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A Review on Theoretical Performance, Combustion, And Emissions in a Diesel Engine Fueled with Diesel-Biodiesel Blends

Vishv Patel, Karan Parekh
Department of Mechanical Engineering, A. D. Patel Institute of Technology, Anand, Gujarat, India

ABSTRACT

This paper evaluates and quantifies 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, biodiesel in pure form and Blended with diesel fuel, and natural gas. For the case of biodiesel, its complete life cycle and the closed Carbon cycle (photosynthesis) were considered. This study reports the effects of engine load and biodiesel percentage on the performance of a diesel engine fuelled with diesel-biodiesel blends by experiments and a new theoretical model based on the finite-time thermodynamics (FTT). In recent years, biodiesel utilization in diesel engines has been popular due to depletion of petroleum-based diesel fuel. In this study, performance of a single cylinder, four-stroke, direct injection (DI) diesel engine fuelled with diesel-biodiesel mixtures has been experimentally and theoretically investigated**.** The ecological efficiency concept depends on the environmental impact caused by CO2, SO2, NOx and particulate material (PM) emissions. The resultant pollution of each one of the mentioned fuels are analysed, considering separately CO2, SO2, NOx and particulate material(PM) emissions. The ecological efficiency for pure biodiesel (B100) is 86.75%; for biodiesel blended with conventional diesel fuel (B20, 20% biodiesel and 80% diesel), it is 78.79%. Finally, the ecological efficiency for conventional diesel, when used in engines, is 77.34%; for gasoline, it is 82.52%, and for natural gas, it is 91.95%. All these figures considered a thermal efficiency of 30% for the internal combustion engine.
Keywords: Fossils Fuels, Anhydrous Ethanol, Carbon Dioxide, ASTM, BSFC, BTE, EGT, MTBE, CPO, ETT, SFC, UBHC

I. INTRODUCTION

The demand for energy is increasing every day, and it has become one of the most important things without which life would be very difficult in this modern world. At present, the major part of energy is obtained from fossil fuel. If the fossil fuel is used at the same rate as is used today, the locked-up hydrocarbons as fuel will be released in the atmosphere as a product of combustion. So, this increases atmospheric pollution and greenhouse gas, which leads to adverse effect on the environment. The only solution to reduce the usage of fossil fuel is to increase the usage of renewable energy resources. Over the wide range of renewable energy resources, biodiesel is a promising energy source. In recent years, renewable energy resources have been proposed as an alternative to petroleum-based fuels. Biodiesel, derived from vegetable oil or animal fat, is considered as an alternative renewable fuel for use in diesel engines. Biodiesels have both advantages and disadvantages, which can be listed as follow, respectively. The advantages of biodiesel as diesel fuel, apart from their renewability, are their minimal sulphur and aromatic content, higher flash point, higher lubricity, higher cetane number and higher biodegradability and non-toxicity. Also, biodiesel contains about 10e11% oxygen by weight. Conversely, disadvantages include their higher viscosity, higher pour point, lower calorific value and lower volatility. Moreover, their oxidation stability is lower, they are hygroscopic and as solvents, they may be cause corrosion of components, attacking some plastic materials used for seals, hoses, paints and coating. They show increased dilution and polymerization of engine sump oil, thus requiring more frequent oil changes. Diesel engines are widely used as a power source for in-sea and on-land transportation vehicles. That operational problems were associated with the use of vegetable oils in a diesel engine was recognized early, with high viscosity being defined as a major cause of these problems. While one paper states that it is “academically necessary to split off the glycerides and to run on the residual fatty acid,” other work goes a step further by interchanging glycerol for ethanol by preparing the ethyl esters of palm oil through a transesterification reaction, with the Belgian patent 422877 probably being the first report of what is termed biodiesel today and testing them in an urban bus. This is probably the first documented use of what is now termed biodiesel, namely the mono-alkyl esters of vegetable oil or animal fats or other triacylglycerol-containing feedstocks. This approach was then rediscovered approximately forty years later in the early stages of renewed interest in vegetable oils and their derivatives as diesel fuel.

