

A BRIEF REVIEW ON EXAMINATION OF EXPERIMENTAL AND NUMERICAL STUDIES ABOUT USING OF BIODIESEL ON DIESEL ENGINES

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Abstract

Recent concerns over the environment like global warming, weather changes increasing fuel prices and scarcity of its supply have promoted the interest in development of the alternative sources for petroleum fuels. Biodiesel is one of the most important renewable, alternative fuels that no need any modification in diesel engines. If we think of our foreign fuel dependence, determining the abilities of biodiesel as a fuel in diesel engines is really crucial. In this study, early studies about alternative fuels are obtained and these are presented.

DİZEL MAKİNELERDE BİYODİZEL KULLANIMININ SAYISAL VE DENEYSEL OLARAK İNCELENMESİ

Özetçe

Son yıllardaki küresel ısınma, iklim değişimi gibi çevresel kaygılar, petrol fiyatlarındaki yükselmeler ve petrol rezervlerinin tükenmeye başlaması, petrol kökenli yakıtlar için alternatif kaynakların gelişimine olan ilgiyi arttırmıştır. Biyodizel dizel motorlarda değişikliğe gerek kalmadan kullanılacak en önemli alternatif ve yenilenebilir yakıtlardan birisidir. Ülkemizin petrol yönünden dışa bağımlılığı düşünülecek olursa, biyodizelin yakıt olarak dizel motorlarda kullanılabilirliğinin belirlenmesi önem taşımaktadır. Bu düşünceden hareketle bu çalışmada biyodizel ile ilgili daha önce yapılan çalışmaların incelenmesi sonucunda kısa bir literatur özeti sunulacaktır.

Keywords : *Alternative fuels, biodiesel, diesel motors.*

Anahtar Sözcükler : *Alternatif yakıtlar, biyodizel, dizel motorlar.*

1. INTRODUCTION

The diesel engines dominate the field of commercial transportation and agricultural machinery due to its ease of operation and higher fuel efficiency. The consumption of diesel oil is several times higher than that of petrol. Due to the shortage of petroleum products and its increasing cost, efforts are on to develop alternative fuels especially, to the diesel oil for fully or partial replacement. It has been found that the vegetable oils are promising fuels because their properties are similar to that of diesel and are produced easily and renewably from the crops.

Vegetable oils have comparable energy density, cetane number, heat of vaporization and stoichiometric air–fuel ratio with that of the diesel fuel. None other than Rudolph Diesel, the father of diesel engine, demonstrated the first use of vegetable oil in compression ignition engine. He used peanut oil as fuel for his experimental engine. During the World War II, attempts were made to use vegetable oils as fuel in diesel engines. Viscosity of vegetable oils is several times higher than that of diesel. Viscosity of liquid fuels affects the flow properties of the fuel, such as spray atomization, consequent vaporization, and air–fuel mixing in the combustion chamber. Higher viscosity of oils had an adverse effect on the combustion in the existing diesel engines.

In recent years, systematic efforts were under taken by many researchers to determine the suitability of vegetable oil and its derivatives as fuel or additives to the diesel [1–5]. Blending, emulsification, thermal cracking and transesterification are the commonly adoptable methods to use the vegetable oil as fuel in diesel engines. Recent years, biodiesel have received significant attention both as a possible renewable alternative fuel and as an additive to the existing petroleum-based fuels. Biodiesel exhibits several merits when compared to that of the existing petroleum fuels. Many researchers have shown that particulate matter, unburned hydrocarbons, carbon monoxide, and sulfur levels are significantly less in the exhaust gas while using biodiesel as fuel. However, an increase in the levels of oxides of nitrogen is reported with biodiesel. Presently, considerable research has

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been undertaken to understand the performance characteristics of biodiesel-fueled engine as well as the biodiesel production technology [6,7].

