on alternative methods such as selective adsorption, biodesulfurization, oxidation/extraction (oxidative desulfurization) etc. for removing these refractory sulfur compounds from petroleum products [47-53].

Thiophene, benzothiophene, dibenzothiophene, other condensed-ring thiophenes, and substituted forms of these compounds are particularly difficult to remove by hydrodesulfurization. The principal of hydrodesulfurization process is catalytic treatment with hydrogen to convert the various sulfur compounds to hydrogen sulfide [53, 54].

Some acidic supports such as silica-alumina and zeolites as well as alumina for NiMo and CoMo sulfides were examined in the HDS of current gas oil with 340 ppm S by adding 1.67 % H_2S in hydrogen to define their roles to enhance the tolerance against H_2S. The level of H_2S addition was prescribed by considering the amount to be produced from the desulfurization of conventional straight run gas oil, since such a level of product is believed to inhibit the deep desulfurization of the gas oil over the conventional catalyst. Hydrotreated gas oil containing 340 ppm of sulfur was successfully desulfurized to less than 10 ppm S [55].

Effects of the H_2S partial pressure on the catalytic activity and product selectivity of the hydrodesulfurization (HDS) reactions of dibenzothiophene (DBT) and 4,6-dimethyldibenzothiophene (4,6-DMDBT) were investigated over the sulfided $NiMo/Al_2O_3$ and NiW/Al_2O_3 catalysts under the deep desulfurization conditions (sulfur concentrations <0.05 wt. %). In the HDS reaction of DBT and 4,6-DMDBT over NiMo and NiW catalysts, the effects of H_2S on catalytic activity were investigated under deep desulfurization conditions. The addition of Ni on NiMo catalyst weakened the inhibiting effects of H_2S on the HDS activity compared with Mo catalyst. NiMo catalyst was less susceptible to the inhibiting effect of H_2S than NiW catalyst. It was suggested that the addition of Ni relatively suppressed the competitive adsorption of H_2S with DBTs, and then decreased the H_2S inhibition on the HDS reactions of DBTs [56].

Commercial $Co-Mo/Al_2O_3$ catalyst and the synthesized Co-Mo supported carbon catalysts have been compared for activity in the hydrodesulfurization (HDS) of dibenzothiophene (DBT), 4,6-dimethyldibenzothiophene (4,6-DMDBT) and hydrotreated diesel fuel. HDS experiments were carried out in a batch magnetically stirred micro autoclave reactor at 2.9 MPa hydrogen pressure and temperature range from 300 ^{o}C to 380 ^{o}C. Carbon supported catalysts were found to be more active than analogous alumina supported catalysts for both model compounds and commercial diesel fuel. The most active preparation was over three times more active for DBT HDS than a comparable commercial HDS catalyst. For all catalysts studied, the selectivities were close at the same temperature, it was observed that there was a dramatic change in the preferred mechanistic pathway for desulfurization of 4,6-DMDBT. At low temperature, the hydrogenative route is preferred but at high temperature, direct desulfurization predominates [57].

Oxidative desulfurization (ODS) has been given much attention as an alternative technology for deep desulfurization. The ODS is basically a two-stage process, oxidation, followed by liquid extraction. In the ODS process, the sulfur containing compounds are oxidized using appropriate oxidants to convert these compounds to their corresponding sulphoxides and sulphones [46].

Desulfurization of gasoline and diesel fuels has been investigated by chemical oxidation of sulfur containing compounds with hydrogen peroxide in the presence of an acid catalyst such as formic acid and acetic acid, followed by extraction of the oxidized compounds using acetonitrile. Oxidative desulfurization (ODS) of diesel fuel was found to be very promising approach for the reduction of up to 92 % of sulfur at low temperature (50 ^{o}C) and atmospheric pressure. The sulfur level of standard diesel fuel was reduced from the original value of 1044 ppm to less than 100 ppm [46].

2.4 Engine Performance and Exhaust Emissions

National interest in generating alternative fuels for internal combustion (IC) engines continues to be strong due to environmental concerns and/or the uncertainties associated with the future availability of fossil fuel. Mostly, the interest lies in identifying alternative sources of fuel energy supply. The motivation for the need for diversification has prompted the research worldwide into potential alternative sources of fuel energy for IC engines. One feature of alternative sources of fuel energy is that they are well suited for decentralised development to meet the needs for social and economic progress, especially in rural communities where fossil fuels may be difficult or expensive to obtain [58].

An experimental investigation on the application of the blends of ethanol with diesel to a diesel engine was carried out in [59]. First, the solubility of ethanol and diesel was conducted with and without the additive of normal butanol (n-butanol). 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 (NOx) emissions were different for different speeds, loads and blends.

Some researchers [60] evaluated the environmental impact from the use of some renewable fuels and fossils fuels in internal combustion engines. The following fuels are evaluated: gasoline blended with anhydrous ethyl alcohol (anhydrous ethanol), conventional diesel fuel, and biodiesel in pure form and blended with diesel fuel, and natural gas. The CO_2 emissions, according the fuel type in ton of CO_2 for m^3, were calculated. It is observed that the fuel with less CO_2 emissions to the atmosphere is natural gas and the one that it releases most is diesel fuel. Biodiesel presents a similar situation in respect to diesel fuel. In fact, biodiesel emits larger quantities of CO_2 than conventional fuel, but as most of this is from renewable carbon stocks. This fraction is not counted as greenhouse gas emission from the fuel; on the other hand, biodiesel has more oxygen molecules in comparison to diesel fuel; therefore, the combustion process is more complete and, as consequence, a reduction in the CO emissions is possible.

Tan et al. [61] investigated exhaust emissions such as nitrogen oxide (NOx), unburned hydrocarbon (HC) and carbon monoxide (CO) from a light-duty diesel engine with different sulfur content fuels. The results of their experimentally study showed that:

The SO_2 emission increased with the engine load. This is obvious because that the small fuel quantity in the cylinder at low engine load leads to small sulfur concentration in the air–fuel mixture, and low SO_2 emission in the engine exhaust. The SO_2 emission would increase with more fuel injected in the cylinder. The fuel sulfur content has little effect on the NOx emission. The concentrations of HC and CO emissions from the engine are lowered significantly with decreasing fuel sulfur content. The SO_2 concentration increases with the engine load. The curve relating the SO_2 emission and engine load are similar for all the tested flues, and it decreases linearly with the fuel sulfur content.

Mani et al. [62] obtained a fuel from waste plastics using pirolysis method. They analyzed and compared properties of the oil derived from waste plastics with the diesel fuel. It is reported that the properties of obtained fuel similar to that of diesel. They used waste plastic oil as an alternate fuel in a DI diesel engine without any modification. Table 2.1 shows the properties of waste plastic oil, and diesel fuel.

Table 2.1 Comparison of waste plastic oil and diesel [62].

Property	Waste plastic oil	Diesel
Density 30 °C in (g/cc)	0.8355	0.840
Ash content (%)	0.00023	0.045
Gross calorific value (kJ/kg)	44,340	46,500
Kinematic viscosity, cSt 40 °C	2.52	2.0
Cetane number	51	55
Flash point (°C)	42	50
Fire point (°C)	45	56
Carbon residue (%)	82.49	26
Sulfur content (%)	0.030	0.045
Distillation temperature (°C) 85 %	344	328
Distillation temperature (°C) 95 %	362	340

It can be seen from Table 2.1 the calorific value of the oil derived from waste plastics lower than that of diesel. Their experimental results in Figure 2.1 have showed a stable performance with brake thermal efficiency similar to that of diesel. Carbon dioxide and unburned hydrocarbon were marginally higher than that of the diesel baseline. The toxic gas carbon monoxide emission of waste plastic oil was higher than diesel.

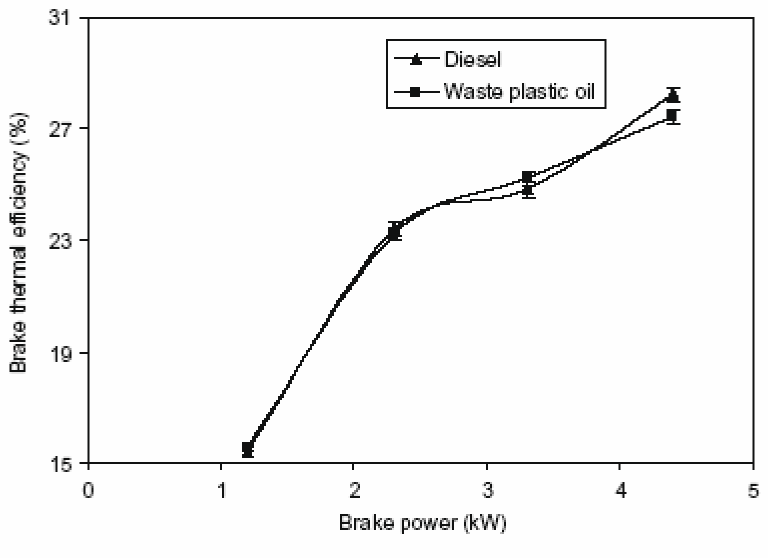

Figure 2.1. Variation of brake thermal efficiency with brake power

CHAPTER 3

3. EXPERIMENTAL SET-UP AND TESTING PROCEDURE

3.1 Introduction

In this chapter, waste lubrication engine oil samples were purified from contaminants, and the clean oil samples were blended with additives of sodium carbonate (Na_2CO_3), lime (CaO) and zeolite. The oil samples with the additives were heated in the reactor and exposed to pyrolitic distillation process separately. They were exposed to thermal and pyrolitic treatment in order to convert them into a diesel-like fuel during the heating process. After that process, the typical characteristics of the fuel, such as density, viscosity, flash and fire point, sulfur content, heating value and distillation temperatures were determined. Effects of the additives on these characteristics were discussed. Also it was discussed whether the obtained fuel would be used in a diesel engine or not.

3.2 Description of the Fuel Production System

A purifying and distillation system was designed and manufactured to purify waste lubricant oil from hazardous materials and reutilize the waste lubricating engine oil. For this purpose, control and measurement elements were installed on the system. The system was installed in the Motor Laboratory, Department of Mechanical Engineering, University of Gaziantep. Schematic representations and picture of the system are shown in Figure 3.1 and 3.2, respectively. The system was consisted of several components, which were named as waste oil storage tank, oil pump and filter, reactor, control panel, fuel storage tank, mixer and condenser. Main functions of the components will be explained briefly. The waste oil storage tank was used to collect waste engine oil or other contaminated oil. The oil pump and filter were used to transfer waste oil sample from the storage tank to the reactor, and then purify the oil from the contaminants. The other most important component is the reactor, which is the heart of the system. Basically, the reactor of this system has a cylindrical shape with inner diameter and overall effective chamber length of about 30 and 40 cm, respectively. The reactor was designed and manufactured to heat the waste oil sample. Its capacity is enough for producing approximately 25 liters fuel. It proved to be adequate for testing the produced fuel characteristics, and engine performance. It includes an electrical heating unit which can be used to heat the waste oil mixture up to 600 °C. The electrical heater has resistance heaters, and a voltage control which is used to adjust the heating rate.

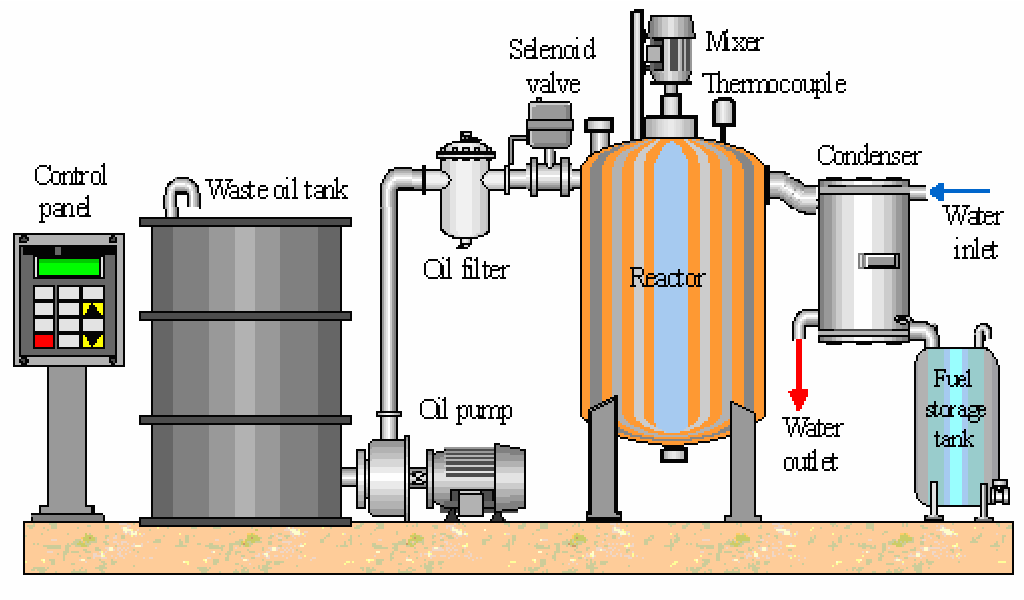

Figure 3.1 Schematic diagram of the purification and distillation system.

Figure 3.2 Picture of the purification and distillation system.

The heating control is performed by the control panel. The mixer is employed for blending the waste oil sample taken into the reactor to obtain uniform temperature in it. If the mixer were not used, then there would be a temperature layer within the reactor. This is a very important system component. Last component of the system is the condenser unit that is used to distillate the oil vaporized in the reactor. A water-cooled condenser was used to condense the fuel vapor vaporized at temperature ranges between 140 ^{o}C and 430 ^{o}C. Temperature measurements were obtained by means of thermocouples placed in the locations where such measurements were needed; namely, in the middle of the reactor and oil vapor streams in the condenser.

3.2.1 Detailed description of fuel production system's components

Fuel production system includes a waste oil storage tank (Fig 3.9), wherein used waste engine oil is collected and stored. Waste oil is drawn out of storage tank by a waste oil transfer pump and delivered to metallic filter which is removing the particulate contaminants from the waste oil. After leaving the filter the waste oil flows into reactor where it is combined with additives such as lime, CaO, and Na_2CO_3. The components of reactor are showed in from Fig 3.5 to Fig 3.7. The reactor has an electrical unit which is controlled by Pt100 platinium resistance thermometer and electronic thermostat Enda ETC 942. The electronic thermometer and electronic control unit are showed in Fig 3.3 and Fig 3.4 respectively.

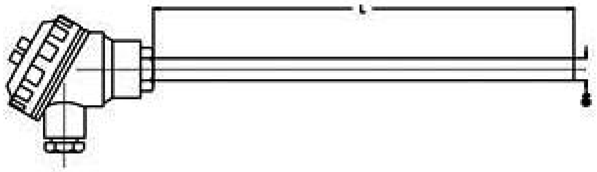

Figure 3.3 PT100 Platinum Resistance Thermometer

PT100 (Platinum Resistance Thermometers) can be used in temperature range of -200°C, + 850°C, they have much more reliability than the thermocouples have. Principle of the measurement of temperature is to measure the resistance of platinum element. PT100, which is the most common resistance thermometer, has 100Ohm at 0°C and 138.4 Ohm at 100°C. The relation between temperature and resistance in small range of temperatures is almost linear. For example, error in 50°C is about 0.4°C if we assume the range from 0°C to 100°C is linear.

ETC942 is programmable digital thermostat based on a microprocessor with a selectable relay or SSR control output for On/Off, P, PI, PD, PID action and soft start or self-tuning function. For the alarm output, selectable NO or NC relay offers 4 different output types. The unit is provided with configurable input for Pt100 and thermocouples (J, K, T, S, R). Optional RS485 module is available for communication via Modbus RTU protocol. Both the set and process values are viewed on a 2x4 digit display. ETC942 allows 3 levels parameter protection to prevent authorized access to settings.

Figure 3.4 Enda ETC 942 Digital Thermostat

The power of electrical heating unit is selected as 8 kW. Because of during the pyrolysis and distillation process oil-additive mixture should be at uniform temperature, the oil in the reactor is mixed by an electrical mixer with 150 rpm which has 200 W electrical power. The reactor was made from stainless steel which has 5 mm thickness and it was insulated with 100 mm stone wool layer. The optimum insulation thickness of reactor can be calculated as follows;

The reactor is to be covered with adequate insulation so that the temperature of the outer surface of the insulation does not exceed 35 ^{o}C when the ambient temperature is T_o= 25 ^{o}C. Heat transfer coefficient outside the reactor is taken as ho=25 W/m^2.^{o}C. Heat transfer from the reactor to the ambient air goes to maximum value at the maximum temperature of reactor. The temperatures of inner surface of reactor and ambient air were assumed as 420 ^{o}C and 25 ^{o}C respectively. The other assumptions are given in below;

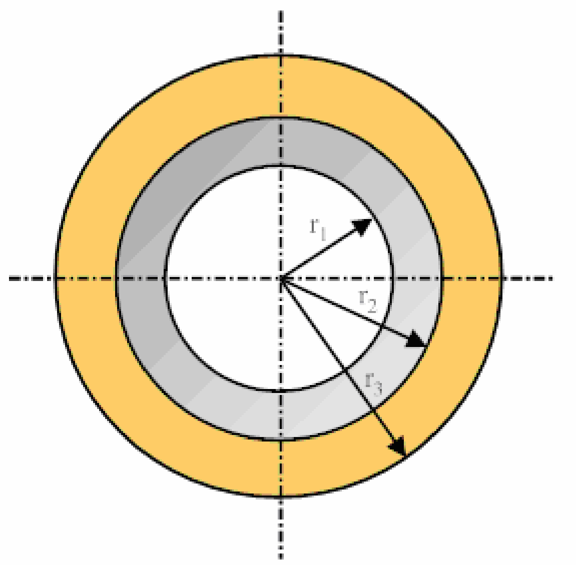

Figure 3.5 Reactor covered with stone wool.

- Heat transfer is steady
- Thermal conductivities are constant
- The thermal contact resistances are negligible

The dimensions of reactor are
r_1=150 mm and
r_2=155 mm respectively.

$$R_1 = R_{reactor} = \frac{\ln\left[\frac{r_2}{r_1}\right]}{2\pi k_1 L} \tag{3.1}$$

$$R_2 = R_{insulation} = \frac{\ln\left[\frac{r_3}{r_2}\right]}{2\pi k_2 L} \tag{3.2}$$

$$R_o = R_{convection} = \frac{1}{h_o A_3} \tag{3.3}$$

All resistances are in series the total resistance is determined to be

$$R_{total} = R_1 + R_2 + R_o \tag{3.4}$$

$$Q = \frac{T_i - T_o}{R_{total}} = \frac{T_i - T_o}{\frac{\ln\left[\frac{r_2}{r_1}\right]}{2\pi k_1 L} + \frac{\ln\left[\frac{r_3}{r_2}\right]}{2\pi k_2 L} + \frac{1}{h_o A_3}} \tag{3.5}$$

The outer surface temperature of insulation is specified to be 25 ^{o}C, the rate of heat loss can also be expressed as

$$Q = \frac{T_3 - T_o}{\frac{1}{h_o A_3}} \tag{3.6}$$

Relations (3.5) and (3.6) equal to each other.

$$\frac{T_i - T_o}{\frac{\ln\left[\frac{r_2}{r_1}\right]}{2\pi k_1 L} + \frac{\ln\left[\frac{r_3}{r_2}\right]}{2\pi k_2 L} + \frac{1}{h_o A_3}} = \frac{T_3 - T_o}{\frac{1}{h_o A_3}} \tag{3.7}$$

Solving Eq (3.7) for r_3 by using EES (Engineering equation solver) software gives r_3=0,2417 m. Then the thickness of stone wool insulation required is

t=0,08669 m =8.67 cm.

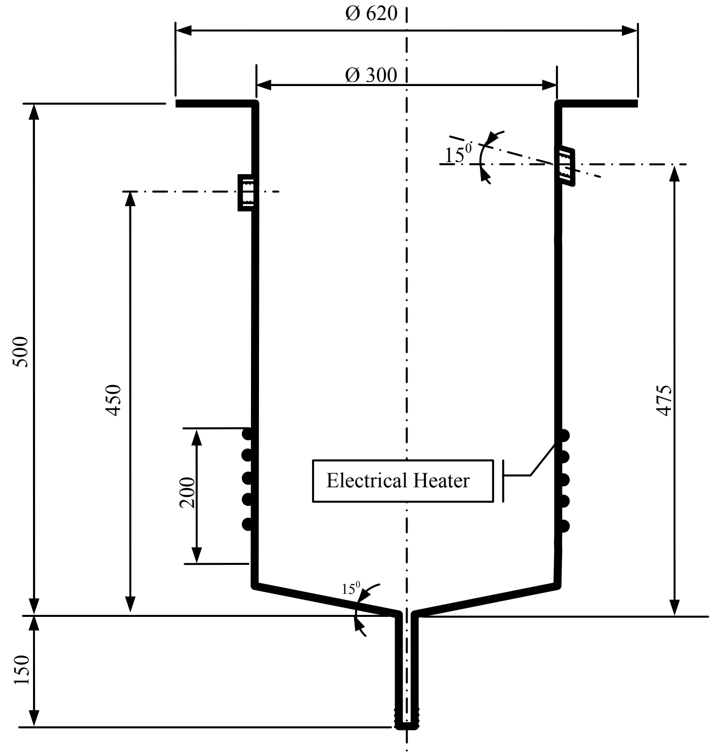

Figure 3.6 The inner reservoir of reactor.

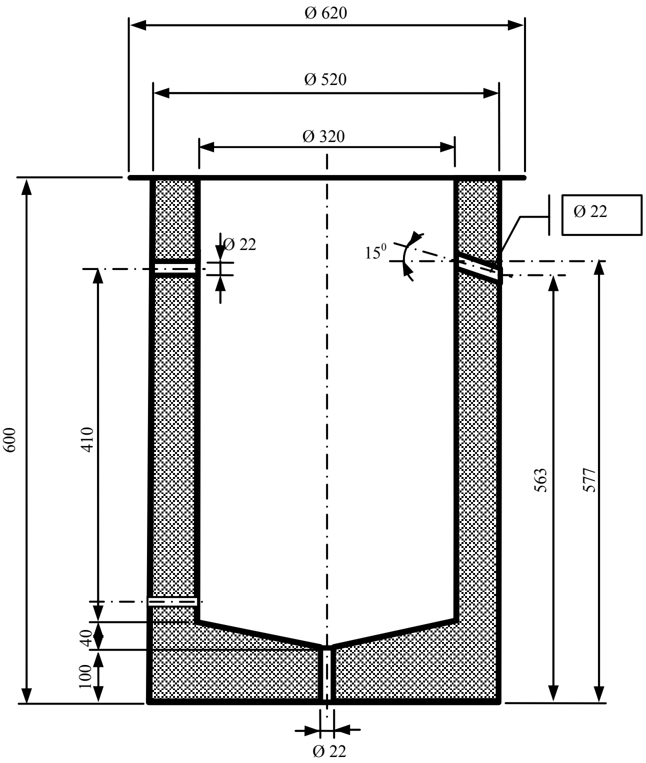

Figure 3.7 The outer structure of reactor.

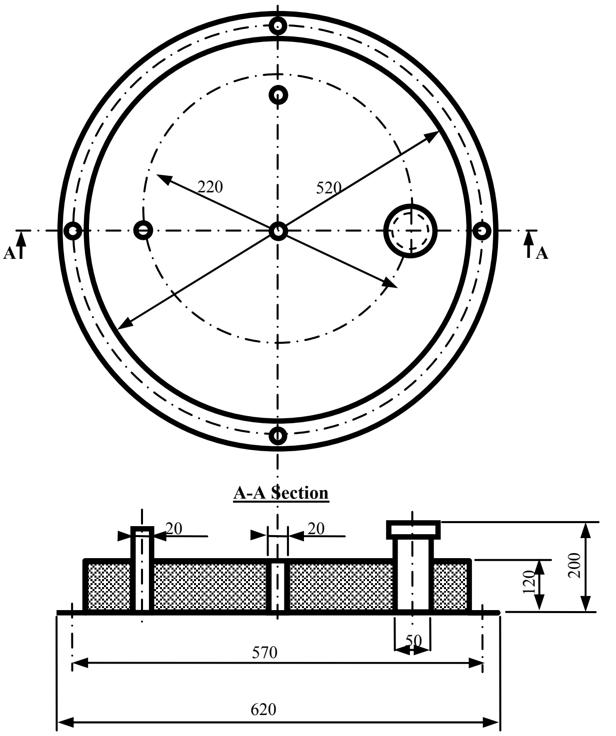

Figure 3.8 The top cover of reactor.

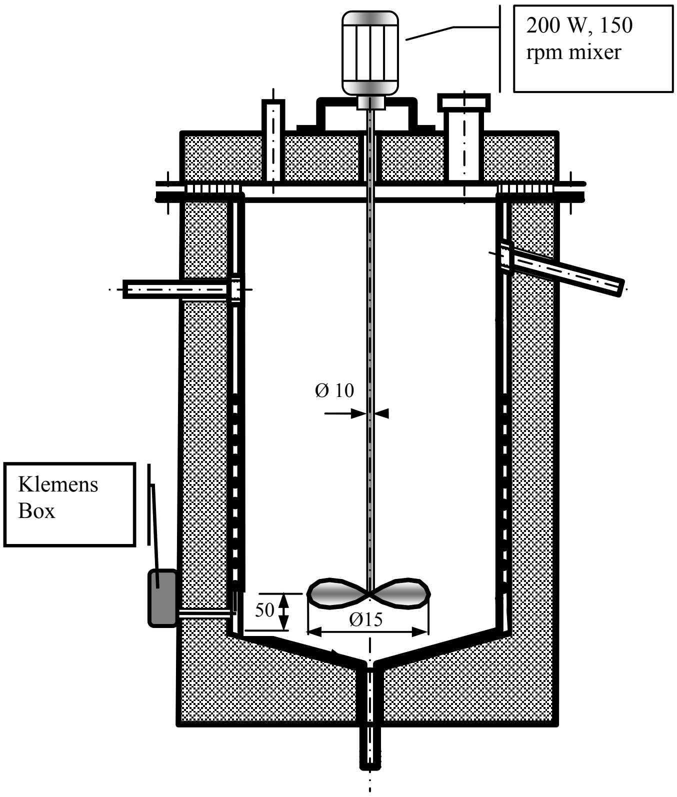

Figure 3.9 The constructed reactor.

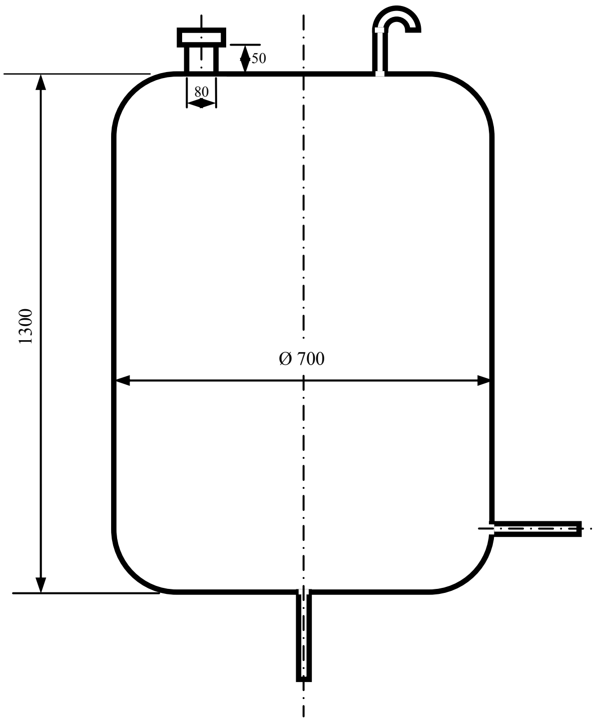

Figure 3.10 Waste oil storage tank.