With ever-increasing research interest as well as production and use of methyl esters of plant oils as biodiesel, especially since the mid- to late 1990s, standards were developed tailored largely toward these methyl esters. The first standard was established in Austria in 1991 followed by other European standards, most notably the German standard DIN 51606. Standards in individual European countries have been superseded by the European standard EN 14214. In the United States, concurrently the biodiesel standard ASTMD6751 was developed. It may be noted that ASTM D6751 states that biodiesel meeting its specifications is to serve as blend stock for blends with petrodiesel and therefore is applied to neat biodiesel. Relatedly, the standard ASTM D7467 covers blends at levels of 6–20% biodiesel and an ASTM specification WK52154 for blends >20% is under development. Blends of up to 5% biodiesel with petrodiesel are covered by the petrodiesel standard ASTM D975 with these blends required to meet the specifications for neat petrodiesel. The EN and ASTM standards now often serve as reference standards for other biodiesel standards world-wide. These standards address a variety of fuel quality issues caused by the properties of the major fuel components, the mono-alkyl esters of fatty acids, and by minor constituents (contaminants). It may be noted that viscosity, in the form of kinematic viscosity, as the major issue for using biodiesel instead of vegetable or plant oils, is limited in these standards to ensure that alkyl (usually methyl) esters are indeed used as biodiesel.

Vegetable oils are converted into biodiesel, which is well suited for diesel engines. Its low impact on the environment and economic benefits are the major reasons for the use of biodiesel.

Vegetable oils are nontoxic sources of renewable energy and do not contribute to global carbon dioxide (CO2) build-up. Therefore, vegetable oils as fuels have been studied extensively in recent. Years. Rahman et al, investigated palm oil as one of the vegetable oils widely used as a diesel fuel alternative. Other studies on alternative fuels that investigated the use of coconut, moringa, peanut, soybean, and rapeseed oils generated positive results.

Many earlier works have explained the process involved in the Production of biodiesel; so, that part is not dealt with in this paper. In many review papers, standards of biodiesel are tabulated so the standard is not mentioned in the paper. This paper reviews various Reports on the performance and emission characteristics in C.I engine. A deep understanding of the physical and thermal properties of biodiesel in C.I engine is necessary, so they are tabulated in this paper. Almost all the earlier works have done their blends on volume basis.

II. METHODS AND MATERIAL

A. Discussion

The diesel engine, a version of the internal combustion engine relying on self-ignition of a fuel under conditions of elevated heat and pressure (thus also often termed the compression-ignition Engine), was developed in the 1890s. Its inventor, Rudolf Diesel (1858–1913), tested numerous fuels at that time as he describes in his book *Die* Entstehung des Dieselmotors. As Diesel describes in this book and elsewhere, the first use of a vegetable oil as fuel for a diesel engine occurred at the World Exposition in Paris in 1900. At the request of the French Government, which at that time was interested in developing fuels of local origin for its African colonies for sake of energy independence, a small diesel engine ran on peanut (groundnut) oil. Apparently, this was only one of five diesel engines shown at that exposition. In any case, as Diesel reports, the engine ran smoothly on this fuel with the onlookers not noticing this ongoing experiment. Later on, through the 1920s until approximately the end of World War II, there are numerous reports in the literature on the use of vegetable oils in diesel engines, often under the theme of energy independence. During that time, several researchers recognized that the high viscosity of vegetable oils can lead to operational problems such as engine deposits. One suggestion was to split off the glycerol moiety and run the engine on fatty acids, although it was recognized that this approach could also cause operational issues. Under current aspects, probably the most interesting and significant work was described in Belgian patent 422877 issued in 1937 to Chavanne. In this patent and some later publications, the ethyl esters of palm oil, obtained by transesterification of the oil with ethanol, are described. The first test of this fuel in 1938 in an urban bus is also discussed.

Besides the biodiesel standards mentioned above, numerous legislative and regulatory efforts promoting the cause of biodiesel have accompanied or facilitated its rising production and use. For example, in the United States, biodiesel production in 2014 was approximately 6.65 billion litres after about 6.84 billion litres in 2013, and in the European Union it was approximately 10,367,000 metric Tons (approximately 11.77 billion litters) in 2013 with a production capacity of 23,093,00 metric tons in 2014. Worldwide production in 2014 has been at given as 29.7 billion litres (approximately 26,144,000 metric tons), with the top producer being the United States (4.7 billion litres) followed by Brazil and Germany (3.4 billion litres each), Indonesia (3.1 billion litters), Argentina (2.9 billion Litres), and France (2.1 billion litres), with the EU accounting for 11.6 billion litres. Issues related to production that have affected biodiesel use include feedstock availability as not enough vegetable/Plant oils are produced to replace all petrodiesel, and the so called food vs. fuel issue which is based on the claim that fuel production from edible oils may increase their price and reduce their availability while also causing agricultural land to be used for fuel instead of food production.