Biodiesel is a diesel replacement fuel that is manufactured from vegetable oils, recycled cooking greases or oils, or animal fats. Because plants produce oils from sunlight and air, and can do so year after year on cropland, these oils are renewable. Animal fats are produced when the animal consumes plant oils and other fats, and they too are renewable. Used cooking oils are mostly made from vegetable oils, but may also contain animal fats. Used cooking oils are both recycled and renewable [8].

The biodiesel manufacturing process converts oils and fats into chemicals called long chain mono alkyl esters, or biodiesel. These chemicals are also referred to as fatty acid methyl esters or FAME. In the manufacturing process, 45.35 kg of oils or fats are reacted with 4.53 kg of a short chain alcohol (usually methanol) in the presence of a catalyst (usually sodium or potassium hydroxide) to form 45.35 kg of biodiesel and 4.53 kg of glycerine. Glycerine is a sugar, and is a co-product of the biodiesel process.

Raw or refined vegetable oil, or recycled greases that have not been processed into biodiesel, are not biodiesel and should be avoided. Research shows that vegetable oil or greases used in CI engines at levels as low as 10% to 20%, can cause long-term engine deposits, ring sticking, lube oil gelling, and other maintenance problems and can reduce engine life. These problems are caused mostly by the greater viscosity, or thickness, of the raw oils (around 40 mm²/s) compared to that of the diesel fuel for which the engines and injectors were designed (between 1.3 and 4.1 mm²/s). To avoid viscosity-related problems, vegetable oils and other feedstocks are converted into biodiesel. Through the process of converting vegetable oil or greases to biodiesel, we reduce viscosity of the fuel to values similar to conventional diesel fuel (biodiesel values are typically between 4 and 5 mm²/s).

When biodiesel displaces petroleum, it reduces global warming gas emissions such as carbon dioxide (CO₂). When plants like soybeans grow they take CO₂ from the air to make the stems, roots, leaves, and seeds (soybeans). After the oil is extracted from the soybeans, it is converted into biodiesel and when burned produces CO₂ and other emissions, which return to the atmosphere. This cycle does not add to the net CO₂ concentration in the air because the next soybean crop will reuse the CO₂ in order to grow.

When fossil fuels are burned, however, 100% of the CO₂ released adds to the CO₂ concentration levels in the air. Because fossil fuels are used to produce biodiesel, the recycling of CO₂ with biodiesel is not 100%, but substituting biodiesel for petroleum diesel reduces life-cycle CO₂ emissions by 78 %. B20 reduces CO₂ by 15.66 %.

Biodiesel reduces tailpipe particulate matter (PM), hydrocarbon (HC), and carbon monoxide (CO) emissions from most modern four-stroke CI engines. These benefits occur because the fuel (B100) contains 11 % oxygen by weight. The presence of fuel oxygen allows the fuel to burn more completely, so fewer unburned fuel emissions result. This same phenomenon reduces air toxics, because the air toxics are associated with the unburned or partially burned HC and PM emissions. Testing has shown that PM, HC, and CO reductions are independent of the feedstock used to make biodiesel. The EPA reviewed 80 biodiesel emission tests on CI engines and has concluded that the benefits are real and predictable over a wide range of biodiesel blends (Please see Figure 1) [9].