3.3 Investigation of Optimum Pyrolysis Temperature and Time

In present study, the optimum pyrolysis temperature and time were established for fuel obtained from waste engine oil by pyrolysis method. For this temperature and time parameters given in Table 3.1 were examined, various parameters of fuel samples such as distillation, density and viscosity were shown as graphics below. For each experiment in Table 3.1, the same amounts of waste engine oil put into reactor and for different times for each temperature were carried out. For example reactor maximum temperature is set-up 300 ^{o}C with pyrolysis time of 120 minutes for first fuel sample. After experiment it was observed that the selected parameters of 300 ^{o}C and 120 minutes time were not suitable for obtaining fuel sample. Therefore the same amount of waste engine oil was put into reactor and experiment was run by selecting pyrolysis time as 150, 180, and 210 minutes for 300 ^{o}C and 350 ^{o}C temperature values. It was noticed that there was not enough fuel amount 300 and 350 ^{o}C temperatures with any of selected pyrolysis time.

Table 3.1 Pyrolysis time and temperature values for fuel production.

Sample number	Amount of waste oil (g)	Process temperature (^{o}C)	Time (min.)	Amount of obtained fuel (g)
1	230	300	120	Not obtained
2	230	300	150	Not obtained
3	230	300	180	Not obtained
4	230	300	210	Not obtained
5	230	350	120	3
6	230	350	150	3,4
7	230	350	180	4
8	230	350	210	4,5
9	230	400	120	79
10	230	400	150	95
11	230	400	180	116
12	230	400	210	134
13	230	450	120	216,4
14	230	450	150	225
15	230	450	180	227
16	230	450	210	227

As a result, the selected temperatures of 300 ^{o}C and 350 ^{o}C were not right temperature values for obtaining enough fuel sample amount. Hence higher temperature values were used for next experiments. Pyrolysis times given in Table 3.1 used at 400 ^{o}C and 450 ^{o}C various fuel samples were obtained.

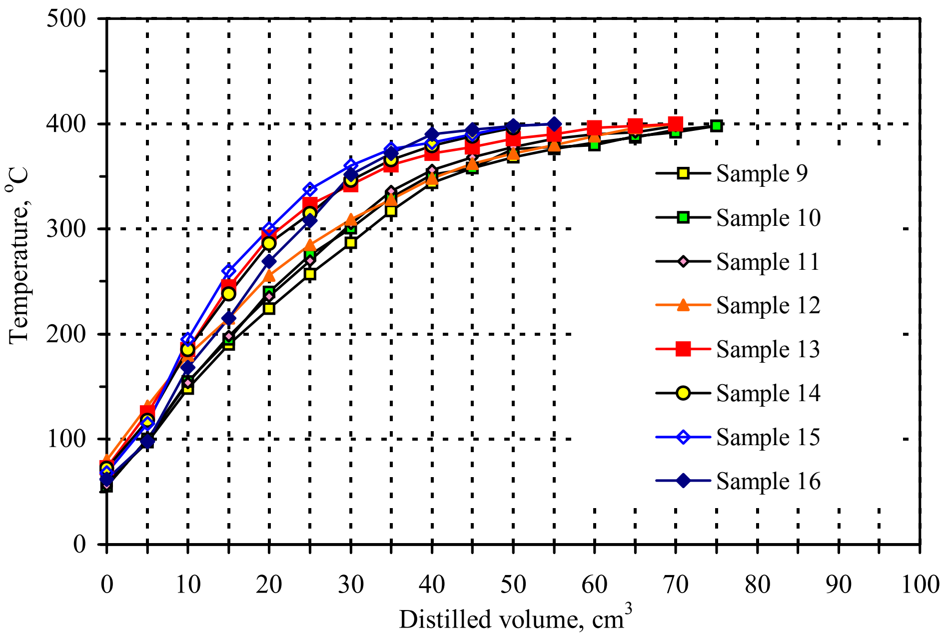

Figure 3.11 Distillation curves of obtained fuel samples.

Distillation curves, density and viscosity properties of obtained fuel samples were given in Figures 3.3, 3.4, and 3.5 respectively. Obtained fuel samples at 450 ^{o}C temperature was heavier than fuel samples obtained at 400 ^{o}C (Fig 3.3) as well as the amount was higher when higher pyrolysis time was used according to Table 3.1.

Figure 3.12 and 3.13 shows the properties density and viscosity of fuel samples obtained at 400 ^{o}C and 450 ^{o}C temperatures and 120, 150, 180 and 210 minutes respectively. It was clearly observed that using higher pyrolysis time increased density and viscosity of fuel samples.

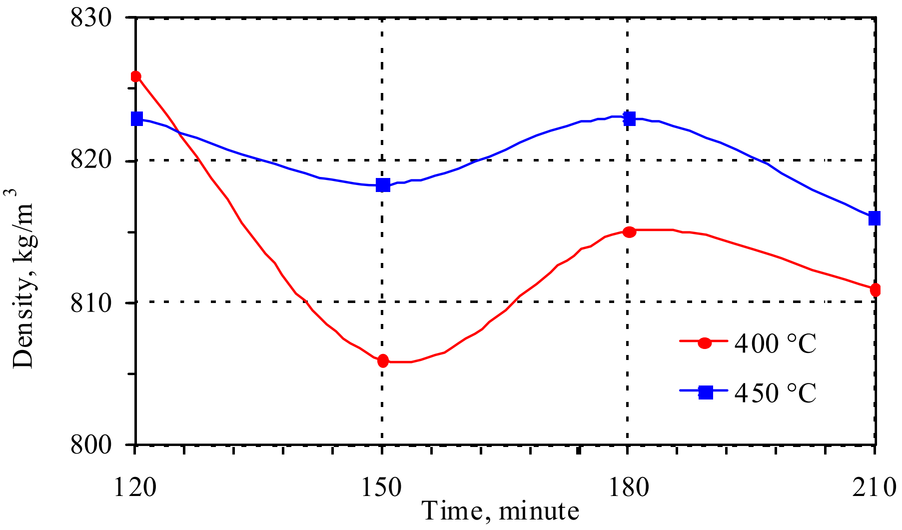

Figure 3.12 Density variations of fuel samples.

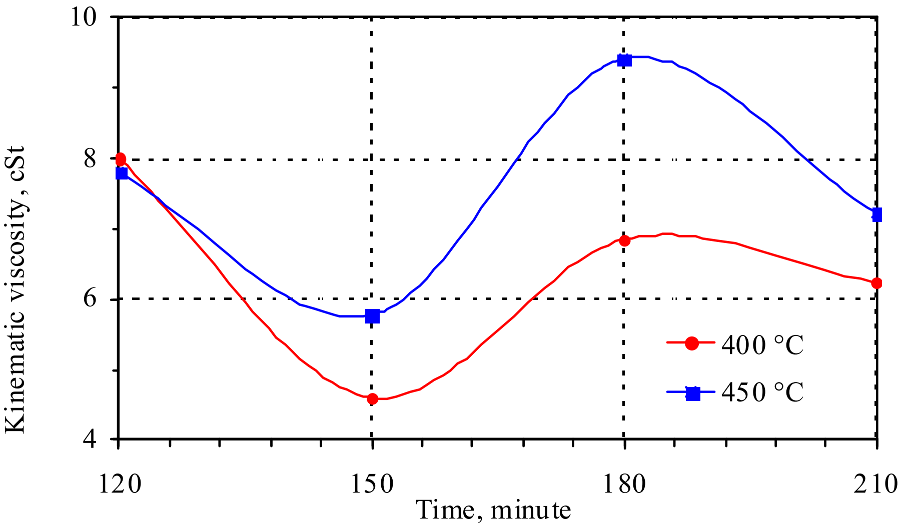

Figure 3.13 Viscosity variations of fuel samples.

Because of electronic system properties controlling electrical power and temperature of reactor, heating process in higher temperature differences provides higher heat flux. Therefore waste engine oil is distilled not fully pyrolysis due to selecting lower pyrolysis times. Over coming this problem, reactor temperature first set up 330 ^{o}C and waste engine oil was kept in reactor for 1 hour at 330 ^{o}C constant temperature. Then for each 30 minutes reactor temperatures increased 30 ^{o}C additionally for starting distillation process. Final temperature value was 420 ^{o}C. Figure 3.6 shows the obtained temperature profile.

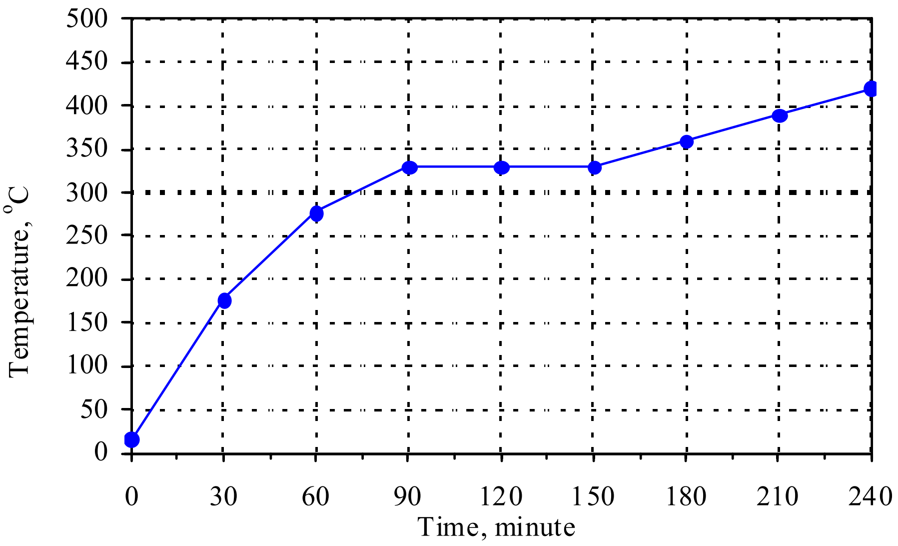

Figure 3.14 Temperature profile for pyrolitic distillation process.

3.4 Testing Equipments and Testing Procedure

The typical characteristics of obtained fuel, such as density, viscosity, flash and fire point, sulfur content, heating value and distillation temperatures were conducted in the oil-fuel laboratory at Mechanical Engineering Department of Gaziantep University. The brief description of test equipments which are used in this study has benn given in below:

3.4.1 Testing equipments

3.4.1.1 Density

Density is a fundamental physical property that can be used in conjunction with other properties to characterize the quality of crude oils, light and heavy fractions of petroleum and petroleum products. 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.

3.4.1.2 Distillation

The fuel sample is evaporated and condensed under controlled conditions, and observations are made of the temperatures at which various percentages are recovered and/or the percentages recovered at specified temperatures. The distillation apparatus is shown in Fig 3.15.

Figure 3.15 K45000 Distillation apparatus

The distillation device consists of fully insulated stainless steel condenser and heater units. Heater unit includes flask support platform, viewing window, 1000W heater with stepless variable control, and rack and pinion heater elevation mechanism with push-turn control knob. Please inquire about higher wattage heaters. White receiving flask background facilitates viewing of fractions during test. It is available with right-hand or left-hand heater unit for convenient pairing. Includes graduate support block and flask support boards. It conforms to ASTM D86, E133 and related ASTM and international standards

3.4.1.3 Flash point

For flash point determinations of fuel samples, K16200 Pensky-Martens Closed Cup Flash Tester in Fig 3.16 was used. This device determines flash points of a wide range of products by a closed cup method with two option speed stirring of the sample. Smooth operating cover mechanism slides shutter open and applies test flame at the turn of a knob. Cover fits over brass test cup and includes pilot flame, test flame reference bead, built-in stirrer and plated brass thermometer ferrule. It is equipped with a 750W nickel-chromium heater with stepless variable control for accurate, repeatable temperature rate of rise settings per specifications. Heater unit is enclosed in stainless steel housing with cooling vents. It includes line cord receptacle and switch for accessory slow speed stirrer. It conforms to ASTM D93 and related specifications. It conforms to ASTM D93 and related specifications

Figure 3.16 K16200 Pensky-Martens closed cup flash tester.

3.4.1.4 Viscosity

Kohler brand K21410 model (Fig 3.17) viscosity measuring device was used to viscosity determination of fuel samples. The time required for 60mL of sample to flow through a calibrated orifice under precisely controlled conditions is determined. Saybolt Universal Seconds (SUS) is the standard measurement for lubricants, insulating oils, and lighter fuel grades. K16200 conforms to ASTM D88, D244, E102, and related specifications

Figure 3.17 Viscosity determination device.

3.4.1.5 Sulfur level determination

The Eltra CS500 Carbon/Sulfur determination device which is given in Fig 3.18 was used during the sulfur determination tests of obtained fuel samples.

Figure 3.18 Eltra CS500 Carbon/Sulfur deterrminator.

The sample is weighed in a combustion boat on an electronic balance which is interfaced to the CS-500. By pushing a button the sample weight is transferred into the CS-500. If required the sample weight can also be entered manually. The ceramic boat with the sample is placed on the furnace platform. The start key is pressed and the analysis cycle begins. The sample is entered into the furnace. At the end of the cycle, the analysis results appear on the built in display.

3.4.1.6 Heating value determination

A bomb calorimeter was used to measure the heating value of fuel samples. The schematically representation of bomb calorimeter has been shown in fig 3.19. Bomb calorimeters have to withstand the large pressure within the calorimeter as the reaction is being measured. Electrical energy is used to ignite the fuel, as the fuel is burning, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter. When the air is escaping through the copper tube it will also heat up the water outside the tube. The temperature of the water allows for calculating calorie content of the fuel. The bomb, pressurized with excess pure oxygen (typically at 30atm) and containing a known mass of sample (typically 1-1.5 g) and a small fixed amount of water (to absorb produced acid gases), is submerged under a known volume of water (2000 ml) before the charge is (again electrically) ignited.

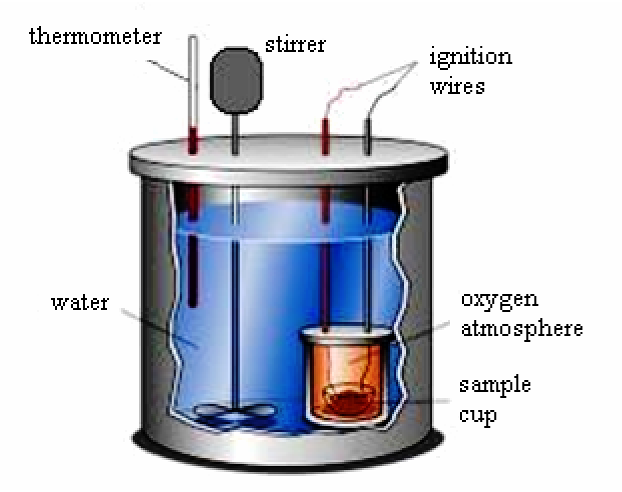

Figure 3.19 Schematically representation of bomb calorimeter.

The bomb, with sample and oxygen, form a closed system - no air escapes during the reaction. The energy released by the combustion raises the temperature of the steel bomb, its contents, and the surrounding water jacket. The temperature change in the water is then accurately measured. This temperature rise, along with a bomb factor is used to calculate the energy given out by the sample burn. The heating value of fuel sample is calculated by using equation (3.8).

$$Hu = \frac{m_w . C_p . (T_i - T_f)}{m_f . 10^{-3}} \text{(kj/kg)} \tag{3.8}$$

3.4.1.7 Moisture determination

Extracting solvent is added to the titration cell. Titration moisture in the solvent with Karl Fischer reagent until solvent equilibrium is reached. Add a fixed amount of sample. Titrate with Karl Fischer reagent having a known factor (mg H_2O/mL) until the endpoint is found. The Karl Fischer reagent factor can be determined using water standard or methanol standard. Then the moisture concentration of the unknown sample can be calculated.

Figure 3.20 Karl Fischer moisture titrator.

3.4.2 Testing Procedure

The waste lubricant oil is highly viscous and contains sulfur, carbon soot, small metal particles and some gum-type materials. It has high level of these materials. For example, it has plenty of sulfur with an amount of approximately 6000 ppm. This value is reasonably high. The contaminants originally exist in lubricating oils. Various additives are generally added in the lubricating oil to decrease sulfur amount. Three types of additives were used in this study. In order to purify and distillate the waste oil, several tests were carried out. The testing procedure can be summarized as follows:

The waste lubricant engine oil used in the present study was collected from waste lubricating oil of automotive engines used in University of Gaziantep Campus, Turkey. The waste oil collected was taken from the storage tank and filtered using a qualitative filter of 20 micron to purify it from heavy metal particles, carbon soot, gum-type materials and other impurities. The purified waste oil leaving from the filter was taken into the reactor. Three additives known as (Na_2CO_3), zeolite and lime

(CaO) were added to the clean oil in the reactor and blended with mass basis of 2 %, 4 %, 6 %, 8 % and 10 %, separately. The thermal and pyrolitic treatments of the samples were performed in the presence of additives. Each sample mixed continuously was distillated and collected in a container. Characteristics of the produced fuel such as density, viscosity, flash and fire points, sulfur content, heat of combustion and distillation were examined, and results were given in Table 3.2 and the Figures in the following section.

Table 3.2 Properties of diesel fuel and DLF obtained in the study.

Properties	**Diesel fuel TS3082-EN 590**	**DLF TS3082-EN 590**
Density at 15 °C, kg/m^3	820-845	818
Viscosity at 40 °C, mm^2/s	2-4.5	3.49
Flash point, °C	>55	57
Sulfur, ppm	650	3500
Water, mg/kg	<200	130
Lower heating value, kJ/kg	42700	42500
Temperature at 250 °C, max. volume (% v/v)	65	20
Temperature at 250 °C, min. volume (% v/v)	85	90
Volume at % 95, max. temperature, °C	360	360

This experimental study was carried about purification and conversion of the waste engine oil into diesel-like fuel by blending purified oil and additives of Na_2CO_3, zeolite and CaO with mass basis of 2, 4, 6, 8 and 10 percent. Fuels were produced from the waste engine oil by applying pyrolitic distillation method. Thermal and physical characteristics of the produced fuel samples such as flash point, density, viscosity and sulfur contents, and distillation tests, were examined by using measurement devices. Results obtained from the measurements were given in Table 3.2 and in relevant Figures. These Figures were depicted and discussed in the sections below in order to investigate effects of the additives on these tests, especially on distillation test.

3.5 Effects of the Additives on Flash Point and Density

The flash point of a flammable fuel is the lowest temperature at which it can form an ignitable mixture in air. At this temperature the vapor may cease to burn when the source of ignition is removed. The flash point is often used as one descriptive characteristic of liquid fuel, but it is also used to describe liquids that are not used intentionally as fuels. Density is also important property of a fuel since air-fuel mixture and flame can propagate uniformly in combustion chamber of an engine. Therefore, effects of the additives on the flash point and density are studied in this work. Figs. 3.21 and 3.22 show variation of flash points and densities of the blends with respect to additive weight ratios.

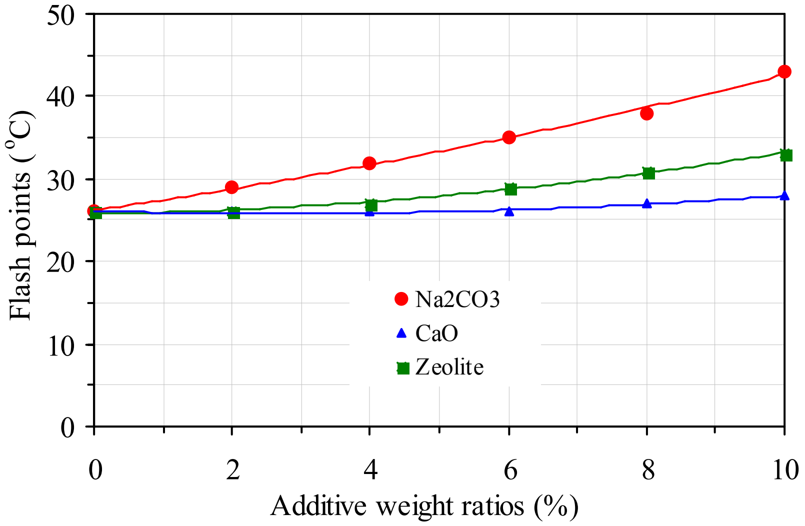

Figure 3.21 Effects of additives on flash points.

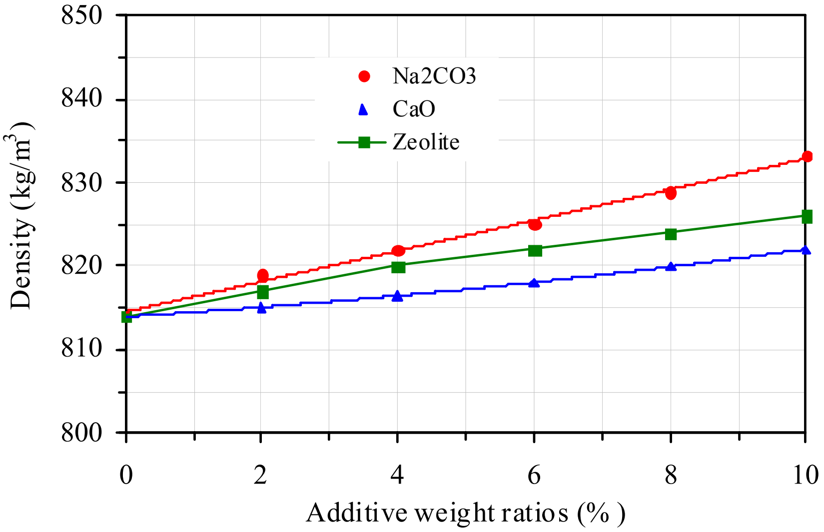

Figure 3.22 Effects of additives on density.

These Figures show that flash points and densities increase with the additive content. Densities of the samples increase as a dependence of densities of the additives. While plash point of the waste purified engine oil is 26 °C, it increases up to 43 °C when the Na_2CO_3 with the ratio of 10 % is blended with the engine oil. Under the same conditions, when the CaO and zeolite are mixed with the same ratios, they increase up to 28 °C and 33 °C, respectively. This indicates that volatility of the fuel sample decreases, but its weight increases considerably. However, when the CaO is blended with the waste engine oil at the ratio of 10 percent, there is low variation in the flash and density of the sample. That is; it is observed that the effect of the Na_2CO_3 on the flash point is higher than the other additives, whereas the effect of the CaO is fairly lower.

3.5.1 Effects of the additives on sulfur

One very important consideration in the selection of a diesel fuel is its sulfur content. While sulfur is one of the combustible elements in the fuel and generates energy, the primary product of that combustion is sulfur dioxide (SO_2), which is a major environmental pollutant. The sulfur dioxide reacts with atmospheric water vapor to produce sulfurous and sulfuric acids, both of which contribute to acid rains [77]. That is why sulfur amount present in any fuel should be decreased below the Standard values if it is possible. The additives decrease the sulfur amounts present in the waste engine oil, which is shown in Fig. 3.23.

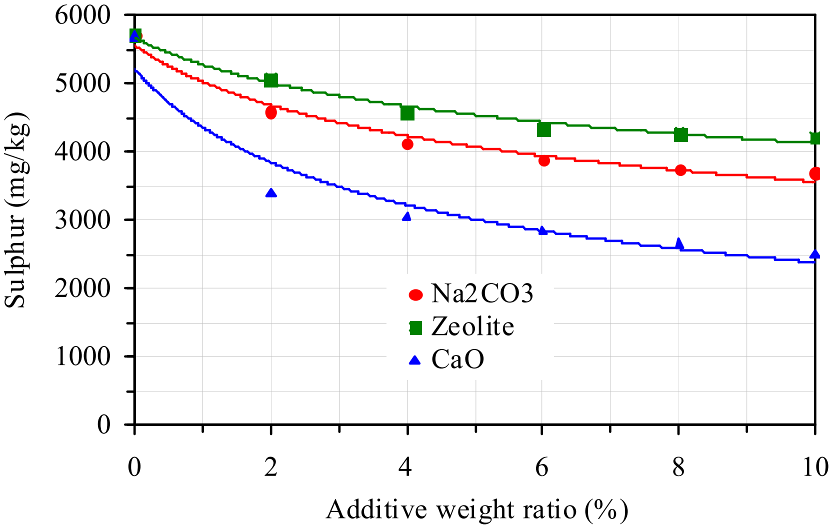

Figure 3.23 Effect of additives on sulfur content.

The figure indicates the effects of additive amounts used in the present study on sulfur content of the purified oil samples. It is obvious in the Figure that all of the three additives have an important role in the decreasing of sulfur content in the waste engine oil. The highest decease in sulfur present in the waste oil takes place when the CaO with the ratio of 10 % is blended with the oil. The sulfur amount decreases from 5710 mg/kg to 2500 mg/kg. The CaO in the three additives is the most effective compound in decreasing the amount of sulfur.

3.5.2 Effects of the additives on distillation temperature

Effects of the additives of Na_2CO_3 zeolite and CaO on distillation temperatures are shown in Figures 3.24, 3.25 and 3.26, respectively. It is evident in Figure 3.24 that distillation temperatures do not decrease for any values of the additives of Na_2CO_3, but they increase for all Na_2CO_3 amounts. That is; weight of the oil sample increases considerably, and its volatility decreases depending on the amount of Na_2CO_3. However, it is clear in Figures 3.25 and 3.26 that 2 percent of zeolite or CaO, which is blended with the waste engine oil, decreases the distillation temperature, and increases the volatility of the sample. Under the same conditions, when 6 and 10 percent of zeolite or CaO are mixed with the oil, the distillation temperatures increase and volatility decreases due to additives. It is not useful to add the additives to the oil because of the increase in volatility. But, it is very useful to add more additives to the oil in order to decrease the amount of sulfur.

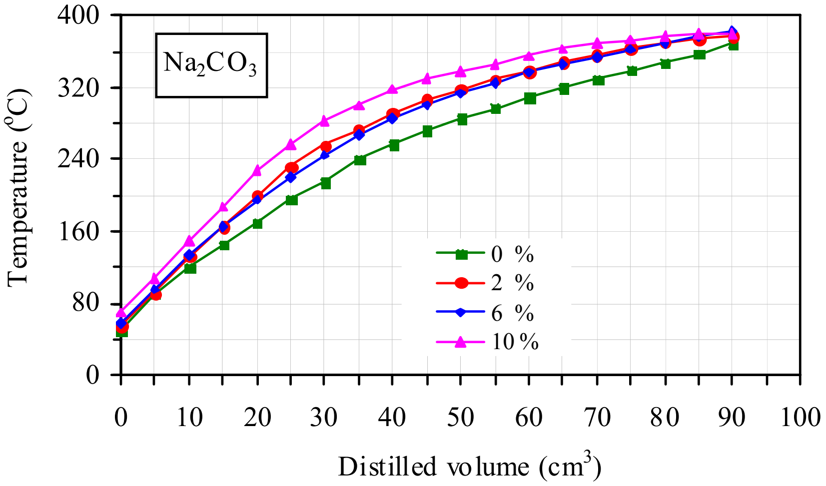

Figure 3.24 Effect of Na_2CO_3 on distillation temperature.