This article has focused on the technical issues that have been facing biodiesel, as well as discuss the fuel and physical properties of biodiesel, as these issues are largely a result of the properties of the components of biodiesel. The issue of feedstocks will be addressed by primarily focusing on their varying composition and how this may affect the use of the biodiesel fuels derived from them.

B. Physical and thermal properties of biodiesel

Calorific value

Calorific value is the energy content per unit mass of the fuel. In other words, calorific value can be defined as the heat energy released while completely burning a known fuel, where the end Products are cooled back to their initial temperature. Heating value is measured using calorimeter by burning known mass of a fuel, and the temperature difference is used to measure the calorificv alue of the fuel. In most cases, the calorific value of the biodiesel is less than diesel, but the difference is not significantly higher as an unusable fuel in C.I engine. The lesser calorific value of the biodiesel indicates that more mass of biodiesel is required to produce equal output produced by the diesel. It is clear that the calorific value of biodiesel is lesser than mineral diesel. Koroch biodiesel has the least calorific value of 35.72 MJ/kg, whereas Mustard biodiesel has the highest calorific value of 40.4 MJ/kg.

Kinematic Viscosity

Viscosity is defined as the internal friction or resistance of a liquid to flow. It is measured by allowing a liquid to flow in a standard size hole. Based on the time, the size of the hole, and the volume of the liquid flow, the viscosity is determined. The viscosity changes for different temperatures. Increase in temperature decreases the viscosity of biodiesel. In most cases, the viscosity of biodiesel is higher than that of diesel. Due to higher viscosity, the atomization property is reduced, so this may increase the fuel droplet size when compared to diesel. Due to the increased droplet size of the injected biodiesel, the shoot emission may increase. On the other hand, the higher viscosity of biodiesel acts as a good lubricating agent, and so mechanical efficiency is improved. It is measured in centipoises (mm2 s_1). It is evident that biodiesel has higher viscosity than diesel.

Density

Density is defined as the ratio of mass to volume or, simply, mass per unit volume. Density of the fuel has influence on total fuel consumption and BSFC. Density of fuel would affect the fuel injection property such as injection timing, spray characteristics and spray penetration. Density of most biodiesel is found to be higher than diesel, so mass of biodiesel would be higher for the same volume of diesel. The spray penetration property for biodiesel would be good and the fuel injection timing would get advanced for biodiesel compared with diesel. 2.5. Flash point Flash point is the minimum temperature at which the fuel produces enough vapour to get ignited when exposed to external fire. The handling of fuel would be safer if the flash point is higher. it is evident that the flash point of biodiesel is three times higher than that of mineral diesel. So, handling of biodiesel is far safer than diesel.

Cloud Point

Cloud point is defined as the temperature at which the fuel shows visible cloudiness. This cloudiness indicates that the fuel starts to solidify. At this stage, the fuel starts to get solidified. The cloud point of biodiesel is higher than diesel, so it is more difficult to operate at lower temperature than diesel.

Pour Point

Pour point is the temperature at which the fuel gets totally solidified and looks like a gel. It shows that the pour point is the minimum temperature at which the vehicle can be operated without any heating aid of the fuel. The pour point of biodiesel is higher than diesel, so it makes less feasible to operate vehicle with biodiesel in colder region than with mineral diesel. it is clear that the same biodiesel from different authors has different physical and thermal characteristics. It may be due to different weather conditions and soil conditions in which the plant was grown. The catalyst, alcohol and the methodology used to produce biodiesel also have influence in physical and thermal Characteristics. To understand the characteristic of different blend ratios of biodiesel and to know the range to which the characteristics can fall, all the different sources of the same biodiesel and diesel are tabulated. To show the influence of diesel with biodiesel in the blend, the properties of diesel from different sources are also mentioned.

Performance and Emission Characteristics of Various Biodiesel and Its Blend in C. I. Engine

Rakopoulos et al. investigated the performance and emission characteristics of a six cylinder turbocharged C.I engine fuelled with sunflower oil methyl esters blended with diesel and cotton seed oil methyl ester carried with diesel as base fuel. The engine was operated at two different speeds – viz., 1200 rpm and 1500 rpm – and at three different load conditions. As the percentage of biodiesel Increased, the shoot density decreased, due to the presence of oxygen in biodiesel. The presence of oxygen in the biodiesel led to make less air fuel ratio area to oxygen rich area. This led to increase The local temperature and NOx. In contrast to other authors, this experiment produced higher HC in biodiesel than diesel. The authors stated that the BTE of biodiesel was almost equal to diesel.