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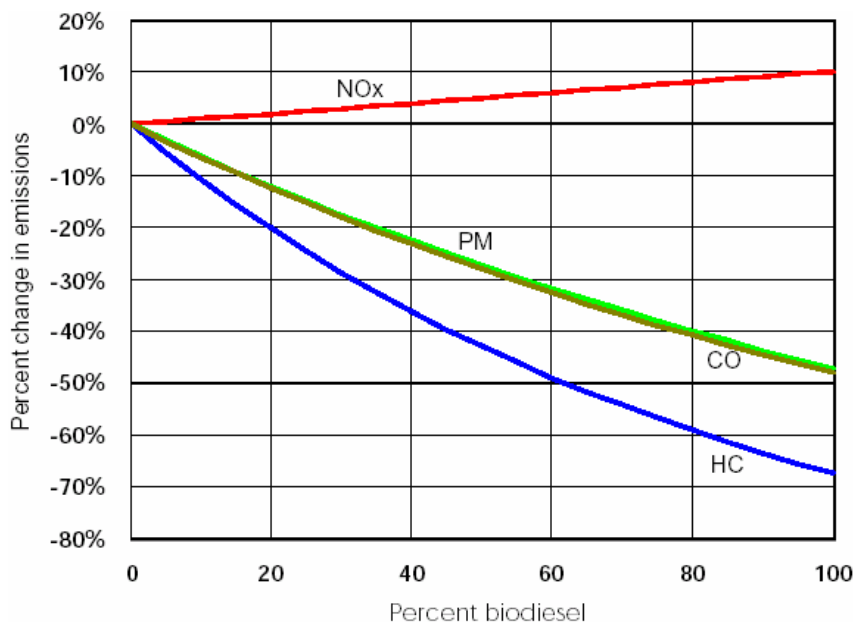


Figure1. Average emission impacts of biodiesel fuels in CI engines

2. LITERATURE REVIEW

The objective of A.Monyem's PhD thesis was to relate the chemical and physical processes associated with biodiesel oxidation to the conditions that affect engine performance and emissions. In addition, a relationship was sought between ASTM D2274i a diesel fuel-based stability test and AOCS Cd 8-53 and Cd 3a-63 which characterize the chemical changes in the fuel. It was expected that the fuel filters would plug as the vegetable oil esters oxidized but no filter plugging was observed in the study even when the fuel oxidized beyond the level that would be encountered in practice. Recent research by others has suggested that the filter plugging may be associated with reactions between the diesel fuel additives and biodiesel. The engine performance of the oxidized biodiesel was similar to that of No:2 diesel fuel with nearly the same thermal efficiency and slightly higher fuel consumption. Oxidized biodiesel produced between 14% and 16%

lower CO and HC emissions and smoke number compared to unoxidized biodiesel. No statistically significant difference was found between NOX emissions from oxidized biodiesel and unoxidized biodiesel. Oxidized biodiesel experienced a one degree shorter ignition delay than unoxidized biodiesel. The ignition delay was almost linearly correlated to CO and HC emissions. A common linear relationship was found between the start of combustion and NOX emissions. When the NOX was plotted against the start of combustion timing, the neat biodiesel produced lower NOX emissions than No:2 diesel fuel [10].

The objective of M.ÇANAKÇI's PhD thesis is to develop a process to utilize rendered fats, known as yellow grease, as a biodiesel feedstock and to build a pilot plant to implement this process. The pilot plant was successfully constructed and is shown to be capable of processing rendered fats containing 40 % free fatty acids. After preparing a sufficient amount of biodiesel from rendered animal fats and restaurant waste oils, the impact of biodiesel on diesel engine exhaust emissions and engine performance was evaluated and compared to No:2 diesel fuel and soybean oil methyl ester. The methyl esters produced from yellow grease gave nearly the same thermal efficiency but higher fuel consumption compared with No:2 diesel fuel. At the operating condition studied, the biodiesel produced 17.77% and 46.27% lower CO and HC emissions, respectively, than No:2 diesel fuel. The Bosch Smoke Number for biodiesel from yellow grease was 64.21% less than with No:2 diesel fuel. The methyl esters had 11.60% higher NOX emissions and engine performance between the biodiesel produced from yellow grease and biodiesel from soybean oil [11]

In M.P. Dorado and his friends study, the exhaust emissions of a Diesel direct injection Perkins engine fueled with waste olive oil methyl ester were studied at several steady state operating conditions. Emissions were characterized with neat biodiesel from used olive oil and conventional Diesel fuel. Results revealed that the use of biodiesel resulted in lower emissions of CO (up to 58.9%), CO₂ (up to 8.6%, excepting a case which presented a 7.4% increase), NO (up to 37.5%), and SO₂ (up to 57.7%), with increase in emissions of NO₂ (up to 81%, excepting a case which presented

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a slight reduction). Biodiesel also presented a slight increase in brake-specific fuel consumption (lower than 8.5%) that might be tolerated due to the exhaust emission benefits. Combustion efficiency remained constant using either biodiesel or Diesel fuel. The proposed alternative for Diesel fuel could significantly decrease the enormous amount of waste frying oil, furthermore becoming less dependent on fossil oil imports and decreasing environmental pollution [12].