It is necessary that distillation curve of any diesel-like fuel should be parallel with the distillation curve of diesel fuel, and also it is necessary that its thermophysical properties are suitable to the same values of the diesel fuel. Under these conditions, utilization of a fuel in a diesel engine will be suitable. It will be useful to compare the distillation test results obtained with the distillation results of a diesel fuel.

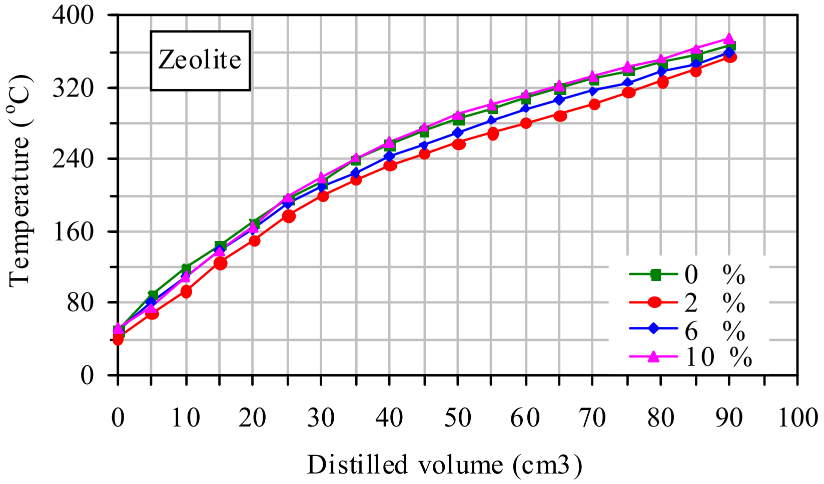

Figure 3.25 Effect of zeolite on distillation temperature.

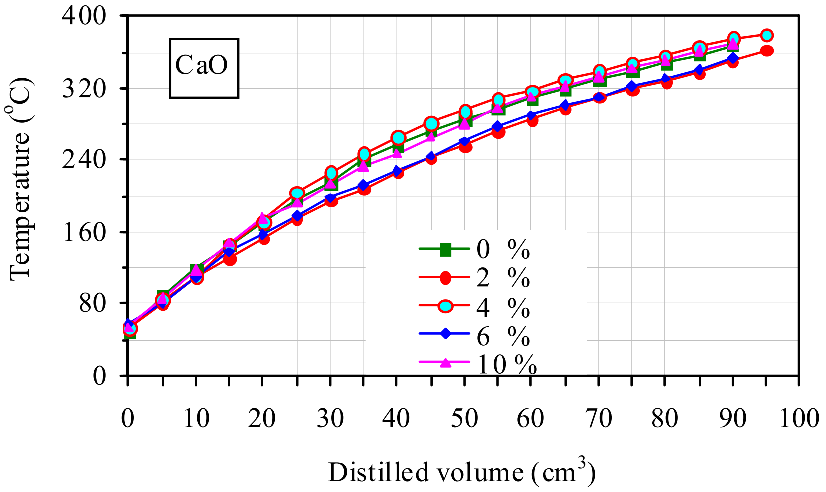

Figure 3.26 Effect of CaO on distillation temperature.

Figures 3.27 and 3.28 depict the distillation test results of the three samples comprised of oil and additives of Na_2CO_3, zeolite and CaO with ratios of 2 % and 10 %, respectively. Distillation test result of diesel fuel is also shown in these Figures in order to compare the effects of the additives on distillation temperatures. The Figures demonstrate that there is no positive effect of the additive of Na_2CO_3 blended with the waste engine oil except for the reduction in the sulfur amount in the sample.

Moreover, the distillation curve of the sample is far away from the distillation curve of the diesel fuel. When the waste engine oil is blended with 2 percent of zeolite and CaO, distillation results of the samples indicate parallel behavior with the curve of the present diesel fuel in a volume of 30 %.

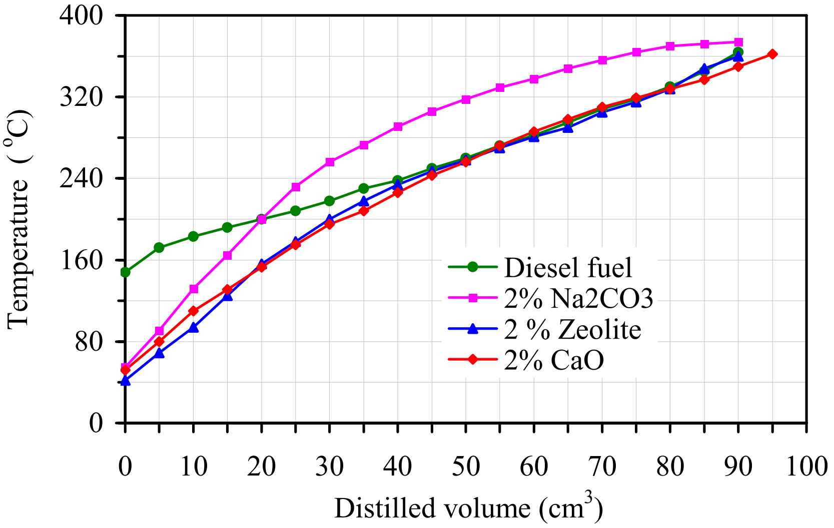

Figure 3.27 Effect of additives (2 %) on distillation temperature.

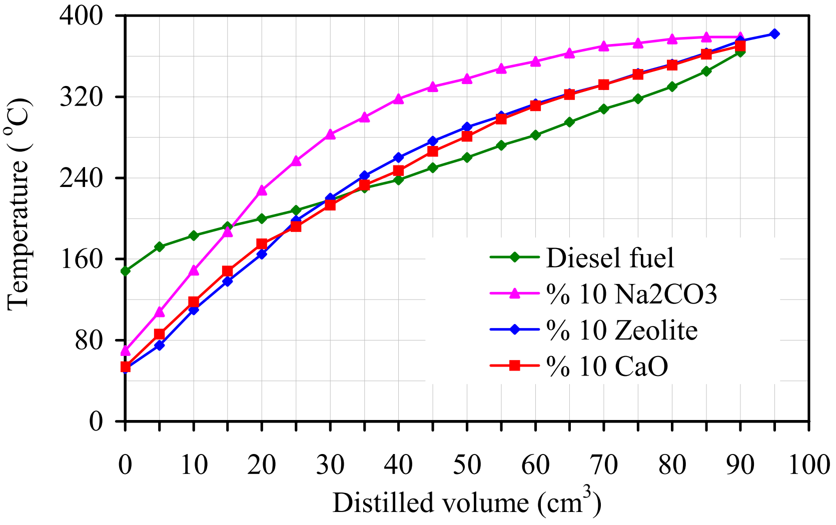

Figure 3.28 Effect of additives (10 %) on distillation temperature.

This is a very important criterion due to the gradual increment of distillation temperature at a finite value. This gradual increment is important because the starting ability and warm-up property of the fuel is evaluated with the evaporation temperatures of 20-70 % vaporization region of the distillation curves [20, 65]. However, the distillation curve of an engine fuel is not a horizontal line [65].

Vaporization at a very narrow band of temperature is not desirable since it will result in an immediate burning and high rate of pressure rise.

The burning of all the fuel increases temperature and the pressure of gas in the combustion chamber. Such a condition can give rise to dangerous effects on engine components [65]. It is necessary that a fuel sample burns gradually in a combustion chamber of an engine. When the sample is used as a fuel in a diesel engine, there will be no damage to engine components. 30 percent amount of the samples is lighter than the diesel fuel. This is useful for the initial starting operation of the engine, but it is detrimental for the engine when the temperature of the engine increases. When 10 percent amount of the two additives are blended with the oil sample, distillation temperatures increase, but they continue to show a behavior parallel to the diesel fuel sample. That is, it is far away from the diesel fuel sample. According to these data, it gives the best results by utilizing 2 percent of CaO as an additive after 30 % of total volume of the blend. The best results can be seen in the Figures of 3.23 and 3.27 as a result of the decrease in sulfur amount in the waste oil and the effect of the CaO on the distillation temperatures. Light and heavy fuels need to be separated from each other in order to eliminate the light portion of the fuel or the detrimental effects of the light portion on an engine. Therefore, purified waste engine oil was blended with 2 % CaO, and the mixed oil sample was distilled. Light amount of the sample comprising approximately first 25 percent of the sample was collected in a container, and the remaining 75 percent part of the sample was collected in another container. The first and second distilled portions were distilled again.

The distillation test results of the heavy fuel, together with the diesel fuel, were shown in Figure 3.29. It is clear that the distillation curve of the heavy fuel resembles to the distillation curve of the diesel fuel. Its distillation curve is smooth and increases gradually like the diesel's curve, and its boiling point is closer to that of the diesel. Hence, the produced heavy fuel from the purified waste oil is named as Diesel-Like Fuel (DLF). But its distillation temperature for each droplet is higher than that of the diesel sample used in the study. The higher distillation temperature will give the higher combustion efficiency, which will increase engine performance.

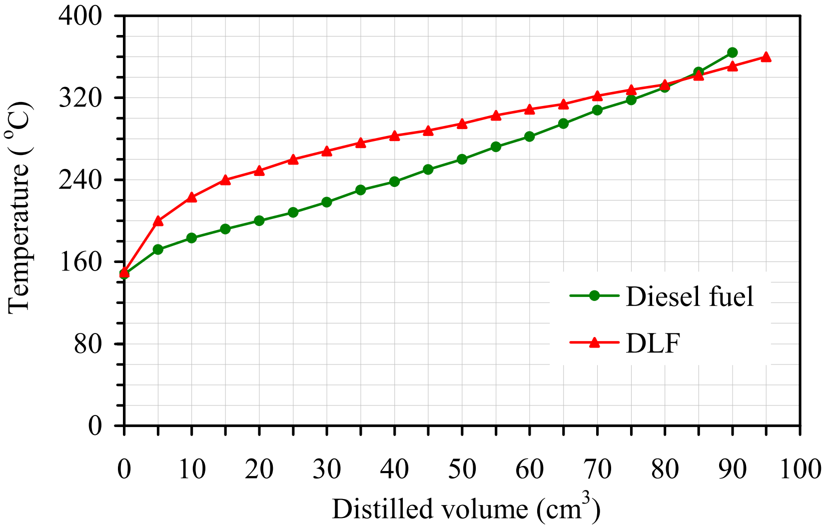

Figure 3.29 Distillation curves of standard diesel fuel and DLF samples.

3.5.3 Characteristics of the produced fuel

Characteristics of any fuel are very important from the point of deciding whether the fuel can be used for desired application or not. Therefore, some characteristics of the produced diesel-like fuel are measured, and these characteristics are shown in Table 3.2, together with standard values of a diesel fuel. The table shows that some of the parameters of density, boiling point, viscosity, flash point and lower heating value are in the standard values of the diesel oil or reasonably close to the standard values. But, sulfur amount is considerably higher than that value. It should be decreased below the value of 50 ppm. Density is another important property of diesel fuel. It is the weight of a unit volume of fluid. The density of diesel fuel ranges between 820 and 845 kg/m^3. Density of diesel-like fuel is measured as 818 kg/m^3, which is close to the lowest limit.

Viscosity is one of the most important properties of diesel fuels, since it affects the operation of the fuel injection equipments particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel. High viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors [77]. Lower heating value (LHV) of the diesel-like fuel is obtained as 42500 kJ/kg by using adiabatic bomb calorimeter. It is close to LHV of typical diesel fuel, which is 42700 kJ/kg. A diesel fuel having of the heating value gives good engine performance during combustion in a diesel engine.

CHAPTER 4

4. ENGINE PERFORMANCE AND EXHAUST EMISSION TESTS

4.1 Introduction

A literature review has been carried out on the recycling of waste engine oil and it has been understood that there are few studies on this topic. In these studies, thermal and physical properties, engine performance, and exhaust emission parameters of the fuel obtained after the recycling process have not been investigated.

Processed waste engine oil has high energy capacity (43.07 MJ/kg) [15], which is close to petrodiesel (43 MJ/kg) or petroleum (42 MJ/kg), slightly lower than that of gasoline (46 MJ/kg), but higher than coal (32–37 MJ/kg) [63], and minimizing its harmful effects on environment has been the motivation behind the study. Therefore, it has been aimed to obtain fuel from waste lubrication oil which can be used in engines and to investigate the effects of this fuel on engine performance and exhaust emission.

4.2 Procedures of the Experimental Works

In this section, a diesel-like fuel named as the DLF was produced from the waste lubricant engine oil utilizing a pyrolitic distillation and purification system, and its effects on engine performance and exhaust emissions were investigated experimentally. With this aim, three mainly processes were employed in this work. It is necessary to explain the experimental procedures of these processes. These are procedures of fuel production process, measurements of the produced fuel characteristics, parameters of performance and exhaust emissions. These procedures are separately explained in the following section.

4.3 Characteristics and Distillation Tests of DLF

Thermal and physical characteristics of fuels and tendency of their distillation curves are very important. Therefore, characteristics of the produced DLF, which are density, flash point, viscosity, sulfur and water content, lower heating value (LHV), and distillation test results were given in Table 3.2 and Figure 3.15, respectively. They were discussed and compared with those of typical diesel fuel used in this study. The thermal and physical characteristics are shown in Table 3.2. It is clear in the table that they are reasonably closer to the values of standard diesel fuel. One of the most important characteristics is LHV, which is calculated as 42500 kJ/kg by using measurement values. It is closer to LHV of diesel fuel with a value of 42700 kJ/kg in Turkish (TS-3082) and European (EN-590) Standards given in the Table 3.2. The LHV of the DLF is closer to the values given in literature for commercial diesel fuels as 42210 kJ/kg [64], 43000 kJ/kg [17-18], 43060 kJ/kg [19] and 43350 kJ/kg [20]. The LHV of the DLF is closer to these values. Table 3.2 shows that distilled volumes or temperatures correspond to values given in these Standards. It is considered that these properties will not cause any problems in engine combustion equipments, and the LHV will not decrease in performance of the engine fueled with DLF. This condition can be understood very well from distillation curve. This curve gives more important ideas about combustion and engine performances, since this curve is an indication of how ignition will take place. It can be decided whether the fuel can be used in engines or not by looking at the curve. The distillation curve of the DLF obtained by decomposing from the waste oil sample and a typical diesel fuel are displayed in Figure 3.15. When the Figure is examined, it is understood that the curve of the DLF resembles and is almost parallel to that of diesel. So, it can be concluded that the DLF can be used efficiently in diesel engines, and there will be no problems in the performance of the engine. These claims are supported by the thermal and physical properties of the sample given in Table 3.2. Distillation temperature increases versus distilled volume smoothly and gradually. This gradual increment is important because starting ability and warm-up property of the fuel is evaluated by the evaporation temperatures of 20-70 % vaporization region of the distillation curves [20]. Each droplet of a fuel should be distilled in a regular and increasing temperature. A fuel sample which is distilled in a constant temperature or very narrow temperature band is not desired fuel [19, 20]. In order to see whether the DLF sample can be used efficiently in engine, it is also necessary to examine and analyze the performance and exhaust emission results after using the sample in diesel engine. These results are given in the following sections, and explained briefly.

In the experimental study, waste lubricant engine oil was first purified from dust, carbon soot, small metal particles and the other impurities by the refining process. The clean oil blended with additive of CaO with ratio of 2 percent was exposed to thermal treatment in the reactor, and a diesel-like fuel named as DLF was produced by applying the pyrolitic distillation method. Characteristics of the DLF and distillation results were examined in order to decide whether the DLF can be used as a fuel in a diesel engine or not. According to the test results, it was decided to burn in a test engine, and performance and exhaust emission parameters were measured during the operation. Characteristics and distillation tests of the DLF and diesel fuel, effect of the fuels on engine performance and emission parameters were given in Figures and discussed in this section, separately.

4.4 Performance and Exhaust Emission Tests of DLF

In order to see whether the DLF sample can be used efficiently in engine, it is necessary to examine and analyze the performance and exhaust emission results after the use of the sample in a diesel engine. Therefore, the DLF sample was used in a diesel test engine at Vocational School of Higher Education in Batman, Batman University. Engine performance parameters and exhaust emission values were measured by the engine and exhaust gas analyzer. The diesel test engine and a hydraulic dynamometer connected to the engine were used for this purpose. The test engine was modeled as Rainbow-186. It has specifications of single-cylinder, four-stroke, air cooled, naturally aspired direct injection. The cylinder has a bore of 86 mm and a stroke of 70 mm.

Table 4.1 Main specifications of the test engine.

Engine model	Rainbow–186
Engine Type	Four stroke
Fuel type	Diesel
Bore	80 mm
Stroke	70 mm
Swept volume	406 cm^3
Compression ratio	18:1
Injection pressure	20 MPa
Cooling type	Air cooled
Maximum torque	40 Nm at 2000 rpm
Maximum power	10 kW at 2000 rpm
Engine position	Vertical

The maximum power output of the engine was 52.2 kW at 2000 rpm. Combustion system of the engine has a hole, piston, direct-injection, and is medium-swirl type. The engine was equipped with a mechanical-PF type fuel pump. The fuel injector has three holes with an opening pressure of 196 bars. The engine was connected to hydraulic dynamometer. The basic specifications of the engine are shown in Table 4.1. Schematic diagram and picture of the test engine setup are shown in Fig. 4.1 and 4.2, respectively.

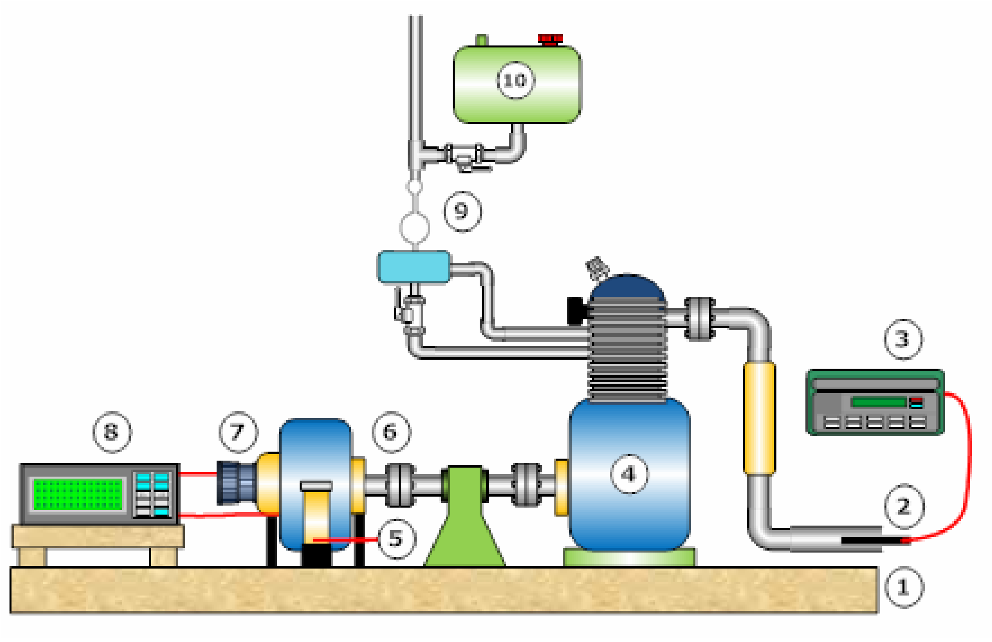

Figure 4.1 Schematic diagram of the test engine and exhaust analyzer

1) engine chassis, 2) exhaust gas analyzing probe, 3) exhaust gas analyzer, 4) single cylinder diesel engine, 5) load cell, 6) dynamometer, 7) tachometer, 8) control unit, 9) fuel burette, 10) fuel container.

In order to measure emissions exhausted from the test engine, Drager brand, MSI Compact 150 modeled gas analysis device was used. This device measures carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_x) emissions with sensitivity of ∓5 ppm, and also O_2 and CO_2 emissions with sensitivity of ∓ 0.3 %. After the engine had reached the operation temperature, the probe of the device was placed in the exhaust pipe. Then, the emission values measured by the device were printed out through a printer on the device. The results for the emissions and performance parameters were given and discussed in below.

Figure 4.2 Diesel test engine and its dynamometer.

4.4.1 Performance parameters of the test engine

Engine performance and exhaust emission tests are very important to observe effects of a fuel on the performance and emission of the engine. Since, these test results indicate an idea whether the fuel is used in an engine efficiently and without any problem or not. For that reason, it is necessary to determine performance parameters of an engine. There are several performance parameters, such as; brake torque (T), brake power (P_b), brake mean effective pressure (Bmep), brake specific fuel consumption (Bsfc) and brake thermal efficiency. It is necessary to find these parameters which can be obtained using measurement values of fuel and air consumptions, heating capacity of the fuel, torque and speed.

4.4.1.1 Brake power

Brake power is described as a function of brake torque. The brake torque applied to the cradled housing was calculated by the moment arm connected to the balance weights [65]:

$$T = F \cdot d \tag{4.1}$$

where T brake torque in Nm, F applied load in N, and d is a distance from the center of rotor in m. Brake power for each speed to be tested can be calculated using the torque value and angular speed measured. The brake power delivered by the engine and absorbed by the dynamometer is the product of torque and angular engine speed [65], which is given in the equation below.

$$P_b = \frac{2\pi \cdot \omega \cdot T}{1000} \tag{4.2}$$

where P_b brake power in kW, ω angular speed in rev/sec.

4.4.1.2 Brake mean effective pressure

Mean effective pressure is another engine performance parameter which is a specific parameter for internal combustion engines (IC). It is defined as the average pressure that the gas exerts on the piston(s) through one complete operating cycle of the engine. It represents level of development of an engine [65]. Since brake power is used in the calculation, so this pressure is called as brake mean effective pressure [65].

$$\mathrm{Bmep} = \frac{P_b \cdot n_r \cdot 1000}{V_d \cdot \omega} \tag{4.3}$$

where n_r the number of crank revolutions for one complete cycle, which is 2 for a four-stroke engine, V_d the total volume of the engine cylinders in dm^3.

4.4.1.3 Brake specific fuel consumption

Another important parameter for IC engines is brake specific fuel consumption (Bsfc) that is a measure of volumetric fuel consumption for any particular fuel [66]. It is given as [20]:

$$\mathrm{Bsfc} = \frac{\dot{m}_f}{P_b} \cdot 10^3 \tag{4.4}$$

where Bsfc brake specific fuel consumption in g/kW.h, and $\dot{m}_f$ fuel mass flow rate in kg/h.

4.4.1.4 Brake thermal efficiency

The brake thermal efficiency is related to the effective power, fuel mass flow rate and lower heating value (Q_{LHV}) of the fuel [20].

$$\eta_{bt} = \frac{P_b \cdot 3600}{\dot{m}_f \cdot Q_{LHV}} \tag{4.5}$$

where Q_{LHV} lower heating value of fuel in kJ/kg.

4.4.2 Engine performance tests

A four stroke, direct injection, naturally aspirated single cylinder diesel engine was employed for the present experimental study in order to investigate effects of the produced DLF on its performance. Schematic drawing, picture and its main specifications of the engine used are given in Figures 3, 4 and Table 4.1, respectively. The experiment was conducted using two fuel samples of the DLF and commercial diesel fuel for evaluating several performance parameters such as torque, brake mean effective pressure (Bmep), brake specific fuel consumption (Bsfc), and thermal efficiency. The data for the DLF and diesel fuel are given in separate Figures for comparison. Figures 4.3, 4.4, 4.5 and 4.6 show variations of torque, Bmep, thermal efficiency and Bsfc with engine speed, respectively. These results are obtained when the DLF and diesel fuel are used in the engine. It is seen that torque and Bmep increase with the engine speed and reach to the maximum value at 2200 rpm, whereas the Bsfc reaches the minimum value at the same speed. The maximum torque values for the DLF and diesel in 2000 rpm are 33.86 Nm and 33.71, respectively. Thermal efficiency curves for both samples of fuels shown in Figure 4.5 support the findings presented in Figure 4.3 and Figure 4.4. As these Figures clearly show, there is not any inconvenience due to DLF. Bsfc is defined as the ratio between mass fuel consumption and brake effective power, and for a given fuel, it is inversely proportional to thermal efficiency [67]. It is expected that the Bsfc should decrease when the brake power increases up to engine speed of 2200 rpm. At high speeds, friction, heat loses and deteriorating combustion increase Bsfc [68]. Curves of the performance parameters for the DLF are similar to those of diesel and are parallel to them in a regular way. It is understood from Figs. 4.3, 4.4, and 4.5 that the torque, Bmep, and thermal efficiency for the DLF is higher than those of diesel while

Figure 4.6 shows that the Bsfc for the DLF is lower than that of diesel. This is an important criterion that makes the DLF advantageous. Initially, it can be considered that LHV leads to the higher performance. However, Table 3.2 demonstrates that LHV is slightly lower than that of the diesel used in the test.

The distillation results given in Fig. 3.11 make it possible to explain this condition; it is caused by the higher distillation temperature of the DLF up to 80 cc of 100 cc volume. The higher temperature will give the higher combustion efficiency. The higher combustion efficiency increases torque, Bmep, thermal efficiency and decreases Bsfc. Test results clearly show that the DLF has a positive effect on the performance parameters of the engine, and it can be safely used as a fuel in diesel engines without any problems.

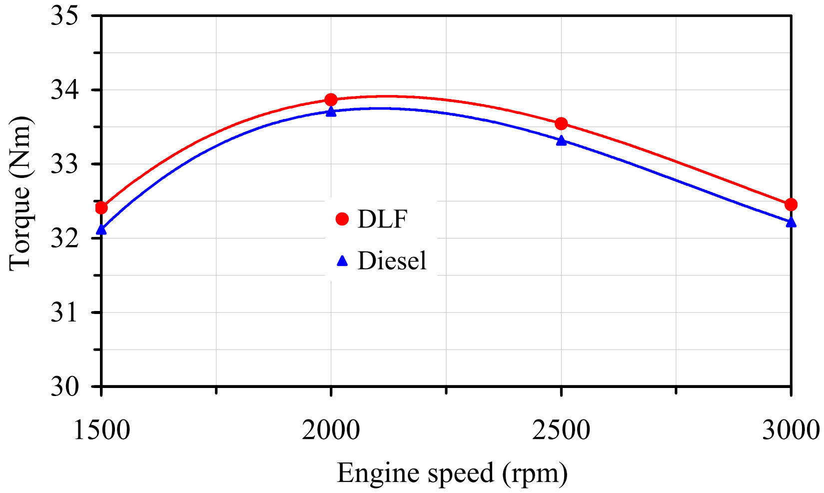

Figure 4.3 Effects of the DLF on engine torque.

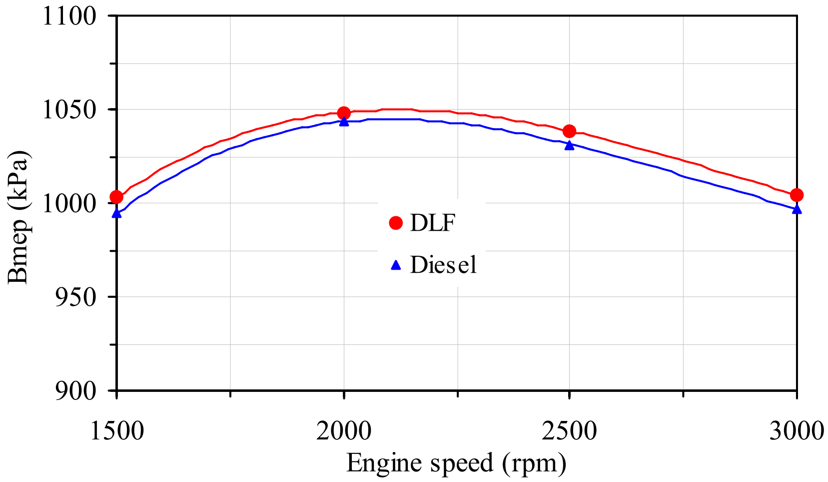

Figure 4.4 Effect of the DLF on the brake mean effective pressure.