The cotton seed oil biodiesel was emission-wise better than the sunflower seed oil biodiesel because of the presence of higher percentage of lighter and saturated palamitic acid in cotton seed. Muralidharan et al. evaluated the performance and emission characteristics with various blends of waste cooking oil biodiesel. Biodiesel was used with different blend ratios, namely 20%, 40%, 60%, and 80% with diesel. A constant speed engine with 1500 rpm was used for test purpose, and the results were compared with standard diesel operation. For all the fuels with increase in load, the BTE increased. With the increase in the percentage of biodiesel, the BTE decreased because of the higher fuel consumption and lower calorific value of biodiesel. B40 had the maximum BTE of 38.46%, i.e., 4.1% higher than diesel. With the increase in load, the exhaust temperature decreased. Due to the lesser calorific value of the biodiesel with the increase in the percentage of biodiesel in the blend, the EGT decreased. For all the blends of the waste cooking oil biodiesel used in this experiment, the mechanical efficiency increased with the increase in load. The blends had higher mechanical efficiency because of the high reaction activity of the fuel. The fuel with blend of biodiesel had higher NOx than diesel because the plant oil naturally had the nitrogen content along with it, and this would get involved in the production of NOx. The peak temperature produced during the combustion of the biodiesel was higher than diesel, so the NOx produced during the combustion of biodiesel was higher Than diesel. The higher viscosity of the biodiesel blends led to poor atomization character and these resulted in an increase in HC compared with diesel. The ignition delay of biodiesel was higher than Diesel, so more fuel was accumulated in the cylinder. This led to the production of more unburned hydrocarbons in the case of biodiesel. With the increase in load, the CO increased because more Amount of fuel was injected during high load, and so CO emission increased. Were tabulated to understand the behaviour of different biodiesels at different engine and operating conditions.

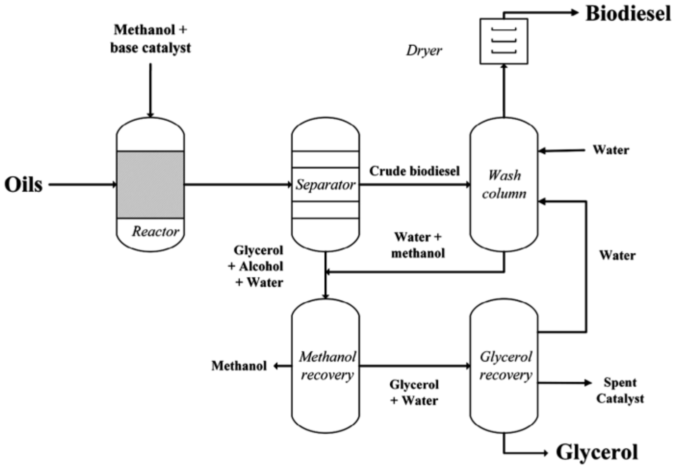
C. Biodiesel Production Transesterification

Summarily, transesterification is the production of one ester from another ester. In the case of biodiesel, this is the production of mono-alkyl esters from a vegetable/plant oil which consists largely of triacylglycerols, i.e., the glycerol esters of long-chain fatty acids, with a low molecular-weight alcohol. As indicated above, methanol is currently the preferred alcohol for this purpose, giving the Methyl esters of the plant oil with a fatty acid profile corresponding to that of the parent oil. The transesterification reaction is well-known and is, to a significant extent, textbook material. It can be catalyzed by both acids and bases, with base catalysis being considerably more rapid. The overall reaction, which is reversible. The most advantageous reaction conditions were established as a molar ratio alcohol: oil of 6:1, 60 °C, 1 h with either 0.5% sodium methoxide (CH_3ONa) or 1% sodium hydroxide as preferred catalyst when using methanol as alcohol. Generally, the reaction temperature should be slightly belowthe boiling point of the alcohol.