The objective of M.Çanakçı and J.H.Van Gerpen's study was to investigate the effect of the biodiesel produced from high free fatty acid feedstocks on engine performance and emissions. Two different biodiesels were prepared from animal fat-based yellow grease with 9% free fatty acids and from soybean oil. The neat fuels and their 20% blends with No. 2 diesel fuel were studied at steady-state engine operating conditions in a four-cylinder turbocharged diesel engine. Although both biodiesel fuels provided significant reductions in particulates, carbon monoxide, and unburned hydrocarbons, the oxides of nitrogen increased by 11% and 13% for the yellow grease methyl ester and soybean oil methyl ester, respectively. The conversion of the biodiesel fuel's energy to work was equal to that from diesel fuel [13].

In C.Purohit's M.Sc. thesis, the simulation of CI engine was carried out C++ programming language. Models incorporated were finite heat release model, cylinder heat transfer model and friction loss model. The simulation was carried out to evaluate the performance of CI engine fueled by biodiesel. Biodiesel used in simulation were rapeseed oil, sunflower oil and soybean oil. The effects of various engine parameters such as compression ratio, engine speed and equivalence ratio on engine performance were evaluated. The results obtained were compared for validation with experimental data obtained from the literature [14].

In N.Usta's investigation, an experimental study on the performance and exhaust emissions of a turbocharged indirect injection diesel engine fuelled with tobacco seed oil methyl ester was performed at full and partial loads. The results showed that the addition of tobacco seed oil methyl ester

to the diesel fuel reduced CO and SO₂ emissions while causing slightly higher NO_x emissions. Meanwhile, it was found that the power and the efficiency increased slightly with the addition of tobacco seed oil methyl ester [15].

In A.Keskin and K.Aydın's experimental study, production of hazelnut oil biodiesel and usability as an alternative fuel for diesel engine were studied. Having determined physical and chemical fuel properties of hazelnut oil biodiesel and diesel fuel, they were tested between 1800 and 3200 rpm at a full load in a single cylinder direct injection diesel engine. During the test, performance and emissions of the engine were measured. According to diesel fuel values, torque, power and specific fuel consumption of the engine with hazelnut oil biodiesel did not show significant variety. CO and smoke emission decreased with hazelnut oil biodiesel, however at particularly low engine speeds, NO_x emissions increased. No SO_x emission in exhaust gas was determined [16]

In Y.D.Wang and his friends experimental investigation, experimental tests had been carried out to evaluate the performance and gaseous emission characteristics of a diesel engine when fuelled with vegetable oil and its blends of 25%, 50%, and 75% of vegetable oil with ordinary diesel fuel separately. Tests on ordinary diesel fuel had also been carried out for comparison purposes. A series of tests were conducted and repeated six times for each of the test fuels. The engine works at a fixed speed of 1500 rpm, but at different loads respectively, i.e. 0%, 25%, 50%, 75% and 100% of engine full loads. The performance and the emission characteristics of exhaust gases of the engine were analyzed and compared. The experimental results showed that the basic engine performance – power output and fuel consumption were comparable to diesel when fueled with vegetable oil and its blends. The emission of nitrogen oxides (NO_x) from vegetable oil and its blends were lower than that of pure diesel fuel. This emission character found in the tests to some extent was of significance for the practical application of vegetable oil to replace ordinary diesel fuel [17].