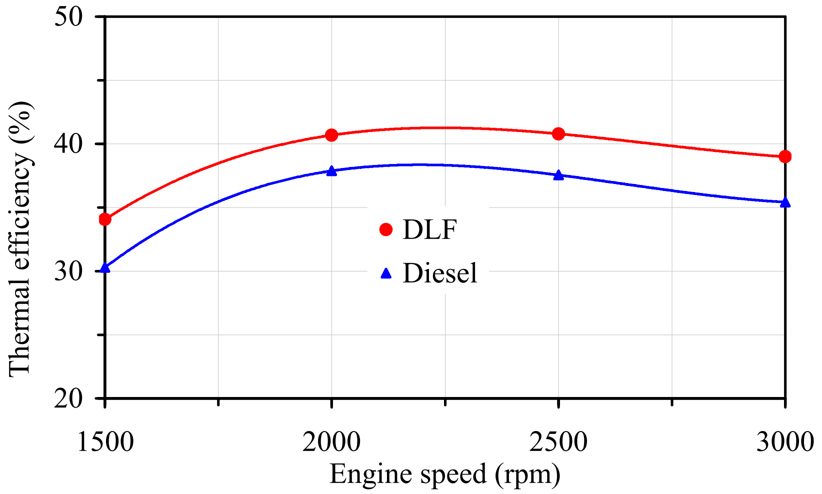

Figure 4.5 Variation of brake thermal efficiency with engine speed.

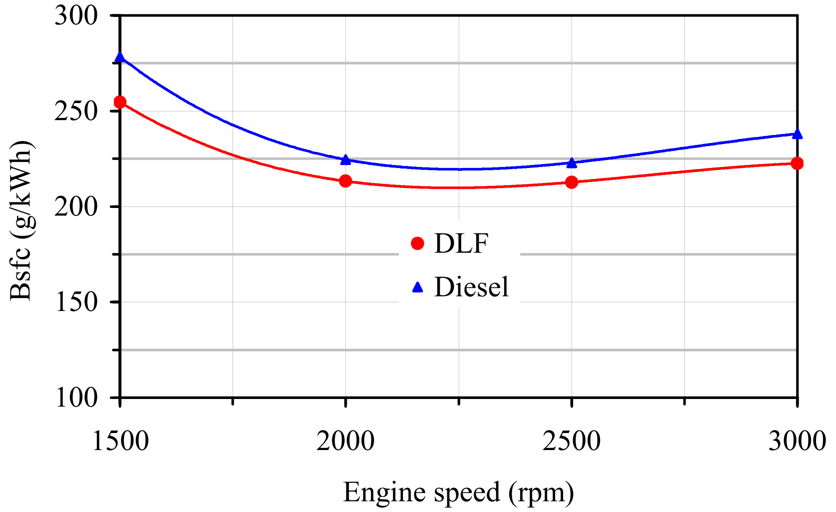

Figure 4.6 Variation of brake specific fuel consumption versus engine speed.

4.4.3 Exhaust Tests

It is known that exhaust temperature and emission values are extremely important in addition to engine performance. Therefore, exhaust temperature is measured continuously during the performance test. Variation of exhaust temperature with respect to engine speed for the DLF tested is given in Fig. 4.7 in order to compare results obtained from the use of diesel. When the DLF sample is used, the exhaust temperature is higher than that of the diesel sample, and it increases with the engine speed. The measured exhaust temperature varied between 414 ^{o}C and 515 ^{o}C for the DLF as compared to 397 ^{o}C and 477 ^{o}C for diesel indicating remarkable variation in exhaust temperature. The higher values in temperatures for the DLF depend on the higher distillation temperatures, since any fuel distilled at higher temperature increases combustion temperature when it is combusted.

As a result of the higher combustion temperature, exhaust gas temperature will increase. High temperatures in the exhaust are not desirable, for they cause higher energy transfer from the combustion chamber to the surrounding. High heat transfer decreases thermal efficiency of the engine at a finite value. This situation can be controversial for the performance parameters. The parameters with lower values are obtained while higher values than the values given in Figures 4.3 through 4.5 are acquired.

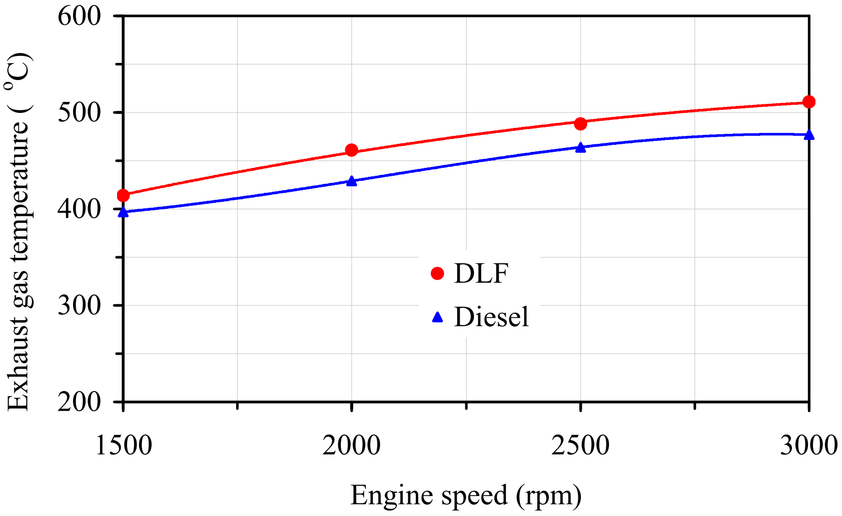

Figure 4.7 Variation of exhaust gas temperature with engine speed.

The results concerning the exhaust emissions of sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen oxide (NO_x) and oxygen (O_2) measured by exhaust analysis device during the tests are presented in this section. Variations of the SO_2, CO, NO_x and O_2 values with engine speed for DLF and diesel samples are presented in Figure 4.8, 4.9, 4.10 and 4.11, respectively.

The fact that SO_2 values measured for DLF used in the engine are high compared to those of diesel in Figure 4.8 seems to be normal. It is an expected condition that the SO_2 for the DLF should be higher than that of the diesel fuel, for the amount of sulfur in DLF is higher than diesel, which is supported by Table 3.2. SO_2 values are of great importance in terms of both energy loss and environmental values, because SO_2 gases released to the atmosphere cause sulfuric acid, H_2SO_4 rains by reacting with water vapor in the atmosphere. The rains harm all living things. Therefore, it is necessary to decrease the sulfur amount of the DLF under the standard values.

CO and NO_x are two toxic products of combustion emissions in the exhaust, which are shown in Figures 4.9 and 4.10, respectively. In these Figures, the CO and NO_x emissions from the engine operated with the DLF are higher than those of diesel for all engine speeds. O_2 emission values for the DLF are slightly lower than those of diesel shown in Figure 4.11. In a stochiometric combustion process, it is essential that there are no CO and NO_x in the combustion products.

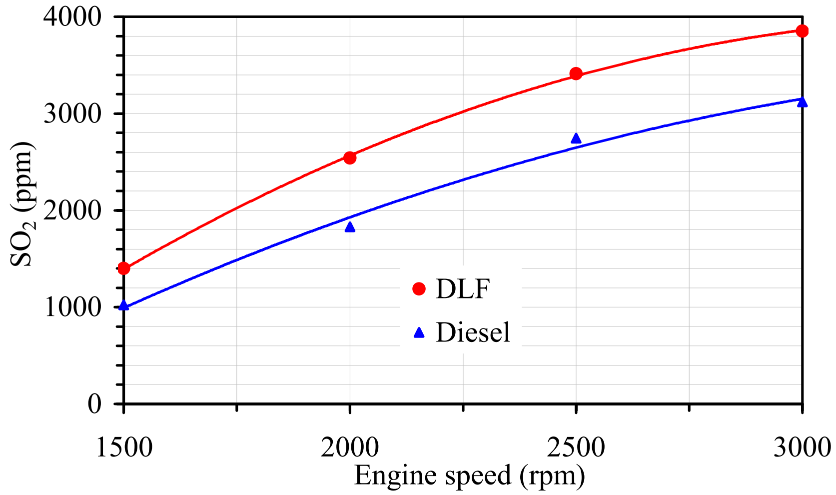

Figure 4.8 Variation of SO_2 emission with engine speed.

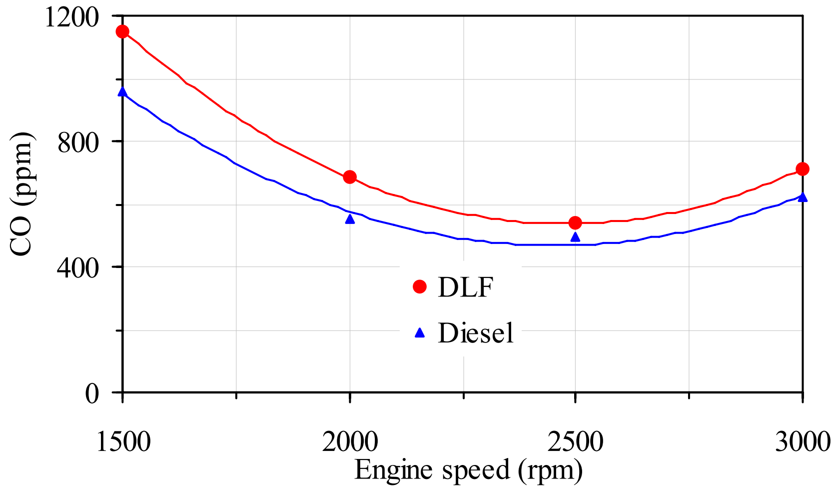

Figure 4.9 Variation of CO emission with engine speed.

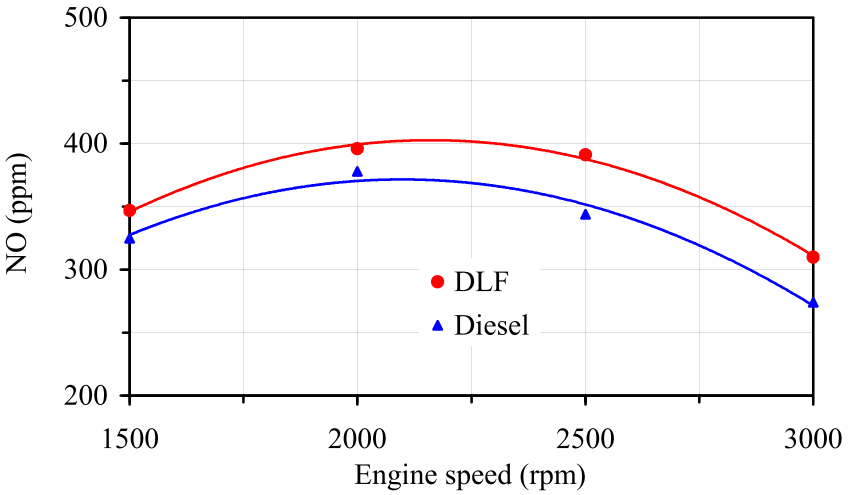

Figure 4.10 Variation of NO emission with engine speed.

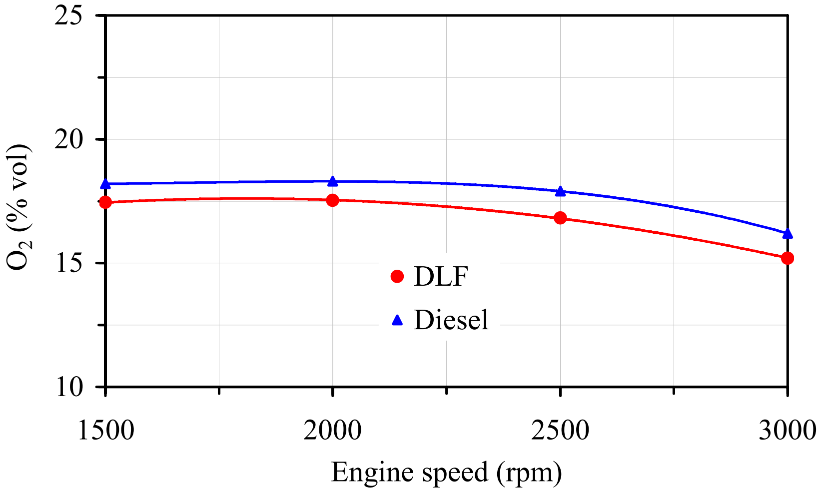

Figure 4.11 Variation of O_2 emission with engine speed.

All of the carbon and nitrogen presented in the fuel and air should be converted to CO_2 and N_2 in the product during the process. It is understood that CO and NO_x are present although O_2 also exists in the emissions. Emissions of CO from a diesel engine mainly depend upon the physical and chemical properties of the fuel [69], air–fuel ratio and engine temperature [68], deficiency of oxygen, and the fact that less time is available for the completion of combustion [19], all of which cause incomplete combustion. Air-fuel ratio is the most essential parameter which leads to emissions of CO, CO_2 and HC [70]. The NO_x and CO values reach the highest and the lowest points [20], respectively at a speed of about 2200 rpm. Fig. 4.9 and 4.10 clearly illustrate that these emissions decrease with engine speed of up to 2200 rpm, and then increase again with the engine speed. The idea that NO_x and CO values reach the highest and the lowest points respectively at a speed of about 2200 rpm finds support in the literature [19]. The highest and the lowest points are the inflection points of the curves in the Figure. The increasing of the CO amount after the inflection point is the result of increasing temperature of the combustion chamber, deficiency of oxygen at high speed and less time available for completion of combustion [19]. The high values of the emission components are not desirable outcomes, as they both lead to energy loss and environmental pollution. Moreover, the low value of O_2 for DLF in the exhaust compared to diesel can be explained with the fact that air fuel ratio for this test is low. It is clear that there will be a decrease in CO amount if air fuel ratio is increased.

Studies on how to reduce CO and NO_x components which occur as a result of ignition will be an important gain for environmental values and energy consumption, and this will also contribute to economy positively.

CHAPTER 5

5. SULFUR REMOVING PROCESS

5.1 Introduction

The sulfur content in the engine and diesel fuels is continuously reduced by regulations to lower levels. The current specification in Europe and the USA calls for a maximum sulfur content of 50 ppm in gasoline and diesel by 2005 [42], and this level will be reduced to below 10 ppm by the year 2010 (Figure 5.1) [42]. Oxidative desulfurization (ODS) has been given much attention as an alternative technology for deep desulfurization. The ODS is basically a two-stage process, oxidation, followed by liquid extraction. In the ODS process, the sulfur containing compounds are oxidized using appropriate oxidants to convert these compounds to their corresponding sulphoxides and sulphones. These are preferentially extracted from light oil due to their increased relative polarity [71, 72]. Any unused oxidant that remains in the light oil can be removed by water washing and extracting. The oxidized compounds can be extracted from the light oil by using a non-miscible solvent. Depending on the solvents used for extraction, the oxidized compounds and solvent are separated from the light oil by gravity separation or centrifugation. The light oil is water washed to recover any traces of dissolved extraction solvent and polished using other methods, such as absorption using silica gel and aluminum oxide. The solvent is separated from the mixture of solvent and oxidized compounds by a simple distillation for recycling and re-use. By using this process, the maximum sulfur removal is achieved with minimum impact on the fuel quality [73]. Many oxidants have been investigated which include peroxy organic acids, catalyzed hydro peroxides, inorganic oxidants such as inorganic peroxy acids, peroxy salts, ozone, etc. [74]. The development and application of oxidation/extraction method (ODS) are considered among the most desired options because they can lower the sulfur without negative impacts on capital investment. However, there are two major problems associated with ODS. First, the oxidants chosen do not always perform selectively. Some oxidants cause unwanted side reactions that reduce the quantity and quality of the light oil. The second problem is the selection of a suitable solvent for the extraction of the sulfur compounds [46].

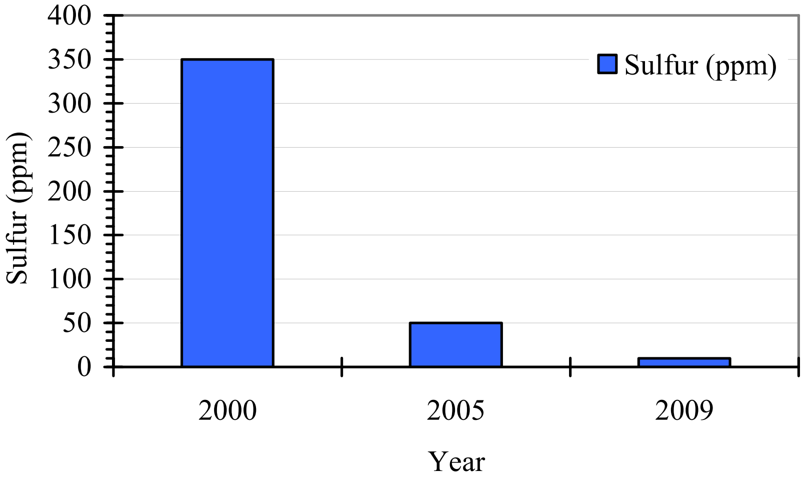

Figure 5.1 Euro III sulfur limit for diesel fuel.

5.2 Oxidative Desulfurization

2-4-6-8-10 g of a mixture of 10g of 98 % hydrogen peroxide, and 20 g of 30 % formic acid were added to five samples of 100ml of DLF. The samples were heated at 40-50-60-70 °C for 120 minutes. Then all samples were extracted with 15 ml of distilled water. The upper layer was submitted for total sulfur determination. Then, the top layer of each sample was separated ands submitted to total sulfur determination.

The graph shown in Figure 5.2 demonstrates the temperature and amount of acid-hydrogen peroxide effects on oxidation. The results shown the graph in Figure 5.1 demonstrate that the sulfur was reduced from 3500 ppm to 2150 ppm when reacted with 10 g of formic acid-H_2O_2 at 50 - 60 and 70 ^oC. Higher temperatures did not have any impact on the sulfur content in the diesel sample. From the graph in Figure 5.2, 10 g formic acid-H_2O_2 mixture and 50 ^oC were the optimum conditions to achieve oxidation in the DLF sample. After one day sulfur level of same sample (10g formic acid - H_2O_2 added at 50 ^oC) has been measured and obtained 1000 ppm. This is indicating that after oxidation process the sample must be rested.

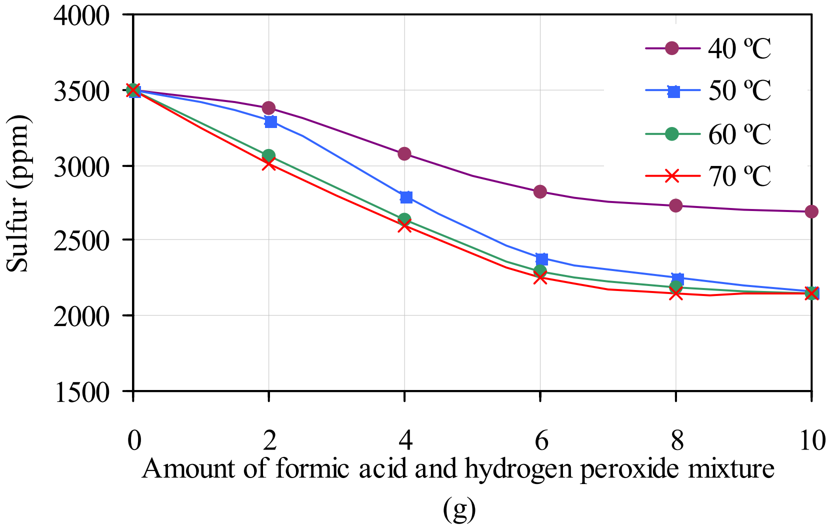

Figure 5.2 Variation of sulfur level with amount of formic acid-hydrogen peroxide at different temperatures.

SO_2 values are of great importance in terms of both energy loss and environmental values, so it is necessary to decrease the sulfur amount of DLF under the standard values. For this reason hydrogen peroxide-formic acid ratio was selected as 2/1 and sulfur removing process was repeated at 50 ^oC. It can be monitored that from Figure 5.3 sulfur level decreases with increasing amount of mixture of hydrogen peroxide-formic acid at 50 ^oC.

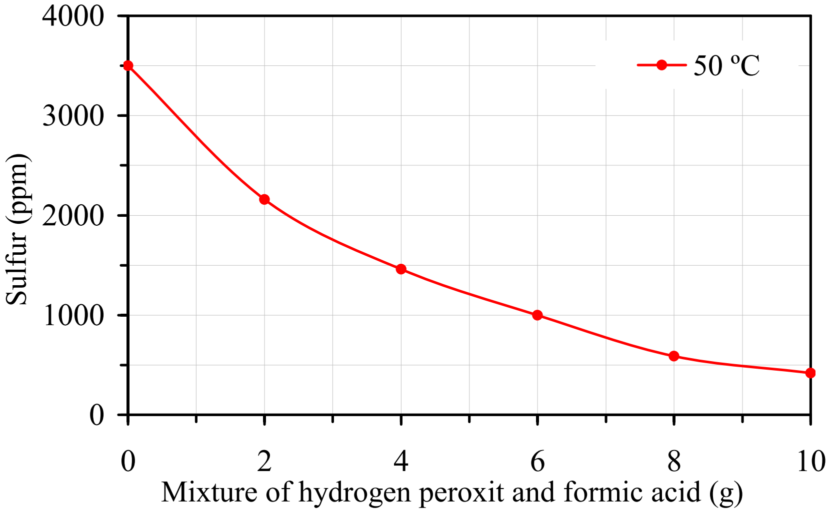

Figure 5.3 Variation sulfur level using (2/1) ratio of hydrogen peroxide-formic acid at 50 ^oC.

5.3 Characteristics and Distillation Tests of Lsdlf

The thermal and physical properties of the fuel used in engines and the characteristics of the distillation curves are very important, and as this curve is an indication of how ignition will take place, whether the fuel will be used in engines can be decided by looking at the curve. Each bit of the fuel should be distilled in a regular and increasing temperature.

A fuel sample which is distilled in a stable temperature is not desired fuel; therefore, the distillation curves of the samples obtained from waste oil are calculated besides the thermal and physical properties of the samples, and whether using the sample fuel in engine is appropriate is decided by looking at these curves. The distillation curves of DLF and LSDLF obtained by decomposing from the sample and a typical diesel sample are displayed in Figure 5.4. When the Figure is examined, it is seen that the distillation curve of the sample is close and similar to that of diesel. So, it can be concluded that the sample can be used efficiently in diesel engines, and there will not be any problem in the performance of the engine. Table 5.1 given below shows that these claims are supported by the thermal and physical properties of the sample. In order to see whether the LSDLF sample can be used efficiently in engine, it is necessary to examine and analyze the performance and exhaust emission results after the use of the sample in engine.

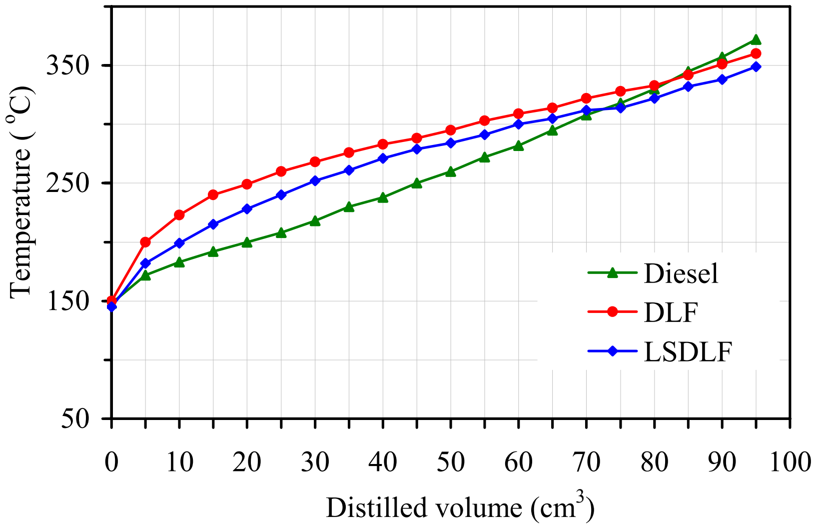

Figure 5.4 Distillation curves of DLF, LSDLF, and a typical diesel

Table 5.1 Some properties of diesel and diesel like fuel.

Properties	**Diesel**	**DLF**	**LSDLF**
Chemical formula	$C_{12,226}H_{23,29}S_{0,0575}$	----	---
Molecule weight	120-320	---	---
Density (kg/m^3)	820-860	818	814
Boiling point (^{o}C)	148-350	150-360	145-338
Viscosity (cSt)	2.5-3.5	3.49	3.2
Flash point (^{o}C)	>55	57	56
LHV (kJ/kg)	42700	42500	42100
Sulfur amount (ppm)	650	3500	420
Water (mg/kg)	<200	130	115

5.4 Performance and Exhaust Emission Tests of Lsdlf

At this stage of study engine performance and exhaust emissions test of fuel sample which is named as lowered sulfur diesel like fuel (LSDLF) have been investigated. The diesel test engine shown in Figure 4.1-4.2 and a hydraulic dynamometer connected to the engine were used for this purpose. The control panel of the test engine used in the experiment is presented in Figure 5.5 while its technical features are presented in Table 5.2 GREENLINE 8000 modeled gas analysis device seen in Figure 5.6 was used for measuring the engine exhaust emissions. This analysis device measures carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen dioxide (NO_x) emissions ± 1 ppm, and O_2 and CO_2 emissions ± 0.1%. The probe of the device is placed in the exhaust pipe, and after the engine has reached the operation temperature, the values measured by the device are printed out through a printer on the device.

Figure 5.5 Diesel test engine control panel.

Therefore, the LSDLF sample was used in a diesel test engine at Batman University, Automotive Department of Vocational School, and the engine performance parameters and exhaust emission values were measured. The results were given and analyzed below.

Table 5.2 Technical features of Greenline 8000 exhaust gas analyzer device

Parameter	**Sensor type**	**Range**	**Max. Perception time**	**Accuracy**
O_2	Electrochemical	0-25 %	20 s	±0.1 % vol
CO	Electrochemical	0-8000 ppm	50 s	<300=±10 ppm
NO	Electrochemical	0-4000 ppm	40 s	<100 ppm=±5 ppm
NOx	Calculated	0-4000 ppm	--	--
SO_2	Electrochemical	0-4000 ppm	40 s	<100 ppm=±5 ppm
CO_2	Calculated	0-99.9 %	--	--
CxHy	NDIR	0-5 %	20 s	±5 %
Tgas	Thermocouple K	0-1000 ^oC	--	±(0.3% rdg+0.3)

Figure 5.6 Greenline 8000 exhaust analyzing device.

5.4.1 Engine performance tests

Figure 5.7, 5.8, 5.9 and 5.10 respectively show changes in torque, brake mean effective pressure, brake thermal efficiency and brake specific fuel consumption obtained when LSDLF and Diesel are used in the engine with engine speed. In Figure 5.7, 5.8, and 5.9, it is understood that the torque, brake mean effective pressure, and engine thermal efficiency of LSDLF is higher than those of diesel while Figure 5.10 shows brake specific fuel consumption of LSDLF is lower than that of diesel.