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In B.Kegl's investigation, he discussed the influence of biodiesel on output characteristics of a diesel engine and optimal timing setup for its injection pump. The influence of biodiesel was studied by running experiments on an NA diesel bus engine MAN D2 2566 with a direct-injection M system. The fuel used was biodiesel produced from rapeseed. Special attention was focused on the determination of the optimal injection-pump timing with respect to engine harmful emissions, engine fuel consumption, and other engine performance parameters. These engine characteristics were compared against those obtained using conventional D2 diesel. Experiments with biodiesel and D2 were run on several engine operating regimes. The engine was monitored for possible operation problems and carefully examined after the tests. The results obtained were presented and analyzed. It was shown that with carefully optimized timing of the pump, the harmful emission of NOX, smoke, HC, and CO can be reduced essentially by keeping other engine characteristics within acceptable limits [18].

In C.D. Rakopoulos and his friends experimental study, an extended experimental study was conducted to evaluate and compare the use of various Diesel fuel supplements at blend ratios of 10/90 and 20/80, in a standard, fully instrumented, four stroke, direct injection (DI), Ricardo/Cussons 'Hydra' Diesel engine located at the authors' laboratory. More specifically, a high variety of vegetable oils or bio-diesels of various origins were tested as supplements, i.e. cottonseed oil, soybean oil, sunflower oil and their corresponding methyl esters, as well as rapeseed oil methyl ester, palm oil methyl ester, corn oil and olive kernel oil. The series of tests were conducted using each of the above fuel blends, with the engine working at a speed of 2000 rpm and at a medium and high load. In each test, volumetric fuel consumption, exhaust smokiness and exhaust regulated gas emissions such as nitrogen oxides (NOX), carbon monoxide (CO) and total unburned hydrocarbons (HC) were measured. From the first measurement, specific fuel consumption and brake thermal efficiency were computed. The differences in the measured performance and exhaust emission parameters from the baseline operation of the engine, i.e. when working with neat Diesel fuel, were determined and compared. This comparison was extended

between the use of the vegetable oil blends and the bio-diesel blends. Theoretical aspects of Diesel engine combustion, combined with the widely differing physical and chemical properties of these Diesel fuel supplements against the normal Diesel fuel, were used to aid the correct interpretation of the observed engine behavior [19].

In A.S. Ramadhas and his friends investigation, biodiesel was produced using unrefined rubber seed oil. A two-step trans-esterification process (i.e. acid-alkaline trans-esterification) was developed for the production of methyl-esters of rubber seed oil. The properties of this biodiesel were closely matched with those of diesel fuel. The performance tests were carried out on a C.I. engine using biodiesel and its blends with diesel (B20 and B100) as fuel. The effects of relative air-fuel ratio and compression ratio on the engine performance for different fuels were also analyzed using this model. The comparison of theoretical and experimental results were presented [20].

In M.Çanakçı and his friends study, the applicabilities of Artificial Neural Networks (ANNs) had been investigated for the performance and exhaust-emission values of a diesel engine fueled with biodiesels from different feedstocks and petroleum diesel fuels. The engine performance and emissions characteristics of two different petroleum diesel-fuels (No. 1 and No. 2), biodiesels (from soybean oil and yellow grease), and their 20% blends with No. 2 diesel fuel were used as experimental results. The fuels were tested at full load (100%) at 1400-rpm engine speed, where the engine torque was 257.6 Nm [21].

In C.Y. Lin study, the biodiesel produced by a transesterification technique was further reacted by using a peroxidation process. Four types of diesel fuel, biodiesel with and without an additional peroxidation process, a commercial biodiesel and ASTM No. 2D diesel were compared for their fuel properties, engine performance and emission characteristics. The experimental results showed that the fuel consumption rate, brake thermal efficiency, equivalence ratio, and exhaust gas temperature increased while the bsfc, emission indices of CO₂, CO and NO_X decreased with an increase

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of engine speed. The three biodiesels showed a higher fuel consumption rate, bsfc, and brake thermal efficiency, while at the same time exhibited lower emission indices of CO and CO₂ as well as a lower exhaust gas temperature when compared to ASTM No. 2D diesel. Moreover, the biodiesel produced with the additional peroxidation process was found to have an oxygen content, weight proportion of saturated carbon bonds, fuel consumption rate, and bsfc that were higher than the biodiesel produced without the additional process; while at the same time the brake thermal efficiency, equivalence ratio, and emission indices of CO₂, CO and NO_x were found to be lower. In particular, biodiesel produced with the addition of the peroxidation process had the lowest equivalence ratio and emission indices of CO₂, CO and NO_x among all of the four test fuels [22].

In D.Y.C. Leung and his friends investigation, the performance of biodiesel in a single-cylinder diesel engine was studied and optimized by varying the engine settings, including the injection timing, injection pressure, and fuel pump plunger diameter. The engine emissions were found to be lowered for particulate matters (PM) and hydrocarbon (HC) with the use of biodiesel, but an obvious increase in the oxides of nitrogen (NO_x) was observed, particularly at high engine loadings. The results revealed that individual adjustment of the above-mentioned parameters could not acquire a good balance between PM and NO_x emissions. On the other hand, multiparameter engine adjustment with the consideration of their cross-interactive effects can keep the benefit of reducing PM and HC without increasing NO_x emission and sacrificing fuel combustion efficiency [23].

The objective of D. Agarwal and his friends research work was to investigate the usage of biodiesel and EGR (Exhaust gas recirculation (EGR) is effective to reduce NO_x from diesel engines because it lowers the flame temperature and the oxygen concentration in the combustion chamber.) simultaneously in order to reduce the emissions of all regulated pollutants from diesel engines. A two-cylinder, air-cooled, constant speed direct injection diesel engine was used for experiments. HCs, NO_x, CO, and opacity of the exhaust gas were measured to estimate the emissions. Various engine performance parameters such as thermal efficiency, brake

specific fuel consumption (BSFC), and brake specific energy consumption (BSEC), etc. were calculated from the acquired data. Application of EGR with biodiesel blends resulted in reductions in NOX emissions without any significant penalty in PM emissions or BSEC [24].

In G. Knothe and his friends work, three fatty acid methyl esters, neat methyl laurate, neat methyl palmitate, and technical grade methyl oleate, were selected for exhaust emissions testing in a heavy-duty 2003 six-cylinder 14 L diesel engine with exhaust gas recirculation. These fuels were compared with neat dodecane and hexadecane as well as commercial samples of biodiesel and low-sulfur petrodiesel as the base fuel, thus establishing for the first time a baseline of the exhaust emissions of neat hydrocarbon (alkane) fuels versus neat methyl esters. All fuels were tested over the heavy-duty diesel transient cycle. PM emissions were significantly reduced with biodiesel and methyl oleate (about 77 and 73%, respectively), while reductions with methyl palmitate and methyl laurate were even greater (82-83%) compared to the petrodiesel fuel. PM emissions with biodiesel only slightly exceeded the upcoming emissions standards, raising the possibility that biodiesel may meet these standards using only a diesel oxidation catalyst without employing a particulate trap. NOX emissions increased with biodiesel (about 12%) and technical grade methyl oleate (about 6%) but decreased (about 4-5%) with methyl palmitate and methyl laurate relative to those of the base fuel. PM emissions decreased (about 45-50%) with both dodecane and hexadecane. NOX emissions were reduced (around 15.5-16%) with dodecane and hexadecane compared to those of the petrodiesel fuel. The methyl ester moiety influences exhaust emissions by reducing particulate matter considerably more than neat straight-chain hydrocarbons, which are enriched in "clean" petrodiesel fuels, while NOX exhaust emissions, which showed little chain-length dependence, were less reduced. Thus, no future "clean" petrodiesel fuel should be able to achieve the low PM exhaust emissions levels of biodiesel without additional additive treatments or support by engine technology. Unsaturated fatty esters show slightly increased NOX and PM emissions compared to their saturated counterparts. The soluble organic fraction of the PM emissions was higher for the ester fuels. Hydrocarbon (HC) and CO exhaust emissions

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were also determined. Although HC emissions were low, a strong effect of chain length was observed [25].