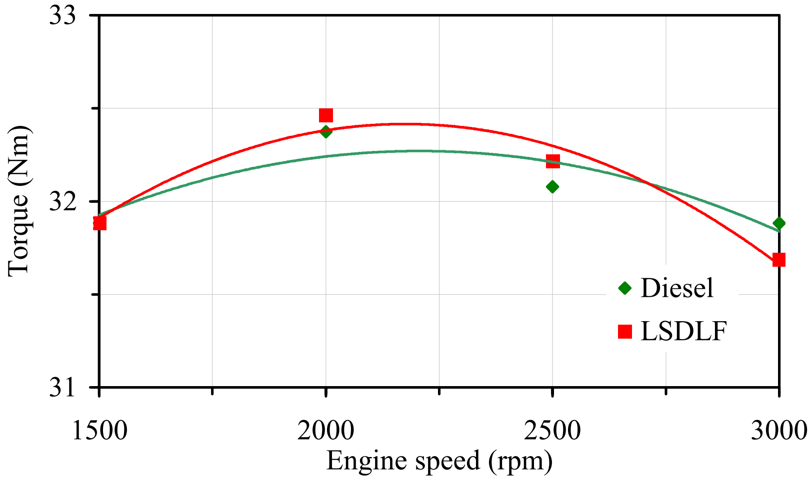

Figure 5.7 Effects of LSDLF on the engine torque

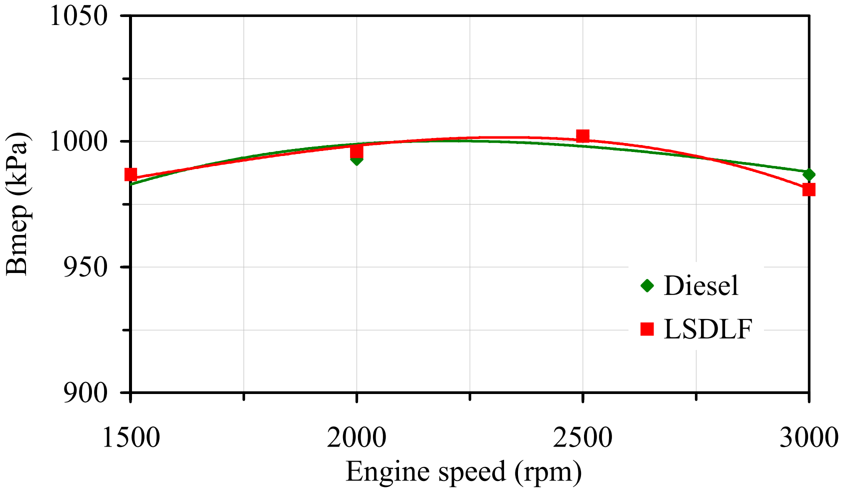

Figure 5.8 Effects of LSDLF on the brake mean effective pressure.

It was determined that torque and brake mean effective pressure increased to 2000 speed/min and reached the maximum value in this speed whereas brake specific fuel consumption reached the minimum value at the same speed. The maximum torque values for LSDLF and diesel in 2000 speed/min. are 32.46 Nm and 32.37 respectively. Thermal efficiency curves for both samples shown in Figure 5.9 support the findings presented in Figure 5.7 and Figure 5.8.

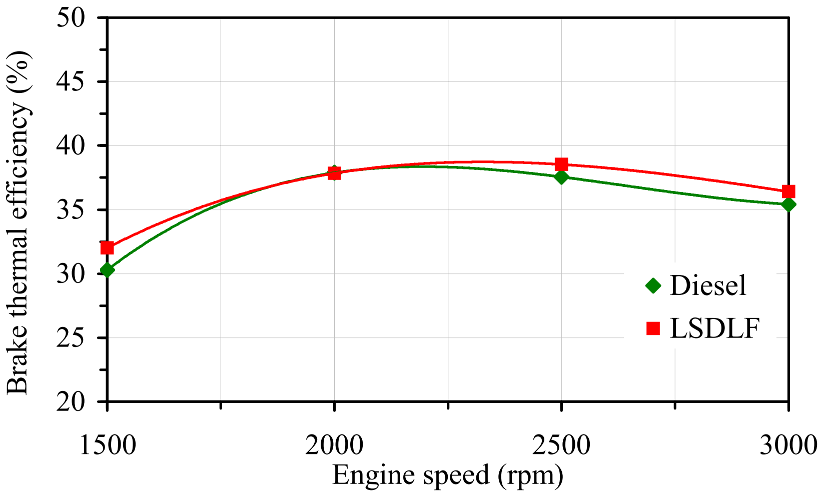

Figure 5.9 Variation of brake thermal efficiency with engine speed.

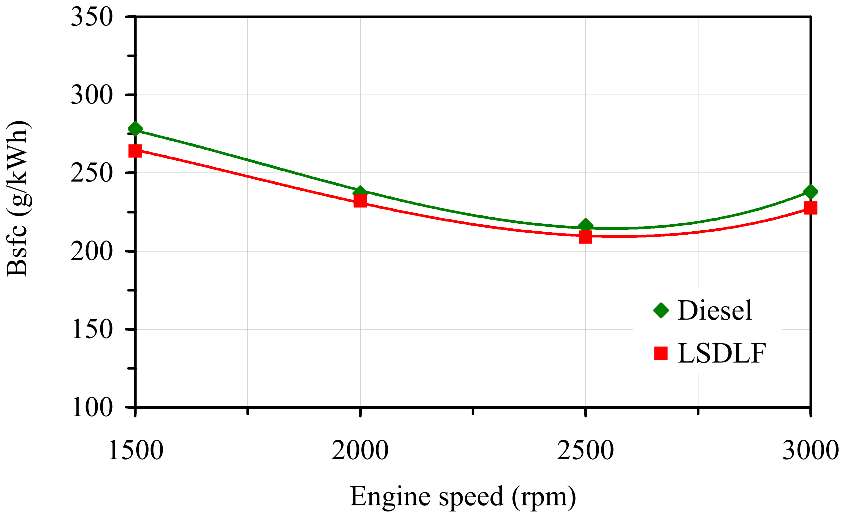

Figure 5.10 Variation of break specific fuel consumption versus engine speed.

As can be understood from these graphs, there is not any inconvenience due to LSDLF. The curve drawn for LSDLF is higher than the values of the curve drawn for diesel, but it is close to the values of diesel and follows in a regular way. This indicates that LSDLF sample can be safely used in a diesel engine depending on other thermal and physical properties of it.

5.4.2 Engine exhaust tests

It is known that exhaust temperature and emission values are extremely important in addition to engine performance; therefore, engine exhaust temperature is measured continuously during the test and exhaust temperature change is given in Figure 5.11. When LSDLF sample is used, the exhaust temperature is high compared with diesel sample, and it increases according to the engine speed. Changes in SO_2, O_2, CO and NO_x values for LSDLF and diesel samples measured by exhaust analysis device are presented with engine speed in Figure 5.12, 5.13, 5.14 and 5.15 respectively. It is normal that SO_2 values of LSDLF are compared to those of diesel in Figure 5.12 because the amount of sulfur (S) in LSDLF is lower than diesel. SO_2 values are of great importance in terms of both energy loss and environmental values, so it is necessary to decrease the sulfur amount of fuels under the standard values. O_2 values of LSDLF are slightly higher than those of diesel in Figure 5.13. CO and NO_x values in the exhaust are shown in Figure 5.14 and 5.15 respectively. In figures, CO and NO_x values for LSDLF are lower than those of diesel.

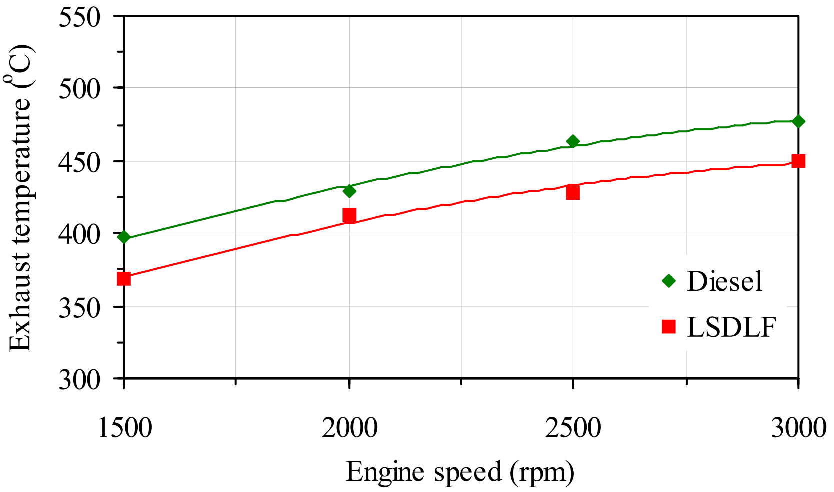

Figure 5.11 Variation of exhaust temperature with engine speed.

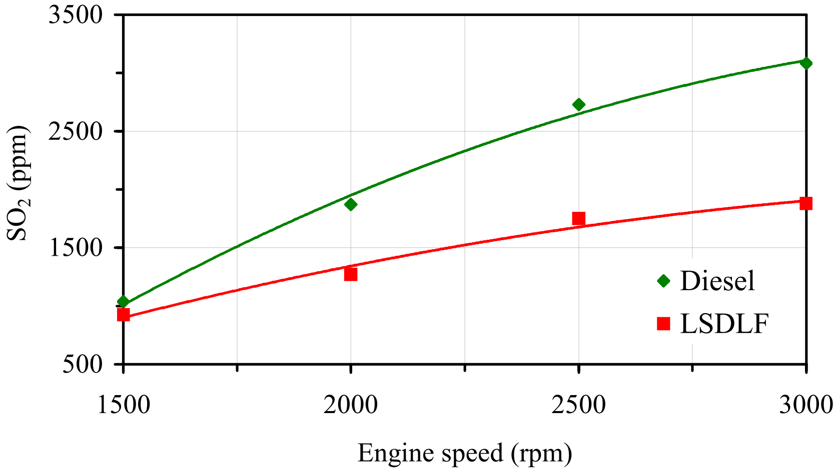

Figure 5.12 Effects of LSDLF on SO_2 emission.

High values of these components are a desirable outcome as they both lead to energy loss and environmental pollution. Why these components exist in exhaust are stated and discussed above. Moreover, the low value of O_2 for DLF in the exhaust compared to diesel can be explained with the fact that air fuel ratio for this test is low. It is clear that if air fuel ratio is increased, there will be decrease in CO amount. Studies on how to reduce CO and NO_x components which occur as a result of ignition will be an important gain for environmental values and energy consumption, and this will also contribute to our country's economy positively.

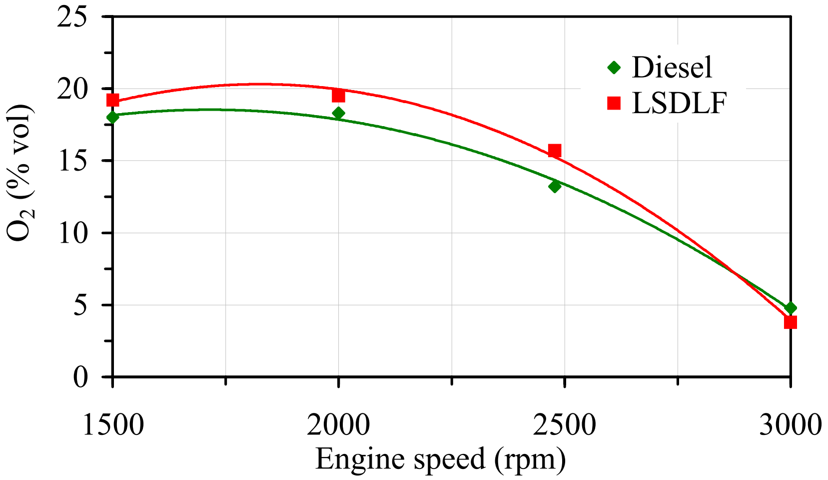

Figure 5.13 Effects of DLF on O_2 emission.

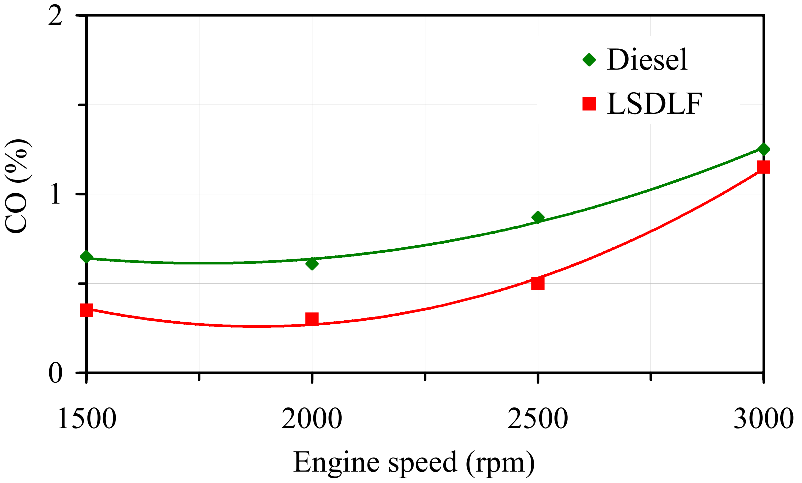

Figure 5.14 Effects of LSDLF on CO emission.

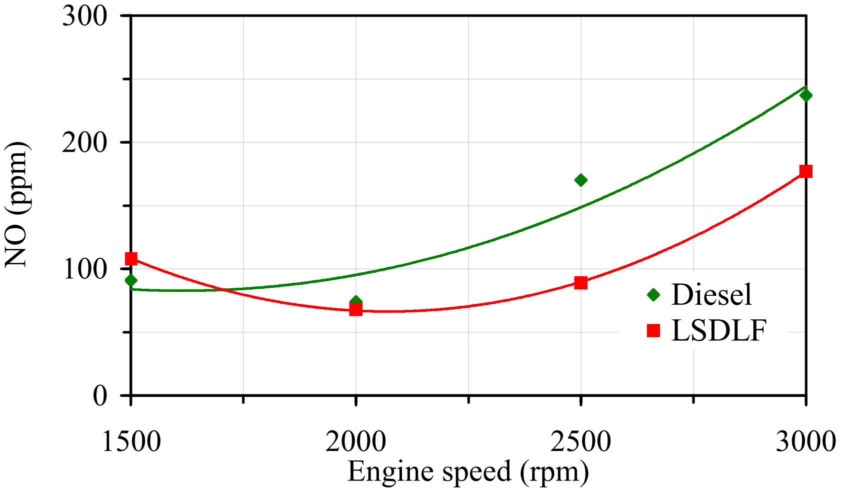

Figure 5.15 Effects of LSDLF on NO emission.

CHAPTER 6

6. OBTAINING GASOLINE-LIKE FUEL FROM WASTE LUBRICATION AND INVESTIGATION OF ENGINE PERFORMANCE AND EXHAUST EMISSION

6.1 Introduction

Fuels produced using CaO with 2 % ratio were separated into two parts which were light fuel with 20 % and heavy fuel with 60 % of the total WLO. Remaining of the WLO is about 20 %, which is rejected from the reactor. The light fuel named as GLF and gasoline samples are used to investigate the effect of the GLF on performance and emissions of a 1300 cc engine manufactured by Fiat. The experimental results showed that the GLF had a positive effect on brake power, thermal efficiency, mean effective pressure and specific fuel consumption. The GLF also raised CO emission and exhaust temperature, but it decreased hydrocarbon (HC) in the exhaust.

In this study, light fuel named as gasoline like fuel (GLF) was produced with the application of thermal and pyrolitic treatment to the WLO. Experimental investigation of the effects of GLF on performance of a spark ignition (SI) test engine and its exhaust emission was performed. Thus, distillation test of the GLF and its characteristics such as density, flash point, and lower heating value were examined. Torque, air and fuel consumption, exhaust gas temperature and emissions such as carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbon (HC) were measured during the performance and exhaust emission tests. Performance parameters like brake power, brake specific fuel consumption, brake mean effective pressure, and brake thermal efficiency were evaluated based on the experimental data collected from the test engine. The results obtained from the test for the GLF were compared with those of gasoline. The experimental work can be described in two main sections: measurements of the produced GLF properties, and measurements of performance and emission parameters.

6.2 Production of the Gasoline Like Fuel (GLF)

It was distilled and then collected in the fuel storage tank in order to examine the characteristics and distillation curve of the produced fuel. At the end of the fuel production, about 20 percent of the mixed oil-additive residue sample put into the reactor was taken out through the discharge valve.

Distillation and some characteristic tests of the distilled fuel such as, density, flash point and lower heating value were performed. The characteristic test results are given in Table 6.1. The distillation test results and characteristics were examined. It was separated into two fuel samples; namely, light and heavy fuels. The light and heavy fuel samples have mass basis of 20 % and 60 % of total waste lubricant engine oil, respectively. The distillation curve of the light fuel sample and a typical gasoline are depicted as Fig. 6.1. As its characteristics and distillation curve are similar to those of gasoline, it is named as Gasoline-Like Fuel (GLF) and is mentioned as such hereafter.

Table 6.1 Some properties of gasoline and GLF

	Gasoline	**GLF**
Chemical formula	$C_4H_{23.29}S_{0.0575}$	--
Molecular weight	105	--
Density (kg/m^3)	780	740
Specific gravity	0.78	0.86-0.9
Boiling point (^{o}C)	30-220	38-262
Viscosity cSt	--	--
Flash point (^{o}C)	-43	25
Lower heating value (kJ/kg)	43890	43000

Characteristics and distillation tests of any fuel are very significant in order to decide whether the fuel will be used without any problem in an engine or not. Therefore, distillation test and some tests related with fuel characteristics such as density, flash point, initial and final boiling points (IBP and FBP), and lower heating value (LHV) were performed by utilizing measuring devices present in the fuel laboratory at Mechanical Engineering Department of Gaziantep University. Key American Standards for Testing and Materials (ASTM) chemical methods such as the determination of IBP, FBP, distillation [75], density [76] and LHV [77] were carried out. Characteristics and distillation test results for the two types of fuels are given in table 6.1.

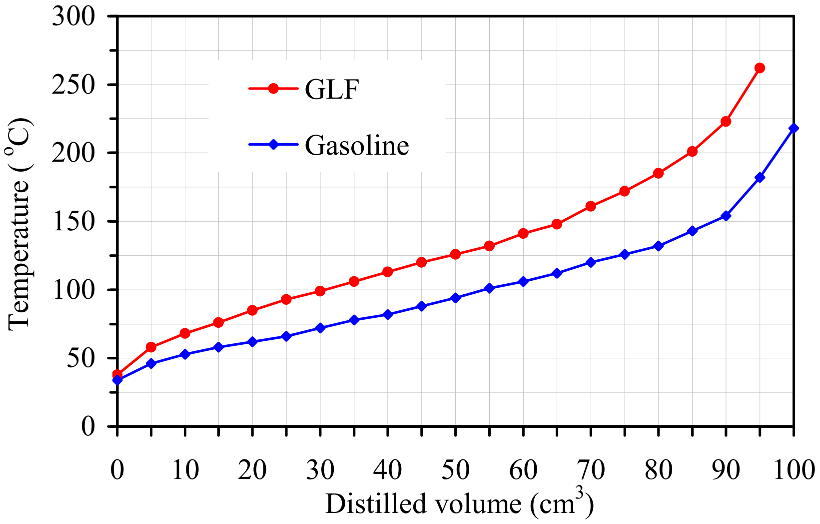

Figure 6.1 Distillation curves of the GLF and unleaded gasolines.

6.3 Characteristics and Distillation Tests of GLF

Characteristics and distillation test results of fuels used in engines are very important, because characteristics and distillation curve of any fuel can be different from each other. So, it can be used to distinguish a fuel from another fuel. Also, it is an indicator of how combustion will take place in the combustion chamber of an engine. Thus, it can be used to decide whether the fuel can be used in an engine or not. Two fuels were used in the present study. These are GLF obtained from the waste lubricant engine oil and a typical unleaded gasoline. Some characteristics of the used fuels and gasoline given in reference [78] as density, flash point, initial and final boiling points, and lower heating value (LHV) are given in Table 6.1. Density is one of the most important properties of these characteristics since it controls the amount of fuel that is burned in the combustion chamber. The higher the amount of fuel sprayed into the combustion chamber, the higher the output of partially oxidized products that is emitted [78]. Density varies between summer and winter grades and from low octane to high octane. In this study, tests for the fuels are performed in summer season. Density of the GLF, which is measured as 740 kg/m^3, is close to that measured values (780 kg/m^3) of the gasoline, and given as 742 kg/m^3 in Ref. [78]. The observation from the experiment suggested that the density of the produced GLF was within the prescribed range of 720-775 kg/m^3 given in EN 228.

Distillation test according to ASTM D86 standard represents another significant characteristic of automotive fuels in relation to their volatility [79]. The volatility determines the tendency of a hydrocarbon to produce explosive vapors, affecting the start and heating of an engine [80]. Volatility of gasoline is more important than the other fuels used since the gasoline is a light fuel; that is, distillation temperature in the engine is lower than the other engine fuels. Gasoline is a mixture of several volatile petroleum hydrocarbons with between 4 and 12 carbon atoms, whose distillation range varies between initial boiling point of 30 ^{o}C and final boiling point of 225 ^{o}C under atmospheric pressure [81]. Many of hydrocarbons have different boiling points. Thus, the gasoline boils or distills over a range of temperatures, unlike a pure compound, water, for instance, that boils at a single temperature [78]. Initial boiling point (38 ^{o}C) of the GLF is within the range, but final boiling point (262 ^{o}C) is higher than the 225 ^{o}C. Only 5 cc of the 100 cc DLF distilled is out of the range given in [81]. Tendency of distillation curve of a fuel used in engines is very important. It is necessary that each droplet of a fuel should be distilled at a uniform and ascending temperature. A fuel distilled at a constant temperature is an undesirable fuel. Therefore, distillation test results of the produced GLF need to be depicted. Results can be used to decide whether the GLF can be used in an engine as a fuel without any problem or not. Figure 6.1 shows the distillation curves of the GLF, gasoline given in [82] and a typical unleaded gasoline taken from an oil station in Gaziantep. It indicates variation of distilled volume with temperature. It is seen that the distillation curve of the GLF resembles to the distillation curve of the gasoline. Its curve shows a continuous and smooth increase in temperature as the distillation process progresses [83] like the gasoline's curve. Its boiling point is closer to that of the gasoline, but the distilled temperature of each droplet is higher than that of the gasoline samples. Higher distillation temperature will give higher combustion efficiency, which will increase engine performance. The gradual increment in distillation temperature is important, because starting ability and warm-up property of the fuel is evaluated by the evaporation temperatures of 20-70 % vaporization region of the distillation curves [19, 20]. This property is related with the volatility of a fuel. Volatility of the GLF is lower than that of gasoline. High volatility improves cold starting ability of the engine, and decreases crank case dilution. But high volatile fuels also are not desired in all working conditions, because they decrease volumetric efficiency and cause vapor lock on hot climate conditions [20]. Also the GLF is distilled at a wide band of temperature, which is the desirable condition. Vaporization at very narrow band of temperature or lower temperature differences between initial boiling and end points is not a desirable condition, since it will result in an immediate burning and a high rate of pressure rise. The immediately burning of all the fuel increases temperature and pressure of the gas in the combustion chamber. That situation can give rise to harmful consequences for the engine components. It is necessary that gradual burning of a fuel sample increases temperature and pressure in a combustion chamber of an engine, which improves performance of the engines [19].

6.4 Performance and Emission Tests of GLF

The experiment of performance and emission characteristics was conducted on a gasoline engine in the Motor Laboratory of Mechanical Engineering Department, University of Gaziantep. Schematic drawing and picture of the Gasoline engine are shown in Figures 6.2 and 6.3, respectively. The engine used in the study has specifications of four-stroke and four cylinders, water cooled cooling system, fueled with carburetor and naturally aspirated. Each cylinder has a bore of 76 mm and a stroke of 71.5 mm.

The maximum power output of the engine was 52.2 kW at 5500 rpm. The engine is produced by the Fiat Company. Besides the engine itself, flywheel, starting motor, alternator, fuel pump, fuel tank, dashboard and exhaust assemblies are mounted to the proper places. Specifications of the engine are shown in Table 6.2 in detail. It was operated with two types of fuels, which are pure gasoline and GLF. All measurement equipments used in the test engine will be explained in this section.

The engine was equipped with measuring elements; that is, weighing device, inclined manometer, dynamometer, tachometer, transducer, data logger, a personal computer (PC) and exhaust gas analyzer. Experimental set up of the gasoline engine and the measuring elements installed on the engine are shown in Figure 6.2 schematically. The elements were calibrated and data logger systems were used to transfer data into the PC. Before starting the data transfer, engine was run for 5 minutes to reach steady state test conditions.

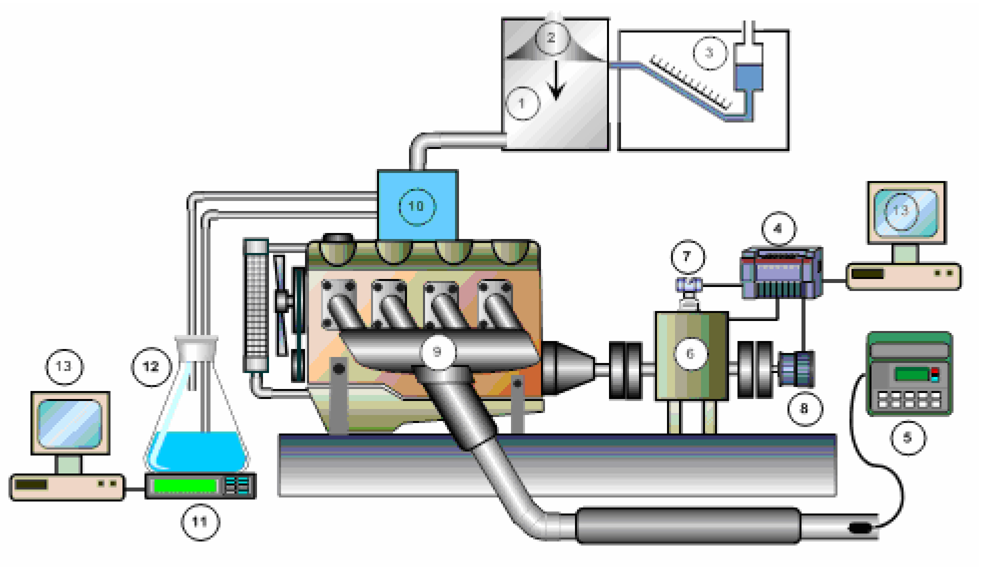

Figure 6.2 Schematics of the test engine and setup

1) air tank, 2) orifice, 3) inclined manometer, 4) data logger, 5) exhaust gas analyzer, 6) dynamometer, 7) transducer, 8) tachometer, 9) exhaust manifold, 10) carburetor, 11) weighing device, 12) fuel container, 13) computer

Figure 6.3 Picture of the gasoline (SI) test engine.

The measurements were started after the engine operated faultlessly. The functions of data logger and computer, measuring elements, and method of measurement are briefly explained as follows:

The weighing machine with sensitivity of 0.1 g was used to determine fuel consumption of the engine. Orifice meter coupled to an inclined manometer was used for measuring mass flow rate of the intake air. A large air tank, which was connected to the engine carburetor with a plastic pipe, was used for damping out the pulsations produced by the engine to form a steady flow of the intake air. Air flow was determined with the difference in pressure. Pressure difference formed by a pipe bowl at the entrance of the air tank was measured by a pressure transducer with analog output. Another analog/digital converter was used to convert this analog output into the digital signal and to transfer the signal to the PC for a definite time interval.