This G. Labeckas and S. Slavinskas's study presented the comparative bench testing results of a four stroke, four cylinder, direct injection, unmodified, naturally aspirated Diesel engine when operating on neat RME (rapeseed oil methyl ester) and its 5%, 10%, 20% and 35% blends with Diesel fuel. The purpose of this research was to examine the effects of RME inclusion in Diesel fuel on the brake specific fuel consumption (bsfc) of a high speed Diesel engine, its brake thermal efficiency, emission composition changes and smoke opacity of the exhausts. The brake specific fuel consumption at maximum torque (273.5 g/kW h) and rated power (281 g/kW h) for RME was higher by 18.7% and 23.2% relative to Diesel fuel. It was difficult to determine the RME concentration in Diesel fuel that could be recognised as equally good for all loads and speeds. The maximum brake thermal efficiency varied from 0.356 to 0.398 for RME and from 0.373 to 0.383 for Diesel fuel. The highest fuel energy content based economy (9.36–9.61 MJ/kW h) was achieved during operation on blend B10, whereas the lowest ones belong to B35 and neat RME. The maximum NOX emissions increased proportionally with the mass percent of oxygen in the biofuel and engine speed, reaching the highest values at the speed of 2000 min⁻¹, the highest being 2132 ppm value for the B35 blend and 2107 ppm for RME. The carbon monoxide, CO, emissions and visible smoke emerging from the biodiesel over all load and speed ranges were lower by up to 51.6% and 13.5% to 60.3%, respectively. The carbon dioxide, CO₂, emissions along with the fuel consumption and gas temperature, were slightly higher for the B20 and B35 blends and neat RME. The emissions of unburned hydrocarbons, HC, for all biofuels were low, ranging at 5–21 ppm levels [26].

In S.Salim's M.Sc. thesis, biodiesels were produced from canola, soybean, cotton and waste sunflower oils using sodium hydroxide as catalyst and methanol as alcohol in the laboratory conditions. The produced biodiesels were blended with low sulphur diesel fuel No.2 in %5 (in volume) at the room temperature. The blends and diesel fuel No.2 were

tested in an indirect injection, turbocharged diesel engine running at full load and different engine speeds. The effects of the biodiesel addition to diesel fuel No.2 on the diesel engine emissions (CO, SO₂, NO_X, smoke and O₂) were investigated. The %5 addition of the methyl ester to the diesel fuel No.2 reduced CO and smoke emissions while causing no remarkable difference in SO₂ and NO_X emissions. In addition, it was determined that %5 addition of the methyl esters to the diesel fuel No.2 did not cause any considerable variation in the engine torque, power, exhaust gas temperature and lubrication oil temperature. Only, the brake specific fuel consumption slightly increased [27].

In A. Demirci and his friends study; it was investigated that the influence of using biodiesel-diesel blends on the exhaust emissions of a single cylinder, four-stroke and direct injection diesel engine. According to the test results; it had been found that there was an efficiency increase in the NO_X emissions and, a decrease in the CO and HC emissions, when the biodiesel amount was increased in the mixture [28].

3. CONCLUSION

Recent concerns over the environment like global warning, weather changes increasing fuel prices and scarcity of its supply have promoted the interest in development of the alternative sources for petroleum fuels. Biodiesel is one of the most important renewable, alternative fuels that no need any modification in diesel engines. If we think of our foreign fuel dependence, determining the abilities of biodiesel as a fuel in diesel engines is really crucial.

It has the major advantages of having high biodegradability, excellent lubricity and no sulfur content [8]. Biodiesel offers many advantages:

- It is renewable.
- It is energy efficient.
- It displaces petroleum derived diesel fuel.

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- It can be used in most diesel equipment with no or only minor modifications.
- It can reduce global warming gas emissions.
- It can reduce tailpipe emissions, including air toxics.
- It is nontoxic, biodegradable, and suitable for sensitive environments.

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