Table 6.2 Test engine specifications.

Type	Fiat
Engine type	Four-stroke
Fuel type	Gasoline
Swept volume	1297 cm^3
Cylinder bore	76 mm
Cylinder stroke	71.5 mm
Compression ratio	7.8:1
Number of cylinders	4
Cooling type	Water cooled in closed circuit
Fuel supply system	Naturally aspirated carburetor
Maximum torque	12.5 kg.m at 3000 rpm
Maximum power	52.2/70 kW/ HP at 5500 rpm
Engine position	Vertical

The engine torque was measured with a hydraulic dynamometer having a range of 0–1017 Nm. Engine speed was measured by a mechanism that counters the ignition number connected to spark plug and a microprocessor connected to the mechanism at a speed of 1 rpm. Engine speed was varied by the throttle valve of the engine controlled by a step motor. Step motor was controlled by conventional software. By using this software, step motor rotation was controlled with a sensitivity degree of 1.8 so that the engine speed variations were realized in very small time intervals.

Exhaust emissions were measured by exhaust gas analyzer, which was calibrated before each test. The outputs were transferred to the PC by RS 232 interface, and they were saved in a suitable format and for a definite time interval for calculations. Exhaust gas temperature (EGT), hydrocarbon (HC), carbon dioxide (CO_2) and carbon monoxide (CO) concentration in the flue gas were measured during the experiment. A k-type thermocouple and a temperature indicator were used to measure the EGT.

6.4.1 Torque and power measurements

In this study the engine performance parameters of obtained fuel samples from waste engine oil were investigated by using internal combustion engine and dynamometer setup. The water brake dynamometer converts the rotating torque of the engine to stationary torque that can be exactly measured and calculated in terms of power. Simply stated, as the amount of water within the dynamometer is increased, the load or resistance on the engine is also increased. The resistance made up by dynamometer increases with the speed of the engine. The power made up by the engine is absorbed by the dynamometer, converted into heat energy and transferred into the water flowing out of the absorption unit. The water might enter about at 15 ^{o}C and leave at 50 ^{o}C.

Figure 6.4 shows the parts of power absorption unit. The rotors are fastened to the main shaft. The stators are an integral part of the dynamometer housing which rotates, within a trunnion bearing, in the same direction as the rotor. However the stator housing is restricted from rotating by the hydraulic load cells which are attached to the trunnion support.

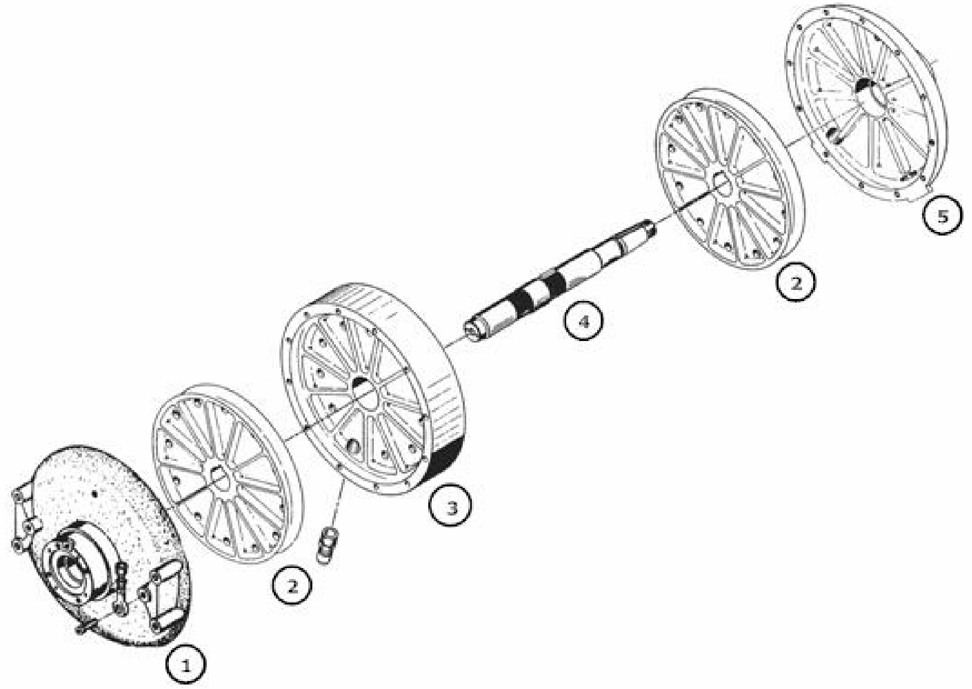

Figure 6.4 The parts of Go Power DA 516 model water brake dynamometer.
1) front cover (stator), 2) rotors, 3) body of absorption unit, 4) main shaft, 5) back cover (stator).

When the force is applied to the hydraulic load cell piston the pressure induced in the load cell is transferred to pressure transducer. The specifications of the dynamometer are shown in Table 6.3. Picture and schematic diagram of water brake engine dynamometer are shown in Figures 6.5 and 6.6, respectively. Equipments used in the experimental study such as water brake dynamometer and hydraulic system, transducer for torque measurement, electrical power supply and voltmeter were schematically shown in Figure 6.5. Torque has obtained in dynamometer when load was applied to engine by dynamometer and thus this causes pressure increase in hydraulic cylinder (4 in Figure 6.5). Then the pressure is measured by transducer in voltmeter (6 in Figure 6.5).

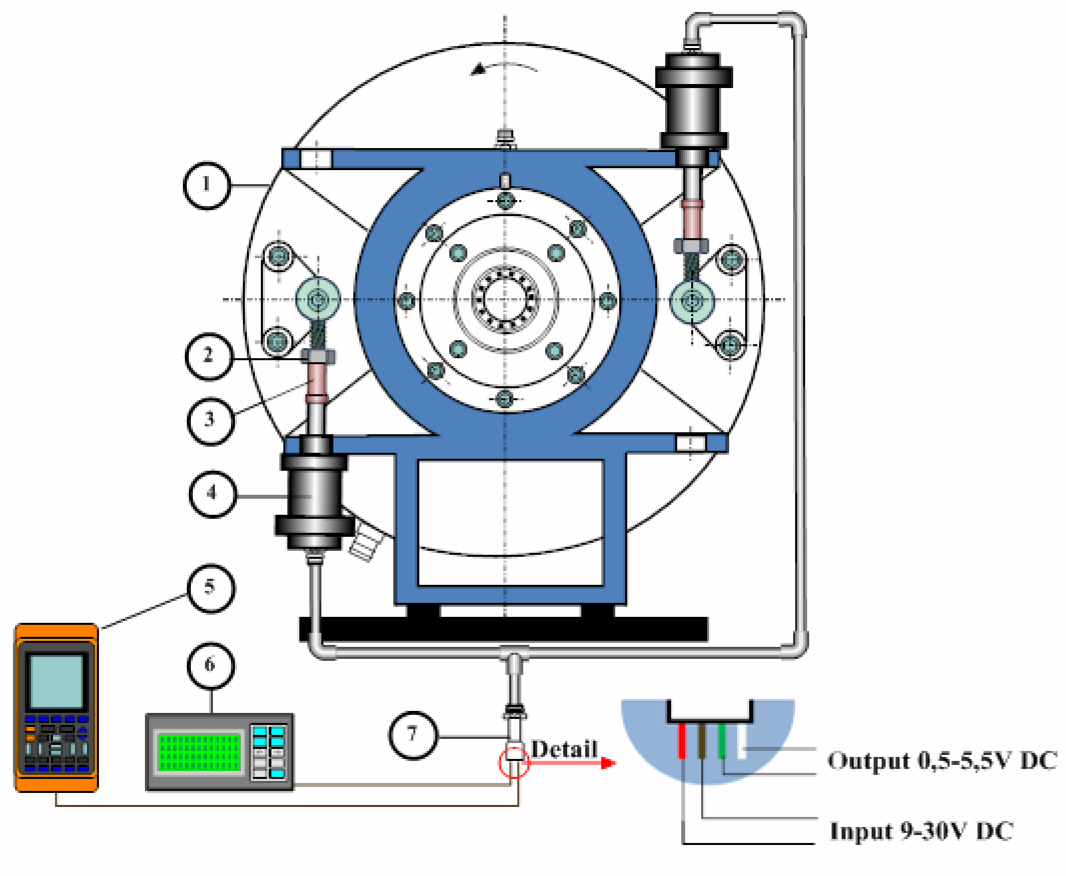

Figure 6.5 Schematic representations of water brake dynamometer and measurement devices. 1) Dynamometer body, 2) jam nut, 3) end push rod, 4) hydraulic load cell, 5) digital voltmeter, 6) electrical power supply, 7) transducer.

Before starting experiments dynamometer is calibrated by controlling air in hydraulic system. After taking air out from hydraulic system, engine is run under without load as idle. During this process jam nuts (2 in Figure 6.5) are loosened for controlling pressure in hydraulic cylinders (2 in Figure 6.5). Therefore system is set-up for 0.5 volt value of voltage in digital voltmeter. After setup procedure, nuts (2 in Figure 6.6) are fastened. Transducer gives 0.5-5.5 volt in 0-250 psi pressure value linear for pressure measurement. The properties of transducer which is used to measure torque were given in appendix.

Electrical voltage in voltmeter translated to torque by equation 6.1.

$$T = V \cdot \frac{250}{5} \text{ (ft.lb)} \tag{6.1}$$

Figure 6.6 Go Power System DA 516 model water brake dynamometer.

Table 6.3 Specifications of used dynamometer.

Type of absorption	Water brake
Construction	High strength aluminum alloy
Operating range (rpm)	5000 continuous, 10,000 intermittent
Torque transducer	Hydraulic load cell
Rotation direction	Clockwise or counter clockwise
Inlet water flow rate (l/s)	2.2
Inlet water pressure (kPa)	240
Water outlet	Gravity drain to atmosphere
Max. torque capacity (Nm)	1017
Max. power capacity (kW)	596
Weight (kg)	43

6.4.2 Engine performance tests

Engine performance and exhaust emission tests are very important to observe the effects of a fuel on the performance and emission of the engine, for test results give an idea as to whether or not the fuel is used in an engine efficiently and without any problems. Therefore, it is necessary to determine performance parameters of an engine. There are several performance parameters such as brake torque (T), brake power (P_b), brake mean effective pressure (Bmep), brake specific fuel consumption (Bsfc) and brake thermal efficiency (η_{bt}). It is necessary to find out these parameters, which can be obtained using measurement values of fuel and air consumptions, heating capacity of the fuel, torque and speed. Calculations of the engine performance parameters were performed as is described in the following sections.

Performance and exhaust emission tests were performed on a Fiat-Murat 131 SI test engine in the Motor Laboratory, Department of Mechanical Engineering, University of Gaziantep. Unleaded gasoline and GLF were used in the test engine as fuels. Schematic diagram and picture of the test engine are shown in Figures 6.2 and 6.3, respectively. The performance parameters and exhaust emissions from the engine running on the GLF and pure gasoline were measured and the measured values for the GLF were compared with those of unleaded gasoline. During the performance tests, some parameters were measured and collected on a computer. These parameters are mass flow rate of fuel and air entering engine cylinders, engine speed and torque. Performance parameters with respect to engine speed, such as brake torque (T), power (P_b), mean effective pressure (Bmep), specific fuel consumption (Bsfc), and thermal efficiency (η_{bt}) were calculated using the measured data. The parameters were presented in graphical forms and discussed in this section.

Variations of engine T, P_b, Bmep, η_{bt} and Bsfc with engine speed are shown in Figures 6.7 through 6.11, respectively. Figures 6.7-6.10 show that the T, P_b, Bmep, and η_{bt} for the GLF are higher than those values of gasoline used, and values of the Bsfc given in Figure 6.11 are lower than the value of gasoline. Figure 6.8 indicates variation of the P_b with engine speed for both fuels of the GLF and gasoline. The engine P_b increases for all engine speeds [84]. The gain of the P_b can be contributed to the increase of the Bmep, and the decrease of Bsfc for engine speed of 2500 rpm. That speed can be understood from the Figures 6.7, 6.9, 6.10 and 6.11.

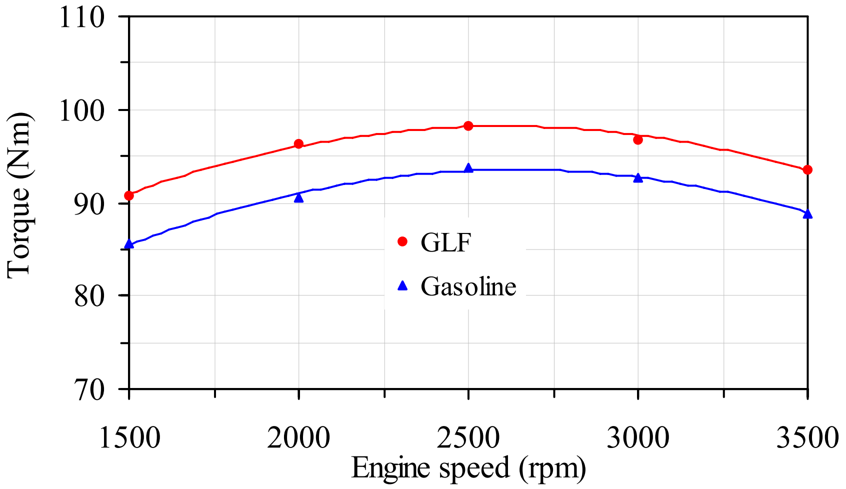

Figure 6.7 Variation of torque with engine speed for GLF and gasoline.

As the engine speed increases reaching a value of 2500 rpm for this study, the T, Bmep and η_{bt}, increase reaching its maximum values, and the Bsfc decreases reaching minimum value [19, 84]. This decrease is due to the increase in η_{bt}. It is known that T, Bmep and η_{bt} are directly proportional, but Bsfc is indirectly proportional with the engine brake power given in Eq. (2). While they have higher values for the GLF, Bsfc has lower values, which are expected conditions due to the inverse proportion of the Bsfc with the others.

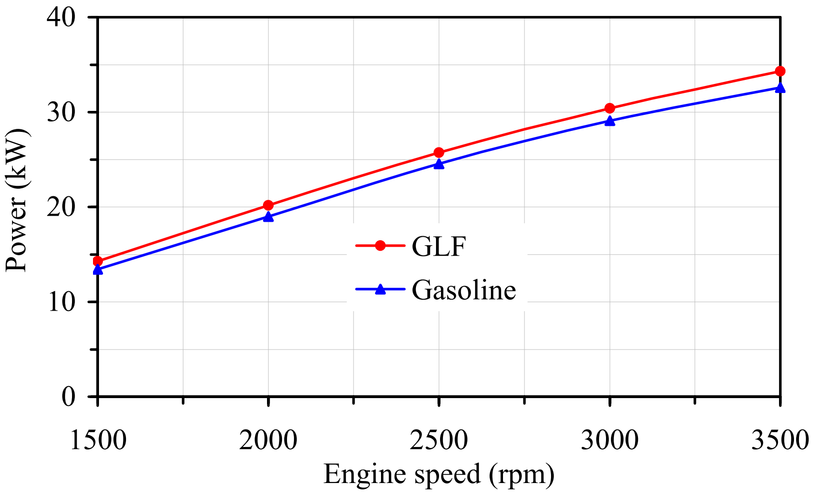

Figure 6.8 Variation of brake power versus engine speed.

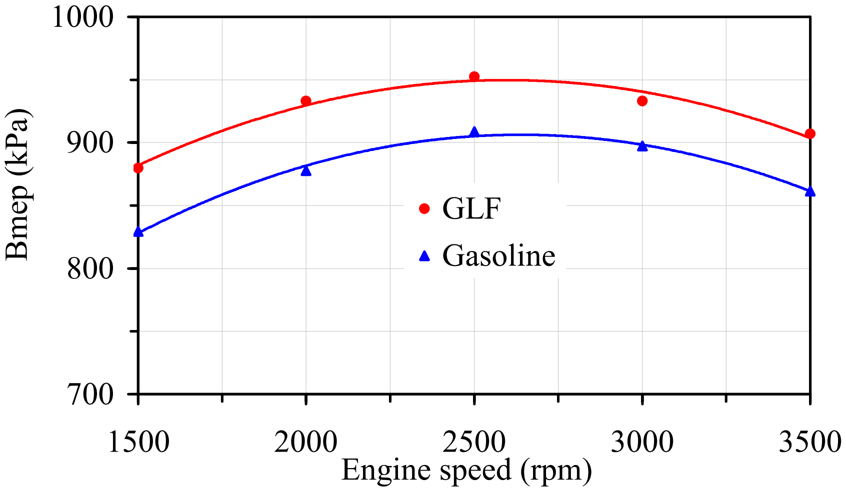

Figure 6.9 Variation of brake mean effective pressure with engine speed.

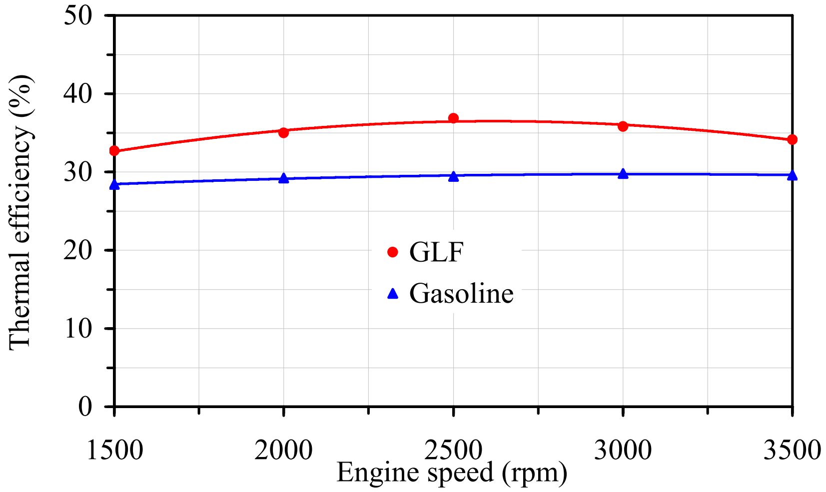

Figure 6.10 Variation of brake thermal efficiency with engine speed.

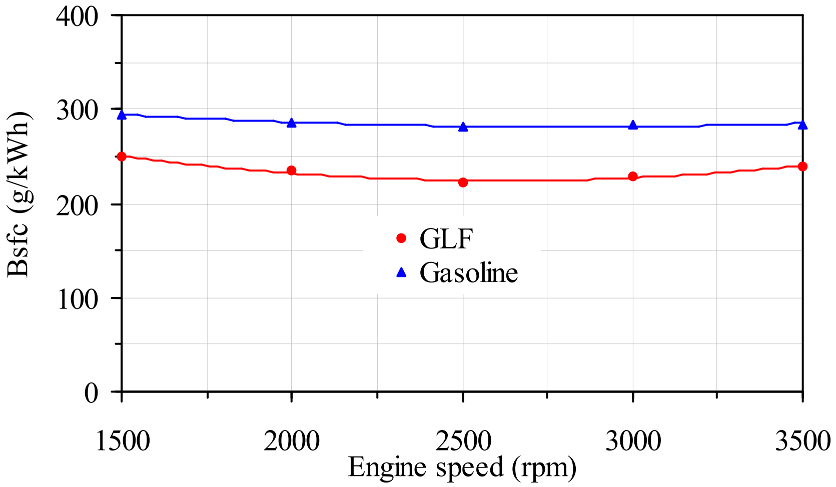

Figure 6.11 Variation of break specific fuel consumption versus engine speed.

The highest T, Bmep and η_{bt} for the GLF and gasoline are obtained as 98.3 and 93.8 kW, 952.4 and 908.2 kPa, and 36.8% and 29.4%, respectively. The highest thermal efficiency is obtained as approximately 36 % and 32 % for the fuels of E20 (80 % gasoline+20 % ethanol) and E0 (100 % gasoline) at an engine speed of 3500 rpm, which are given in [84]. Maximum η_{bt} given in [19] is 31.33 % for blends of 10 % sulfate turpentine with gasoline. The η_{bt} rates obtained in this study for an engine speed of 2500 rpm are close to the values in [84], which are reasonable values. Corresponding values of the Bsfc for the same fuels and the engine speed is approximately 222 and 281 g/kWh, respectively. All of these performance parameters (T, Bmep and η_{bt}) for the GLF and for all engine speeds are higher than those of gasoline fuel with an approximate value of 5%. This is an important criterion that makes the GLF advantageous. Initially, high heating value can be considered as the condition that led to the high performance. But it is seen in Table 6.1 that its heating value is slightly lower than the heating value of the gasoline used in the test. It is possible to explain that condition with the distillation test results given in Figure 6.1. It is caused by the distillation temperatures of the GLF, which are higher than those of gasoline, for higher distilled temperatures of fuels will give higher combustion temperatures. Higher inlet and combustion temperatures of air-fuel mixture increase the combustion efficiency, which also increases the T, P_b, Bmep and η_{bt}, and decreases Bsfc. The test results have clearly shown that the GLF has a positive effect on the performance parameters of the engine, and it can be used as a fuel in the gasoline engine without any problems according to these test results.

6.4.3 Engine exhaust tests

In this section, effects of the GLF on the exhaust temperature, and concentration in the exhaust emissions, such as carbon dioxide (CO_2), carbon monoxide (CO), and unburned hydrocarbon (HC) were given. Experimental data for these parameters measured by exhaust gas analyzer were presented in graphical forms and discussed here. Variation of exhaust gas temperature (EGT) corresponding to tested gasoline and GLF with respect to engine speed is shown in Figure 6.12. The EGT increases with the engine speed. Air/fuel ratio is one of the important parameters that affect the EGT, engine performance parameters and exhaust emissions. Lean air-fuel mixture is one of the reasons of the higher EGT. The lean mixture can cause the increase in the

EGT with the engine speed, for a richer overall air/fuel ratio requires more heat of vaporization to evaporate the excess fuel, resulting in a lower exhaust gas temperature [85]. The EGT with respect to the engine speed for the GLF is higher than that of the gasoline fuel. This is the result of energy increase in the combustion chamber caused by burning of the fuels with increasing of the engine speed. Energy that occurred after burning of the GLF is higher than that of the gasoline. It is considered that the distillation curve explains the increase in exhaust temperature for the GLF. Variation of the EGT increases slightly when the engine speed reaches approximately 3500 rpm, which indicates that there is a balance between heat input to the engine by the fuel charged and heat loss from the engine [19].

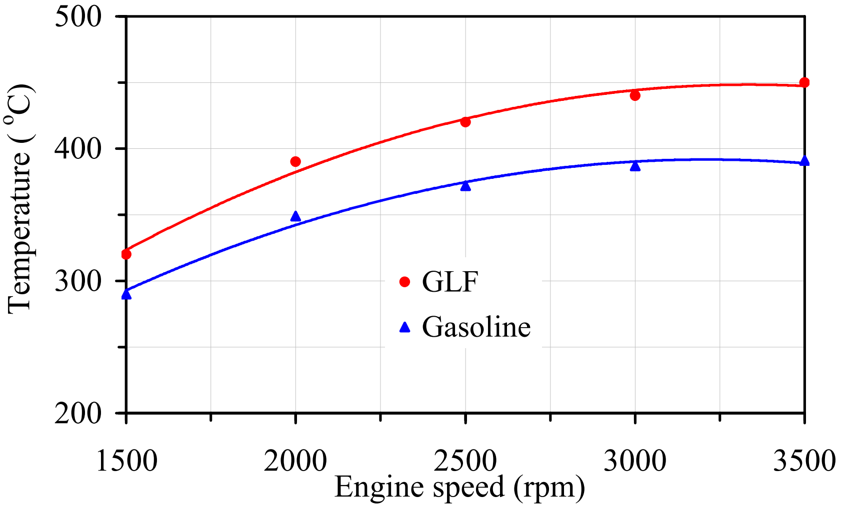

Figure 6.12 Variation of exhaust gas temperature with engine speed.

As a result of combustion of gasoline or GLF, materials such as CO, CO_2, HC, water vapor (H_2O), nitrogen (N_2), and oxygen (O_2) are discharged into the environment. While emissions of the H_2O, O_2, N_2 are not harmful to the environment, the CO, CO_2, HC pollute the environment and atmospheric air. These gases contribute to greenhouse gases and cause global worming. Therefore, it is necessary that these types of gases shouldn't be rejected to the atmosphere or they should be declined below the Standard values. Therefore, exhaust emissions as a result of burning of the GLF obtained from the WLO are measured and depicted in Figures.

Figures 6.13, 6.14 and 6.15 show variation of CO_2, CO and HC with respect to the engine speeds for the GLF and gasoline. Figures 6.13 and 6.14 show that the amounts of CO and CO_2 of GLF are lover than that of the gasoline. Although the amount of CO_2 present in the exhaust gases is a desired condition, CO in the exhaust is an undesired condition due to its being a toxic product of combustion with an energy value that decreases engine performance. Combustion conditions concerning the exhaust products are very important. CO emission depends on many parameters such as chemical structure and homogeneity of the fuel, insufficient time of burning, low and high temperatures and insufficient air. Insufficiency of air is the most important parameter, for it leads to the rejection of the CO from the exhaust without being converted into CO_2. If combustion temperature is very high, then CO_2 can be separated into the CO. As a result, it is one of the toxic products of combustion due to the improper burning of hydrocarbon (HC) [86].

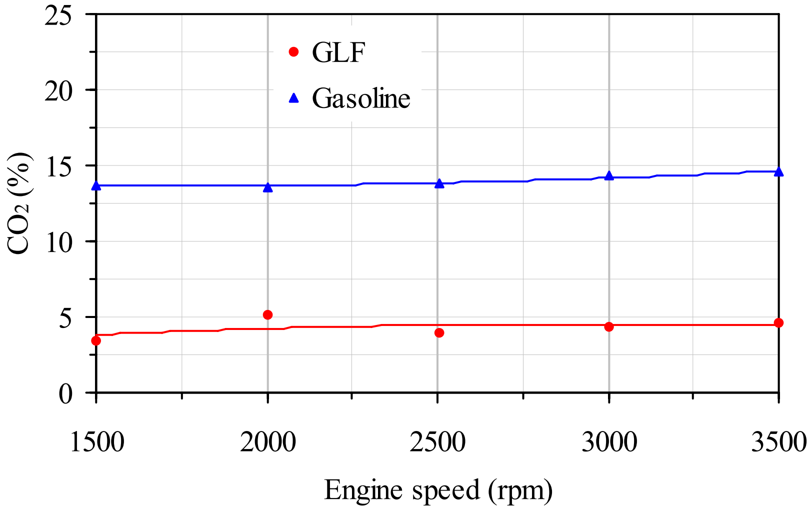

Figure 6.13 Variation of CO_2 emission versus engine speed.

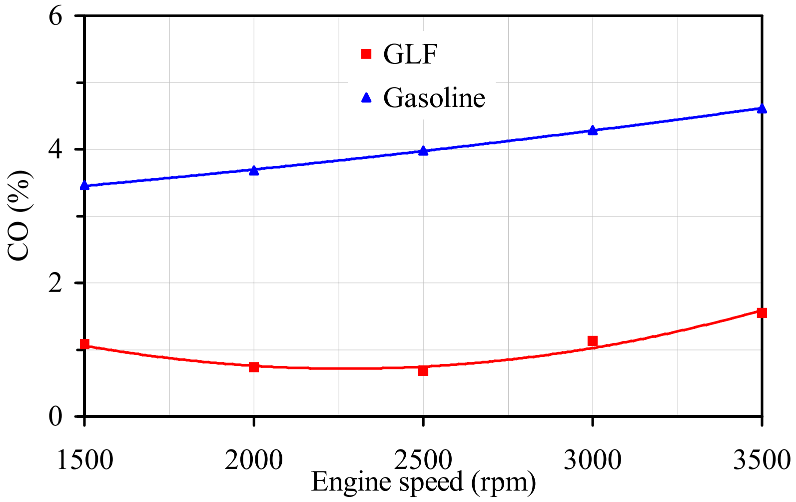

Figure 6.14 Effects of GLF on CO emission

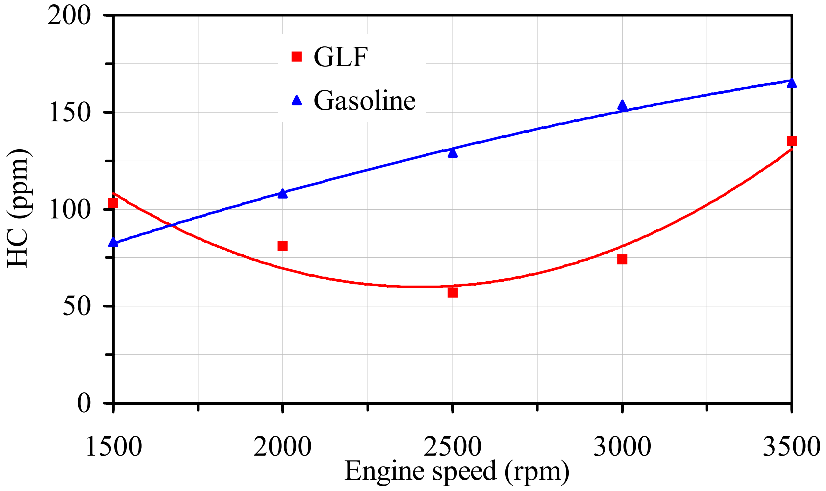

Figure 6.15 Variation of hydrocarbon (HC) emission with engine speed.

The unburned HC in the exhaust of an internal combustion engine is another kind of emission that should be controlled. The HC emissions for the GLF and gasoline are presented in Figure 6.15. The HC emission of GLF is lower than that of gasoline except for low engine speeds. For the engine speed of 2500 rpm, the lowest HC is seen in the exhaust gases. The lower HC present in the exhaust gases is a desired condition, since the HC and CO in the exhaust show that unburned hydrocarbons are rejected to the atmosphere. There are many different sources of the HC emissions. Most of the HC results as a consequence of an unburned fuel–air mixture while the other source is lubricating engine oil and incomplete combustion [65], and the HC increases with increasing ignition delay [20]. Heywood [65] states that SI engine has normally been operated close to stoichiometric, or slightly fuel-rich, to ensure smooth and reliable operation. Leaner mixtures with values of the equivalence ratio between 0.8 and 0.9 give the lowest HC emissions until the combustion quality becomes poor when HC emission rise sharply and engine operation becomes erratic. In a cold engine, fuel vaporization is slow and the fuel flow is increased to provide an easily combustible fuel-rich mixture in the cylinder during the engine warm up. In this process, HC emissions are higher [65, 87]. In this context, the lowest HC is emitted while the SI test engine fueled by the GLF operates at a speed of 2500 rpm, a condition in which the equivalence ratio is lean or close to stoichiometric, or slightly fuel-rich. But, HC increases with the engine speed for gasoline, and it increases when the speed is larger than 2500 rpm for the GLF. It is observed that the engine operates completely at rich gasoline mixture, and engine speed is larger than 2500 rpm for the rich GLF mixture.

CHAPTER 7

7. ENGINE PERFORMANCE AND EXHAUST EMISSION TESTS MIXTURE OF GLF AND TURPENTINE

7.1 Introduction

This chapter presents results of experimental investigation on engine performance and exhaust emission of a gasoline (SI) engine fueled by gasoline-like fuel (GLF), and blends of GLF and turpentine.

There are several advantages of using turpentine as fuel additive, which are environmentally friendly; it is renewable fuel source and heating value of turpentine higher than that of gasoline [89]. The optimum engine performance and exhaust parameters have been obtained by using mixture of turpentine and diesel oil used as fuel at diesel engine with ratio of 20 % turpentine and 80 % diesel [88]. Yumrutaş et. al. [19] investigated performance and emission parameters of a SI engine fueled by gasoline and its blending with turpentine in ratios of 5 % and 10 % on basis of total mass of the fuel. The experimental results in [19] showed that the turpentine has a positive effect on the engine performance parameters, such as brake power, thermal efficiency, mean effective pressure and specific fuel consumption. The turpentine also increases pollutant NOx, unburned hydrocarbon contents and exhaust temperature, but it decreases CO concentration in the exhaust.

The aim of the experimental study which was done in this chapter was to investigate effects of the fuel obtained from waste lubricant engine oil and named as gasoline like fuel (GLF) and blend of the GLF with turpentine on performance of SI engine and its exhaust emission. For this purpose, three main tests, which are characteristics, performance and exhaust emission tests, were performed in this study. Characteristics of the fuel samples used in the SI test engine such as density, flash point, lower heating value (LHV), and distillation tests were examined. Engine speed, torque, air and fuel consumption, exhaust gas temperature and emissions such as carbon monoxide (CO), carbon dioxide (CO2), unburned hydrocarbon (HC) and NOx were measured by using a SI test engine and exhaust gas analyser. Performance parameters were evaluated based on the experimental data collected from the engine. The results obtained from the test for the GLF and blends with turpentine in ratio of 10%, 20% and 30% were presented as Figures and discussed in this chapter.

The GLF was obtained from waste lubrication oil via pyrolitic distillation method. Characteristics of the pure GLF and its mixture with turpentine with amount of 10 %, 20 %, 30 % such as density, flash points, kinematic viscosity, heating value and distilled temperatures were tested by using measurement equipments. Engine performance and exhaust emission parameters were measured by using the fuel samples in the Fiat 1300 cc SI test engine. The results indicate that torque, brake mean effective pressure and thermal efficiency increase but Brake specific fuel consumption decreases with increasing amount of turpentine in the GLF sample. The maximum engine torque for blend of the GLF and 30% of the turpentine is obtained at the engine speed of 2500 rpm. The main effect of 10 %, 20 % and 30 % turpentine additions to GLF on pollutant formation is that the NO_x ratio increases but that of CO decreases. It is observed that the GLF and blends of the GLF and turpentine with the ratio of 10 %, 20 % and 30 % can be used as a fuel in the SI engines without any problems according to the test results.

7.2 Production of the Gasoline-Like Fuel (GLF)- Turpentine Mixtures

Schematic representation of the recycling system is shown in chapter 3 in Figure 3.1. Light and heavy fuels named as GLF and DLF were obtained approximately 25 % and 75 % of the produced fuel respectively. They were collected in two different containers. The GLF and blends of the GLF with turpentine with ratio of 10 %, 20 % and 30 % volume basis were used in the SI engine, and effects of the fuels on the engine performance and exhaust emissions were investigated and discussed in this chapter. It is necessary to measure characteristics of the produced GLF and blending of the GLF with turpentine, performance and emission parameters in order to find effects of the fuels on engine performance and exhaust emission parameters. Therefore, all measurements should be performed, and examined whether the fuels can be used as a fuel in an engine or not without any problem. The measurements can be categorized into three groups which are measurements of the fuel characteristics, measurements of the performance and exhaust emission parameters. The measurements and testing procedures are explained in this section.

7.3 Characteristics and Distillation Tests of the Fuels

Measurements of the fuel characteristics and distillation temperatures are very important in order to test whether the fuels will be used in engines or not. For that reasons, some characteristics of the fuels such as density, flash point, lower heating value and initial and final boiling points and also distillation tests are carried out by using testing equipments. These equipments are presented in the Fuel Laboratory at the Mechanical Engineering Department of University of Gaziantep. These tests are based on American Standards for Testing and Materials (ASTM) methods.

Determination of IBP, FBP, distillation [75], density [76] and LHV [77] were carried out. Characteristics and distillation test results for the fuels are given in this section. Some characteristics of the GLF and blends of GLF and turpentine used in this work were tested. Pure GLF and GLF-turpentine tests and data collection for these fuels were performed on a Fiat SI engine in the Engine Laboratory, Department of Mechanical Engineering, University of Gaziantep. In each test, brake force exerted by crank shaft, air and fuel mass flow rate to the engine, engine speed and lower heating values were measured. Performance parameters with respect to engine speed, such as brake torque (T_b), thermal efficiency (η_{bt}), mean effective pressure (Bmep) and brake specific fuel consumption (Bsfc) were evaluated by using the measured data. In addition to that, the engine emission parameters such as, NO_x, carbon monoxide (CO), carbon dioxide (CO_2), exhaust gas temperature and unburned hydrocarbon (HC) were obtained by using the gas measuring device. All these experimental data generated were presented as graphical forms and discussed here.

Characteristics and distillation test results of fuels used in engines are very important, because characteristics and distillation curve of any fuel can be different from each other. So, it can be used to distinguish a fuel from another fuel. Also, they are good indicators of how combustion will take place in combustion chamber of an engine. Some characteristics of the fuels are given in Table 7.1.

One of the most important properties of the fuels is density. Since, it controls the amount of fuel that is burned in the combustion chamber. The density of the turpentine (880 kg/m^3) is higher than that of GLF (740 kg/m^3). The density of the GLF is close to those values of the gasoline given as 742 kg/m^3 in Ref. [78]. The observation from the experiment suggested that the density of the produced GLF and blending of the GLF and turpentine up to 30 % was within the prescribed range of 720-775 kg/m^3 given in EN 228.

Table 7.1 Some characteristics of turpentine, GLF and their blends

	Turpentine	GLF	GLF+%10T	GLF+%20T	GLF+%30T
Density (kg/m^3)	880	740	754	768	782
Flash point (^{o}C)	39	25	26	27	29
Initial boiling point (^{o}C)	150	38	38	40	42
End point (^{o}C)	180	262	247	246	240
LHV (MJ/kg)	44.5	43.0	43.13	43.3	43.45

Lower heating value (LHV) or higher heating value (HHV) is another important thermal property. LHV and HHV of the turpentine are obtained to be 44.5 MJ/kg and 47 MJ/kg by using adiabatic bomb calorimeter, which are considerably higher than those of the GLF itself. As the percentage of turpentine in the blends increases, the heating value of the fuel sample increases. This indicates that engine will operate at high performance. Initial and final boiling points are also important. Initial boiling points (IBP) of all the used fuels are closer to each other. But, the final or end points (FBP) are reasonably different from each other. The lower IBPs indicate the higher volatile of fuels or vice versa. Volatility of the fuels effects crank case dilution, cold starting feature of the engine, warm-up time of the engine, and running performance acceleration behavior of the engine [19].

Figure 7.1 shows the results of distillation tests of the pure turpentine, pure GLF, and three other fuels obtained by blending of the GLF and turpentine with an amount of 10, 20 and 30 percent, respectively. It is seen from the Figure that 85 percent of pure turpentine vaporizes at very narrow band of temperatures between 145 and 160 ^{o}C. The curve plotted up to the volume of 85 percent is similar to horizontal line. This indicates that there is large amount of pure hydrocarbon in the turpentine. Although, distillation curve of an engine fuel is not a horizontal line. Vaporization at very narrow band of temperature is not desirable since it will result with an immediate burning and high rate of pressure rise. The burning of all the fuel increases temperature and pressure of gas in the combustion chamber. That situation can give rise to dangerous results to the engine components [19]. It is necessary that a fuel sample burns gradually in a combustion chamber of an engine.

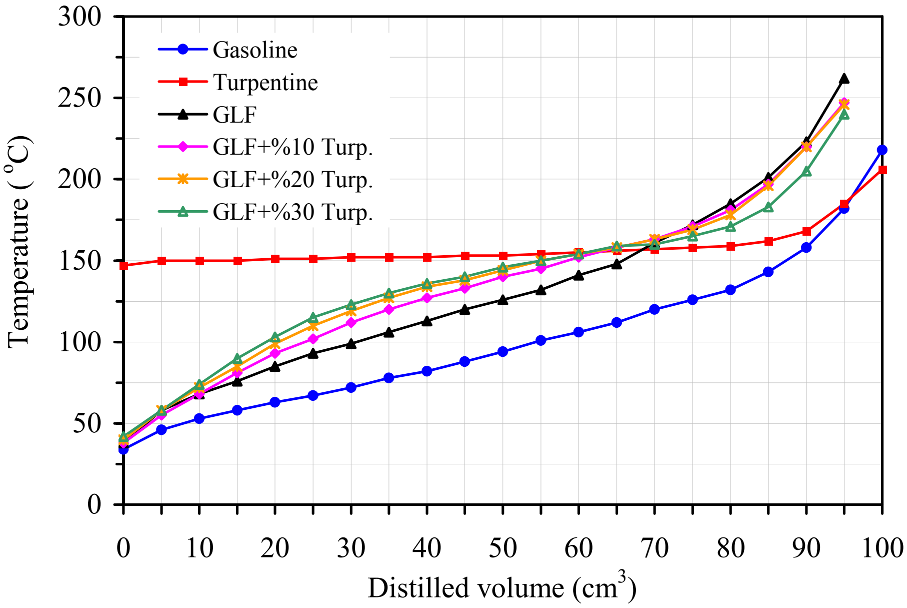

Figure 7.1 Distillation tests of turpentine, gasoline and GLF-turpentine mixtures.

When the turpentine with an amount of 10-20-30 percent is mixed with the GLF, distillation temperature increases smoothly and gradually at a finite value. This smooth and gradual increment is important because starting ability and warm-up property of the fuel is evaluated by the evaporation temperatures of 20-70 % vaporization region of the distillation curves [89, 76]. However, the change in distillation temperature is not proportional to the amount/volume of turpentine blended with the GLF. This indicates that turpentine is solved in the GLF and a new chemical bond has formed. It behaves as a new fuel according to the distillation test results. The fuel blends for these compositions will not give damage to the engine components due to the increasing of pressure or detonation as a result of burning of the fuel immediately. The distillation test results show that fuels obtained by the blending of the GLF with turpentine up to a finite value will be utilized in SI engines without any problem. This is a very important situation from the point of economic and environmental gaining with the utilization of the turpentine and waste lubricant oils.

7.4 Performance and Emission Tests of Fuels

A spark ignition (SI) test engine was used to investigate engine performance and exhaust emissions when GLF and blends of the GLF and Turpentine were used as fuel. Fig. 6.2 in chapter 6 shows the schematic representation of the test engine and exhaust gas analyzer. The exhaust gas analyzer manufactured by Sun Company was used to measure emissions. Details of the test engine's specifications are shown in Table 6.2. It was operated with four types of fuels, which are pure gasoline, pure GLF, and blends of GLF-Turpentine. In order to hold performance parameters, all the measuring equipments required are installed on the engine. Measuring equipments on the test engine were also schematically presented in Figure 6.3.

7.4.1 Engine performance tests

Figure 7.2 through 7.4 show variation of the performance parameters of torque, brake mean effective pressure, brake specific fuel consumption for the GLF, and blends of the GLF and turpentine with ratio of 10, 20 and 30 percents. Effects of 10 %, 20 % and 30 % addition of turpentine into GLF are seen from these Figures. These figures show that T_b, Bmep and Bsfc of GLF and turpentine mixtures are grater than the same values of GLF. But Bsfc of GLF+30 % turpentine is lower than those of others. It is known that T_b and Bmep are directly proportional, but Bsfc is indirectly proportional with the engine brake power [19]. As a result, fuel efficiency increases with increasing amount of turpentine in the GLF sample.

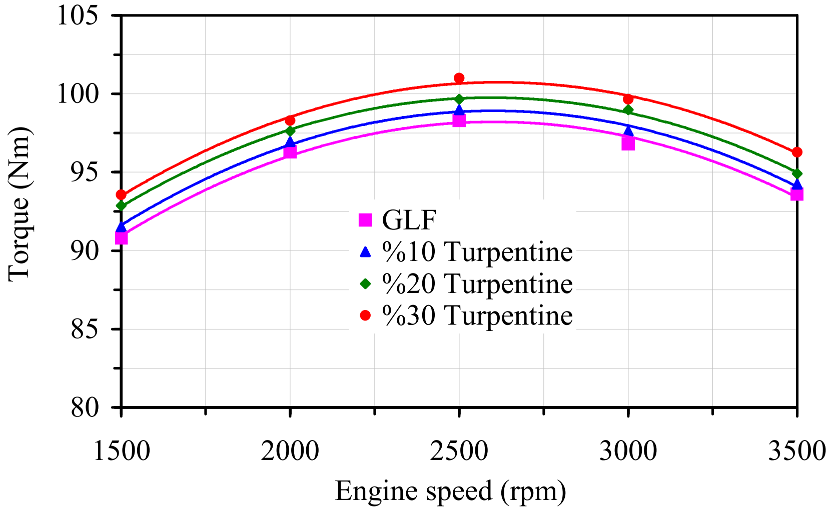

Figure 7.2 Effects of pure GLF, and GLF-Turpentine mixtures on the engine torque.

It is seen from Figure 7.2 and 7.3 that the T_b and Bmep increase up to the highest values, and Bsfc decreases to the lowest values at an engine speed of about 2500 rpm. The maximum engine torque for the pure GLF fuel and the other three blends of 10 %, 20 % and 30 % turpentine are obtained as 98.3, 98.97, 99.65 and 101.1 N-m at the engine speed of 2500 rpm, respectively.

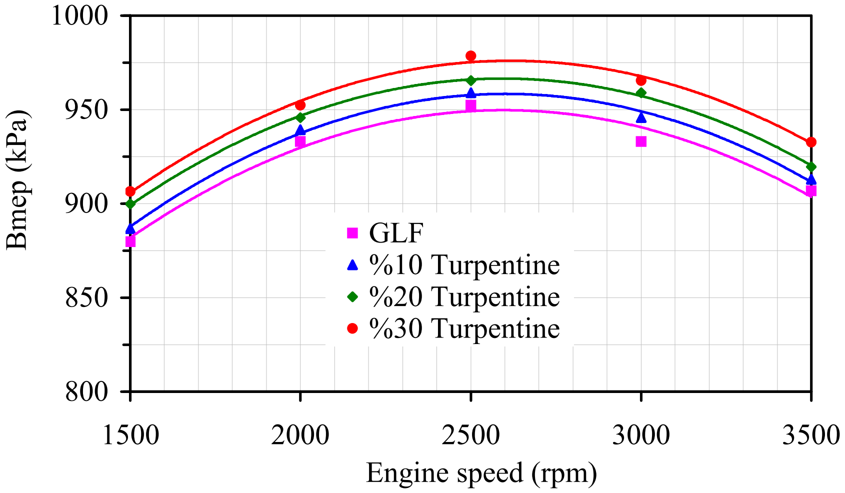

Figure 7.3 Variation of brake mean effective pressure with engine speed.

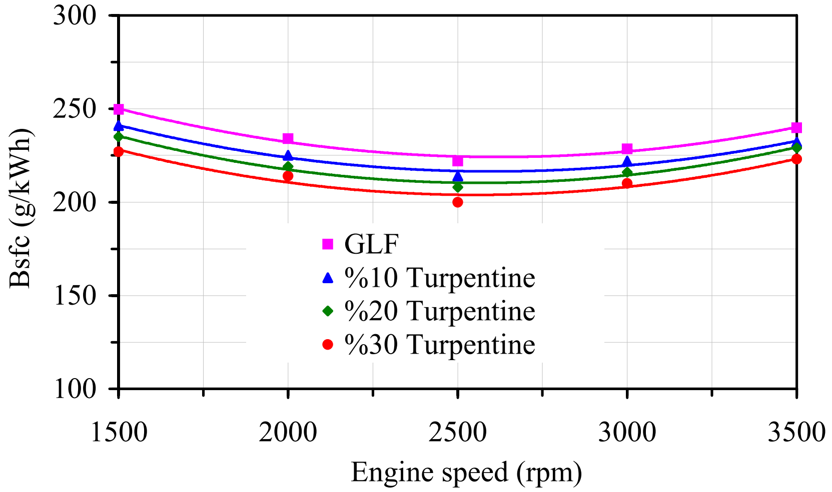

Figure 7.4. Variation of break specific fuel consumption versus engine speed.

That is, when the amount of turpentine in the GLF is increased, then the T_b and Bmep increase. For the same running conditions, Bsfc values decrease gradually and approximately from 222, to 214, 208 and then to 200 g/kWh, respectively. Variation of the η_{bt} with respect to engine speed for three different fuels used in the SI engine in the present study is shown in Figure 7.5.

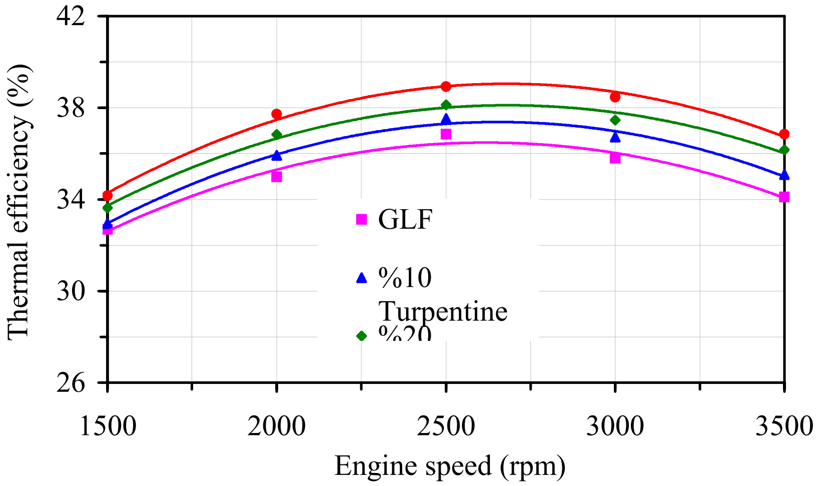

Figure 7.5 Variation of brake thermal efficiency with engine speed.

It is known that η_{bt} is proportional with the engine brake power given in Eq. (5). As a result of the relation, for pure GLF and three other GLF-turpentine blends of 10 %, 20 % and 30 %, η_{bt} increases up to maximum values with increase in engine speed up to 2500 rpm. The corresponding maximum values of the η_{bt} for the same fuels and the engine speed are 36.84, 37.52, 38.13 and 38.92 %, respectively. The lowest value of the η_{bt} (36.84) is obtained when pure GLF is used in the engine. Lower calorific value of the GLF than that of the turpentine causes reduction in the η_{bt} It is observed that the η_{bt} of the engine increase as a function of turpentine amount blended with the GLF. Increase in the η_{bt} for each one of the fuel is due to reduction in heat loss and increase in power developed with increase in speed. The maximum η_{bt} obtained is 38.92 % for blends of 30 % turpentine with GLF, increasing of turpentine amount in GLF gives higher thermal efficiency curves.

7.4.2 Engine exhaust tests

Variation of exhaust temperature corresponding to all tested fuels with respect to engine speed is shown in Figure 7.6.

The exhaust temperature increases with the engine speed and amount of turpentine in the GLF. It is seen from the Figure that the highest value of exhaust gas temperature is measured as 450 °C by using GLF, whereas it is found to be 519 °C by using blend of GLF and 30 % turpentine for the engine speed of 3500 rpm. Gradually increasing of the exhaust temperature with the engine speed is the result of energy increase in the combustion chamber by burning of the fuel sample with turpentine.

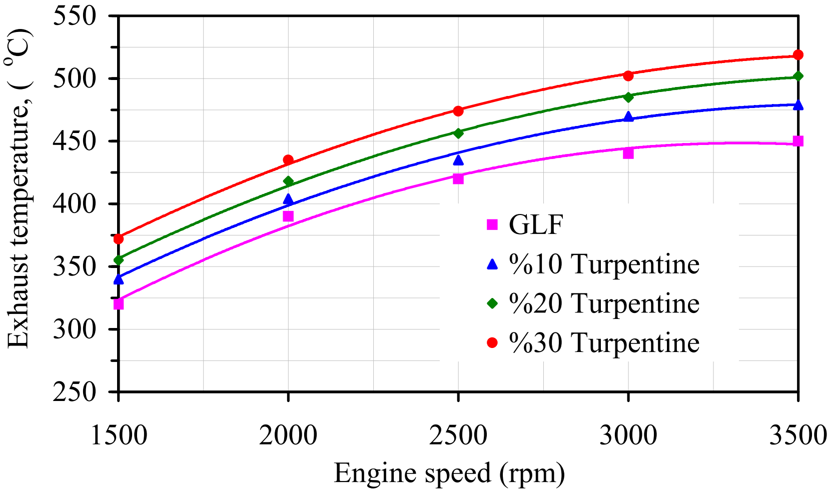

Figure 7.6 Variation of exhaust temperature with engine speed.

Because energy content of the turpentine is higher than that of the GLF. Temperature variation slightly increases when the engine speed reaches 3500 rpm, which indicates that there is a balance between heat input to the engine by the fuel charged and heat loss from the engine.

Figures 7.7, 7.8 and 7.9 indicate variations of CO_2, NO_x and CO concentration in the exhaust emission, respectively. The main effect of 10 %, 20 % and 30 % turpentine additions to GLF on pollutant formation is that values of the CO_2 and NO_x increase but that of CO decreases. The CO_2 and NO_x and CO values reach the highest and the lowest points, respectively at a speed of about 2500 rpm. These are the inflection points of these curves.

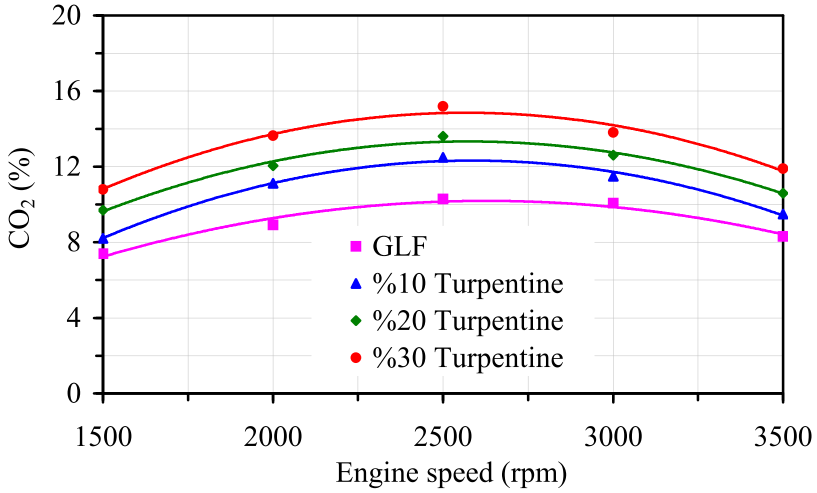

Figure 7.7 Effects of pure GLF and GLF-Turpentine mixtures on CO_2 emission.

The increasing of the CO amount after the inflection point is the result of increasing temperature of the combustion chamber, deficiency of oxygen at high speed, and less time available for completion of combustion. According to these data, turpentine gives best performance parameters such as, torque, mean effective pressure, temperature of combustion chamber, CO ratio, etc., except for NO_x values.

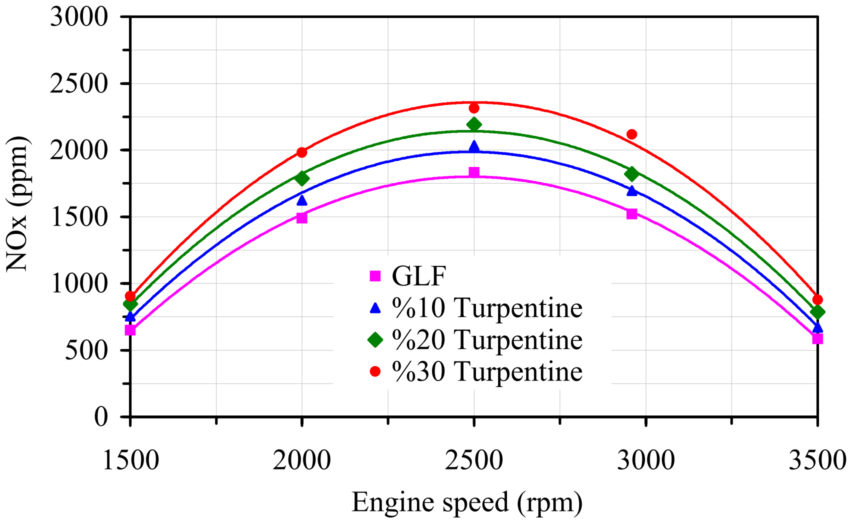

Figure 7.8 Variation of NO_x with engine speed and turpentine amount

Figure 7.10 shows unburned hydrocarbon emission test results for GLF and blend fuel samples with 10, 20 and 30 percent of turpentine. It is observed from the Figure that HC emission gradually increases with turpentine amount. A fuel sample for efficient combustion has to atomize, mix and ignite properly.

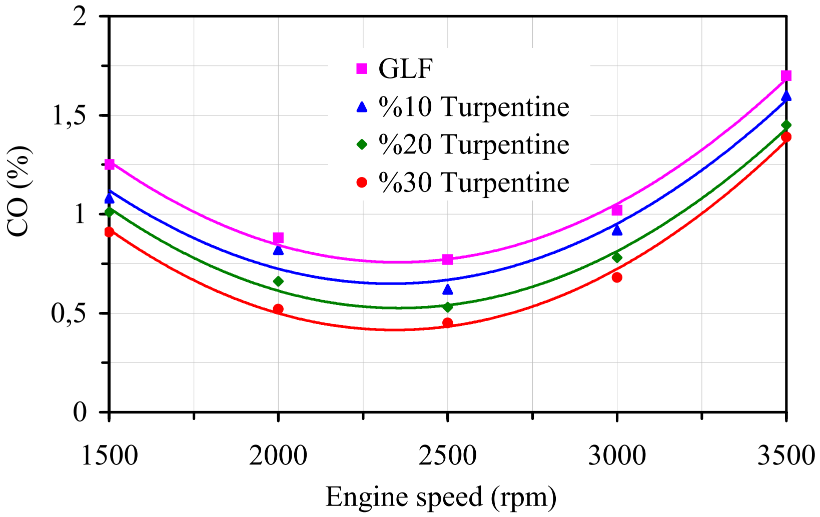

Figure 7.9 Effects of pure GLF and GLF-Turpentine mixtures on CO emission.

Atomization and mixing of a fuel depends on the physical properties of the fuel such as density, viscosity, surface tension and this affects HC emission. Fuel viscosity and surface tension affect the penetration rate, maximum penetration and droplet size which in turn affect the mixing of fuel and air. Since the density of turpentine is higher than that of GLF, higher amount of turpentine in the fuel sample causes increasing of penetration and droplet size, which causes irrelevant mixing of the fuel and air, and improper propagation of flame. As a result, the amount of unburned fuel increases and more HC ends up in the exhaust.

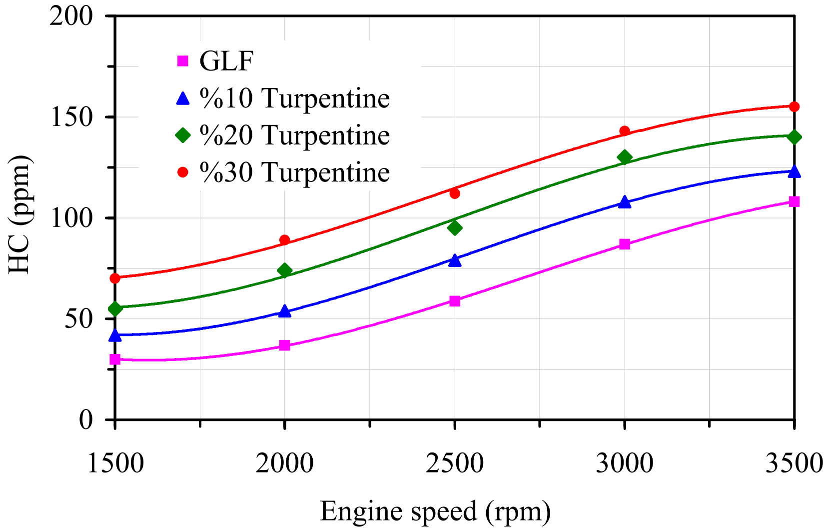

Figure 7.10 Effects of pure GLF and GLF-Turpentine mixtures on hydrocarbon emission.

7.5 Uncertainty Analysis

The uncertainty in calculated results is related to the primary uncertainty for each independent variable. This is based on the method of Kline and McClintock (1953) which state:

$$R = f(x_1, x_2, \ldots, x_n) \tag{7.1}$$

Equation 7.1 is the general form of a calculated result *R*, a function of *n* variables x_1, x_2, ... x_n. We want to estimate the uncertainty in this calculated result based on the uncertainties of the individual variables.

w_R = estimate of the uncertainty in the calculated result R.

w_{x_i} = estimate of the uncertainty in the variable x_i.

$\frac{\partial R}{\partial x_i}$ = sensitivity coefficient for the variable x_i.

$$w_R = \sum_{i=1}^{n} w_{x_i} \frac{\partial R}{\partial x_i} \tag{7.2}$$

Equation 7.2 is a logical but inappropriate estimate of total uncertainty. It seems like you could just multiply the uncertainty in each term by its sensitivity coefficient, and add them all together to get the total uncertainty. Because of the partials might be negative, and this would cancel some of the error, equation 7.2 shouldn't be used.

$$w_R = \sum_{i=1}^{n} \left| w_{x_i} \frac{\partial R}{\partial x_i} \right| \tag{7.3}$$

Equation 3 corrects the potential problems with negative errors, but tends to overestimate the actual uncertainty. Therefore equation 7.3 can not be used.

$$w_R = \left(\sum_{i=1}^{n} \left[w_{x_i} \frac{\partial R}{\partial x_i} \right]^2 \right)^{1/2} \tag{7.4}$$

Equation 7.4 is the one we want. It is referred to as the root of the sum of the squares (RSS) form, and it not only corrects the sign problem, it has another useful characteristic. Equation 7.4 inherits the same level of confidence as the individual terms. For example, if you established a 95% confidence level for each of the w_{xi} values, then w_R will also have a 95% confidence level. Equation 7.4 can be used. Note that the partial derivatives will contain values of the variables themselves. The mean (or "best estimate") value for that variable should be used.

The open form of equation 4 can be written as following

$$w_R = \left[\left(\frac{\partial R}{\partial x_1} w_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} w_2 \right)^2 + \ldots + \left(\frac{\partial R}{\partial x_n} w_n \right)^2 \right]^{1/2} \tag{7.5}$$

Cole Parmer C-68075-50 type pressure transducer was used to torque measurement in this study. The specifications of used transducer have been given in Table1.C in appendix 3. According to Table 1.C the accuracy of transducer is ±0.25% full-scale. For this reason w_T in equation 4 was selected as 0.0025.

Electrical voltage is given by transducer translated to torque by using following equation.

$$T = V \cdot \frac{250}{5} \cdot 1.356 \tag{7.7}$$

Equation 7.9 only depends on voltage (V) variable, thus $\frac{\partial R}{\partial x_1} = \frac{\partial T}{\partial V}$ can be written.

$$\frac{\partial T}{\partial V} = 50 \cdot 1.356$$

Substituting w_T and $\frac{\partial T}{\partial V}$ in equation 7.4 gives the uncertainty for torque measurement

$$W_T = \left[\left(\frac{\partial T}{\partial V} w_T \right)^2 \right]^{1/2} = \left[(50 \cdot 1.356 \cdot 0.0025)^2 \right]^{1/2} \cong \pm 0.17 \text{ (Nm)}$$

Power was given by equation 4.2 in chapter 4. Equation 4.2 can be rewritten as

$$P_b = \frac{n \cdot T}{9554.1401} \tag{7.8}$$

To calculate uncertainty of power:

$$W_{Pb} = \left[\left(\frac{\partial P_b}{\partial T} w_T \right)^2 + \left(\frac{\partial P_b}{\partial n} w_n \right)^2 \right]^{1/2} \tag{7.9}$$

The uncertainty (w_n) of engine tachometer which was used to measure the revolution of engine is 0.5.

$$W_{Pb} = \left[\left(\frac{n}{9554.14} w_T \right)^2 + \left(\frac{T}{9554.1401} w_n \right)^2 \right]^{1/2} \tag{7.10}$$

If equation 7.10 is divided by equation 7.8, the following relation can be written.

$W_{Pb} = \left[\left(\frac{w_T}{T}\right)^2 + \left(\frac{w_n}{n}\right)^2\right]^{1/2} = \left[(0.17)^2 + (0.5)^2\right]^{1/2} \cong \pm 0.53\,\mathrm{kW}$ was obtained as uncertainty of power.

Brake specific fuel consumption was given in chapter 4 by equation 4.4. The weighing machine with sensitivity of ±0.1 g was used to determine fuel consumption of engine.

$$\mathrm{Bsfc} = \frac{\dot{m}_f}{P_b} \cdot 10^3 \tag{4.4}$$

The uncertainty of brake specific fuel consumption can be written as

$$W_{Bsfc} = \left[\left(\frac{\partial B_{sfc}}{\partial \dot{m}_f} w_m\right)^2 + \left(\frac{\partial B_{sfc}}{\partial P_b} w_{P_b}\right)^2\right]^{1/2} \tag{7.11}$$

$$W_{Bsfc} = \left[\left(\frac{10^3}{P_b} w_m\right)^2 + \left(-\frac{10^3 \dot{m}_f}{P_b^2} w_{P_b}\right)^2\right]^{1/2} \tag{7.12}$$

If equation 7.12 is divided by equation 4.4, the uncertainty of brake specific fuel consumption is

$$W_{Bsfc} = \left[\left(\frac{w_m}{\dot{m}_f}\right)^2 + \left(-\frac{w_{P_b}}{P_b}\right)^2\right]^{1/2} = \left[(0.1)^2 + (-0.53)^2\right]^{1/2} \cong \pm 0.54 \text{ (g/kWh)}$$

The uncertainty of exhaust gas measurement can be calculated by following equation.

Distillation temperatures were measured by thermometer which has 0.1 ^{o}C sensitivity and the accuracy of the temperature measurement due to human error is:

$w_h=0.5$

Total uncertainty of distillation temperatures

$$W_{DT} = \sqrt{(0.1)^2 + (0.5)^2} \cong \pm 0.51\,^{o}C$$

Exhaust gas temperature and emission parameters was measured by exhaust gas emission device. The sensitivities of exhaust gas analyzing device for each parameter have been given in table 5.2.

Table 7.2 Uncertainties values for measurements

	T (Nm)	P_b (kW)	Bsfc (g/kWh)	DT (^{o}C)	O_2 (% vol)	CO (ppm)	NOx (ppm)	SO_2 (ppm)	T_{EGT} (%)
Uncertainty (±)	0.17	0.53	0.54	0.51	0.1	10	5	5	0.3

CHAPTER 8

8. THE COST ANALYSIS

The pyrolitic distillation method used to obtain GLF and DLF from waste engine oil. Obtained fuel has been separated as GLF and DLF. 17 liters of fuel sample which is obtained waste motor oil has been separated into 4.25 liters GLF and 12.27 liters DLF. At these processes electrical reactor and chemical additives such as lime, hydrogen peroxide, and formic acid have been used. Over the entire studies the sulfur level of DLF is far more than the standard values, so sulfur amount was decreased with chemical methods. The unit costs of energy and chemicals and their used times listed in table 8.1 and table 8.2.

Table 8.1 The power and working time of the devices in the recycling system.

	Power (kW)	Working time (h)	Used power (kWh)
Reactor	8	4+1.5*	44
Mixer	0.2	4+1.5*	1.1
Oil Pump	0.5	0.4	0.2

*Obtained fuel sample separated into 25 % GLF and 75 % DLF in the reactor. This process has been leaded 1.5 hour.

Table 8.2 The unit cost and amount of used chemicals.

	Amount	Unit cost	Total cost (TL)
Waste engine oil	24 liters	16 Kr/liter	3.84
Lime	0.432 kg	20 Kr/kg	0.0864
Hydrogen peroxide	0.85 liter	2.8 TL/liter	2.38
Formic acid	0.425 liter	2.4 TL/liter	1.02

According to the values in the Table 8.1 and table 8.2 the costs of energy and material can be calculated.

Energy cost = Used total power * unit cost of energy
Energy cost = (44+1.1+0.2)*0.19 = 8.60 TL

The firs cost of fuel production system is determined as 18634 TL without experimental equipment. It has been estimated that the fuel production system will work about 10 years. Fuel production system can produce 57 liters fuel per day. According to these data total fuel production during 15 year can be calculated as

Total fuel production=Daily production*365* Life of fuel production system
Total fuel production=57*365*10=208050 liters
Amortization of fuel production system=Total fuel production/Cost of systeö
Amortization of fuel production system=18634/208050=0.09 TL/liter

8.1 The Unit Cost of GLF:

The cost of raw material = (3.84+0.0864)/19 = 0.207 TL/liter
Energy cost = 8.60/19 = 0.421 TL/liter
Total cost = Energy cost + the cost of raw material+Amortization
Total cost = 0.207+0.421+0.09= 0.718 TL/liter

8.2 The Unit Cost of DLF:

Because of the sulfur level of DLF is higher than the standard values, the ODS process was applied to DLF sample along two hours at 50 ^{o}C. The energy consumption of ODS process is 0.8 kWh.

The cost of ODS process is calculated as 0.8 *0.19=0.152 TL.

The cost of raw material = ((3.84+0.0864)/19)+(2.38+1.02)/14.4 = 0.498 TL/liter
Energy cost = (8.60/17)+(0.152/12.75) = 0.444 TL/liter
Total cost = Energy cost + the cost of raw material +Amortization
Total cost = 0.444+0.498+0.09 = 1.032 TL/liter

The cost calculations showed that production cost of GLF and DLF are 0.718 TL/liter, 1.032 TL/liter respectively. Instead of electrical energy cheaper energy source such as natural gas can be used.

CHAPTER 9

9. GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

9.1 Introduction

This thesis has involved a study of;

1. the production of fuel sample from waste lubrication oil
2. investigation engine performance and exhaust emission of fuel samples
3. sulfur removing process
4. cost analysis of production and sulfur removing process

The literature survey on the waste lubrication oil demonstrated that there had been no previous studies examining the effect of fuel from waste lubrication oil on engine performance and exhaust emission. Therefore four main subjects have been covered; the production of fuel from WLO, engine performance and exhausts emissions, and sulfur removing process. The conclusions have been given under the next four sections.

9.1.1 The production of fuel sample from waste engine oil

A recycling system was designed and constructed by referring to the available literature to obtain fuel from waste engine oil. The feasibility of using waste lubrication engine oils as a diesel-like fuel was investigated experimentally. In this context, a fuel named as diesel-like fuel (DLF) was produced by applying pyrolitic distillation method. In the production process, waste engine oil was purified by using several filters having different mesh sizes. Three additives known as Na_2CO_3, zeolite and CaO with ratios of 2 %, 4 %, 6 %, 8 %, and 10 % were blended with the purified waste engine oil. Characteristics of the DLF, such as density, flash point, viscosity, sulfur content and heating value were tested and found to be close to the values of the diesel fuel used in the present study. The conclusions are as follows:

1. Utilization of Na_2CO_3 as an additive was not useful from the point of distillation temperature variation.

2. Flash point and density increase but sulfur amount decreases with the increasing of additive amounts. The lowest flash point, density and sulfur of the fuel samples were obtained by using CaO.

3. The most suitable distillation curve was obtained when CaO was used as an additive with a ratio of 2 % after 30 percent amount of the sample.

4. The DLF was obtained as 60 percent of the purified waste engine oil. Its distillation curve increases gradually and indicates characteristics similar to diesel fuels used in diesel engines.

9.1.2 Investigation engine performance and exhaust emission of DLF

Effects of diesel-like fuel (DLF) produced from waste engine oil on engine performance and emissions were investigated. In order to carry out the investigation, a fuel named as DLF was produced by using pyrolitic distillation method.

Engine performance tests were carried out with a diesel engine at Vocational High School, Batman University, and exhaust emissions were measured with Drager brand, MSI Compact 150 modeled gas analysis device. According to these test results, the most important conclusions are outlined as follows:

1. The thermal and physical characteristics of the DLF are close to those values of a typical diesel sample. Moreover, its distillation temperature increases gradually, and its behavior is similar to that of diesel fuels used in engines. Results of these properties correspond to those given in Turkish standard values except for the sulfur amount.

2. When the DLF was used, it was observed that torque, brake mean effective pressure and brake thermal efficiency were higher than those of the diesel sample while the brake specific fuel consumption was lower. It was realized that torque and brake mean effective pressure reached the maximum value while brake specific fuel consumption was minimum at 2200 rpm.

3. The sulfur value in DLF is far more than the standard values, so sulfur amount should be decreased with chemical methods. Therefore, studies related to purification and conversion of waste oils into fuels and to decreasing the amount of sulfur present in the DLF should be carried out in order to have a clean environment.

9.1.3 Sulfur removing process

The density, viscosity, flash points, heating value, sulfur amount and distillation tests of the fuel sample were performed in the Oil-fuel laboratory of Mechanical Engineering Department at University of Gaziantep, the engine performance tests were performed with the diesel engine in the Engine Department of Vocational School at Batman University, and exhaust emission tests were performed with GREENLINE 8000 gas analysis device.

1. The sulfur level decreased to 420 ppm after ODS process at temperature of 50 ^oC.

2. The sulfur value of LSDLF is lower than that of standard diesel and DLF.

3. When LSDLF was used, it was observed that torque, brake mean effective pressure and brake thermal efficiency were similar those of diesel while the brake specific fuel consumption was lower. It was determined that torque and brake mean effective pressure reached the maximum value while brake specific fuel consumption was at minimum in 2000 rpm.

4. The engine performance parameters of DLF such as torque, brake mean effective pressure and thermal efficiency higher than those of LSDLF whereas exhaust emissions (SO_2, CO, NO) of LSDLF lower than those of DLF.

9.1.4 Engine performance and exhaust emission of the gasoline like fuel (GLF)

A fuel named as GLF was produced from waste lubrication engine oil to be used in SI engines. Some characteristics of the GLF and a typical unleaded gasoline were obtained using measuring devices. Distillation, performance and exhaust emission tests for these fuels were performed utilizing distillation test unit, SI test engine and exhaust gas analyzer, respectively. Results of these tests were shown in figures and were compared with those results given in literature in the sections above. Here, the most important conclusions are outlined as follows:

1. GLF is obtained at a ratio of 20 percent of total waste lubrication engine oil. There are no negative conditions when the GLF is utilized in the SI test engine. It is observed that the GLF can be used as a fuel in the SI engines without any problems according to the test results.

2. The GLF has positive effects on the performance parameters such as torque, thermal efficiency, brake power, mean effective pressure, and specific fuel consumption when compared with gasoline.

3. Amounts of CO_2, HC, and CO for the GLF are lower than those of gasoline.

9.1.5 Engine performance and exhaust emission tests mixture of GLF turpentine

The characteristics of the GLF and mixtures of the GLF-turpentine, distilled temperatures for these fuels and performance and exhaust emission parameters were examined using measuring devices. They were indicated in table and Figures and discussed in section 4 in detail. The most important conclusions obtained from this experimental study are presented here:

1. The turpentine itself should not be used as a fuel since large amount (85 %) of it distillates at very narrow temperature band.

2. The turpentine dissolves in the GLF, and blends of the GLF with turpentine behave as a unique fuel.

3. Increasing amount of turpentine in the GLF sample has positive effects on the performance parameters. It is observed that the GLF and blends of the GLF with the ratio of 10, 20 and 30 percent of turpentine can be used as a fuel in the SI engines without any problems according to the test results.
4. The T_b, Bmep and η_{bt} increase up to the highest values, and Bsfc decreases to

the lowest values at an engine speed of about 2500 rpm. The maximum T_b, Bmep and η_{bt} and the minimum Bsfc for blend of 30 % turpentine with the GLF is obtained at the engine speed of 2500 rpm.

5. The exhaust temperature increases as a function of the amount of turpentine in the GLF. This is the result of energy increase in the combustion chamber by burning of the fuel with turpentine. Because energy content of the turpentine is higher than that of the GLF.

6. The main effect of 10 %, 20 % and 30 % turpentine additions to GLF on pollutant formation is that the NO_x ratio increases but that of CO decreases.

7. Production cost of GLF and DLF were calculated as 0.718 TL/liter and 1.032 TL/liter respectively.

9.2 Suggestions for Further Investigations

Alternative fuels especially for diesel engines have become increasingly important due to diminishing petroleum reserves, increasing economical situations and awareness of the increased environmental consequences of emissions from petroleum-fuelled engines. In the present study, the feasibility of using waste lubrication engine oils as a diesel-like fuel was experimentally investigated.

The fuel named as GLF which can be used in SI engine was produced from WLO in this study. It was noticed from literature survey that there was no similar study. The torque and Bmep values of GLF are higher than those of gasoline, LVH and Bsfc of GLF lower than those of gasoline. It is not discrepancy. It can be explained by distillation curves of GLF and gasoline.

Finally the study produced a fuel from waste lubrication oil for diesel engine. The performance of this fuel was better than the ordinary diesel.

The followings can be suggested for future studies:

1. Pyrolitic distillation process used to fuel production from WLO. More energy and time required for this method. For this reason solvent extraction technique is more suitable for industrial applications.

2. CO parameters of in the exhaust of GLF should be decreased. It can be reduced by increasing air fuel ratio of engine.

3. More sulfur can be removed from DLF. Before ODS process, hydrodesulfurization method can be applied.

4. Unit production costs of GLF and DLF can be decreased via using different energy sources such as natural gas and coal.

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APPENDIX 1: CONSTRUCTED EXPERIMENTAL SET-UP and IT'S PARTS

Figure A.1. The view of fuel production system at different angels.

Reactor

Condenser

Heat exchanger

Hot oil pump

Control panel

Mixer

Vacuum pump

Oil pump

Figure A.2 The parts of recycling system.

APPENDIX 2: TORQUE AND POWER CAPACITY OF DA-516 WATER BRAKE DYNAMOMETER

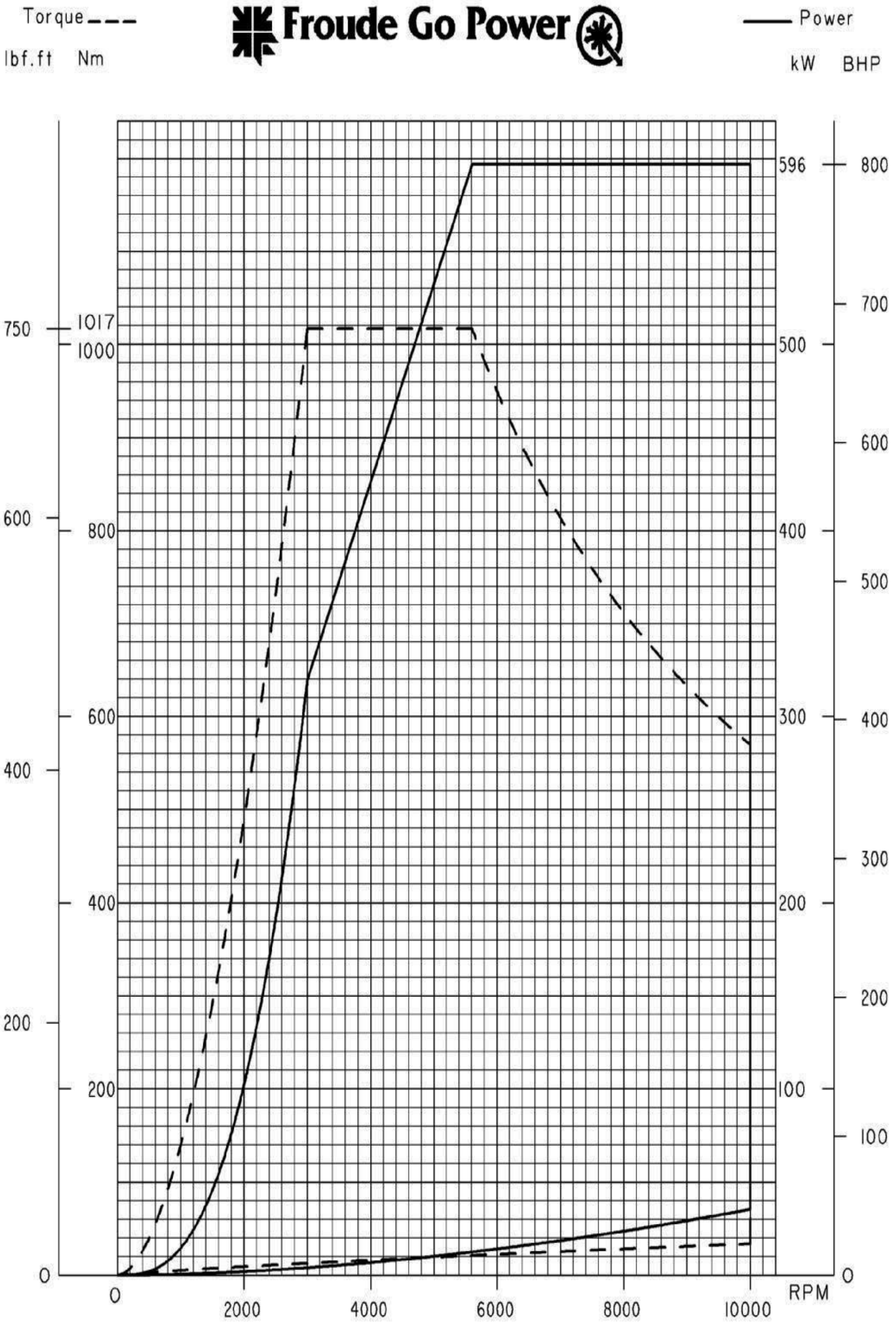

Figure B.1 Torque and power operating capacity of DA-516 dynamometer.

APPENDIX 3: SPECIFICATION OF PRESSURE TRANSDUCER

Table C.1 Specifications Cole Parmer C-68075-50 transducer

Output	0.5 to 5.5 V
Accuracy	±0.25% full-scale
Process connection	1/4" NPT(M)
Power	9 to 30 VDC
Electrical connections	2-ft cable
Dimensions	2 3/4"L x 1 1/2" dia
Wetted parts	17-4 PH stainless steel
Range	0 to 250 psig

Figure C.1 Cole Parmer C-68075-50 transducer

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FOREIGN LANGUAGES

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PUBLICATIONS

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