The 6:1 molar ratio is a 100% increase over the theoretical amount, which is necessary to drive the equilibrium to the right. Furthermore, the free fatty acid content should be less than 0.5% (acid value of less than approximately 1) and the reaction system as free of moisture as possible. Thus, production of biodiesel is becoming more common on a commercial scale using sodium methoxide as catalyst because this catalyst helps maintain low moisture content. The reason is that when using an alkoxide, such as sodium methoxide as catalyst, the water-forming reaction

$ROH + XOH \rightarrow ROX + H_2O$ (R = alkyl, X = Na or K)

Occurring when using hydroxide catalysts is avoided. At the beginning of the transesterification reaction, the mixture of vegetable oil and methanol consists of two immiscible phases, the vegetable oil and the alcohol. This leads to a situation where mass transfer may be limiting the overall reaction rate rather than the actual chemical reaction. Similarly, at the end of the reaction two phases occur, the methyl esters product and glycerol as coproduct. The two phases can be easily separated by gravity (settling of the phases) or centrifugation but the latter is energy intensive. Washing the product ester phase with water is necessary to remove the remaining catalyst and potential contaminants such as glycerol formed during the reaction. The transesterification occurs stepwise, proceeding from the Triacylglycerol starting material via the di- and monoacylglycerols to glycerol, with methyl ester being formed at each step. Although under optimal conditions, the transesterification reaction proceeds to a very high degree of conversion, minor to trace amounts of triacylglycerol starting material as well as mono- and diacylglycerols remain. Even very minor amounts of some of these materials can significantly influence fuel properties. Thus glycerol and the various triacylglycerols are limited in biodiesel standards as free and total glycerol, respectively, with monoacylglycerols being Limited individually in both the ASTM and EN standards while the other acylglycerols are limited individually only in the EN standard. *G. Knothe, L.F. Razon / Progress in Energy and Combustion Science 58 (2017) 36–59* 39 If the feedstock contains a significant amount of free fatty acids as is often the case with low-quality feedstocks such as used cooking oils, trap grease or animal fats, an acid pre-treatment step is usually employed to reduce the free fatty acid content. This pre-treatment consists of esterifying the free fatty acids in the feedstocks to the methyl esters using the desired alcohol and an acid catalyst (H_2SO_4), thereby reducing the acid value. The triacylglycerol portion of the feedstock can then be transesterified by base catalysis using the conditions described above. The "conventional" process for biodiesel production. The aforementioned sensitivity of the transesterification reaction under what might be termed the "standard conditions" toward moisture, free fatty acid content, mass transfer limitations and other factors has caused significant research efforts toward developing other process systems. While it is beyond the scope of this article to deal with these aspects in detail, some salient aspects are briefly discussed here.



Process improvements have approached these concerns by:

a) improving contact between the oil and alcohol phases, either chemically or mechanically;
b) Heterogeneous and enzymatic catalysts;
c) Simultaneous extraction and reaction;
d) Reaction with simultaneous removal of the product;
e) Microwave irradiation.
f) Combinations of all of these have also been extensively studied.

Reducing or Eliminating Mass-Transfer Effects

Novel reactor designs have improved the contact between the oil and methanol phases beyond that which can be achieved using a common paddle-type impeller. These include static mixers, micro-channel reactors, slit channel reactors, oscillatory flow reactors, and rotating tube reactors. Particularly interesting is the use of ultrasound to induce the formation of Cavitational micro bubbles whose collapse induces better convection and mixing. Mass transfer limitations have also been addressed by performing the transesterification at supercritical conditions: ~ 573– 673 K and ~15–45 MPa. At these conditions, the reaction mixture is in one phase only and thus interphase mass transfer constraints are eliminated. At supercritical conditions, the reaction proceeds rapidly with a high yield without a catalyst and is insensitive to the presence of water and free fatty acids. Thus, the system provides twin advantages over the conventional process for transesterification. Waste and crude oils may be used without initial pre-treatment. Furthermore, catalyst removal and separation will be unnecessary. The high pressures and temperatures would drive up capital equipment costs however. High alcohol-oil molar ratios are also necessary. Safety concerns have also been raised about the use of flammable solvents at very high temperatures and pressures. Jet fires having an effect as distant as 190 m have been predicted in the case of a methanol pump rupture. Another approach for eliminating mass transfer limitations is the use of co-solvents like tetrahydrofuran, dimethyl ether and methyl tert-butyl ether (MTBE) to improve the miscibility of the oil and alcohol. With the co-solvents, the reaction mixtures are now single phase and the overall reaction rate is greatly enhanced.

Heterogeneous Catalysts

Heterogeneous catalysts have found significant interest as they usually can be recycled many times and thus avoid having to use fresh methoxide (or hydroxide or other alkoxide) for each reaction batch. Separation is also simplified, the need for washing is reduced and continuous operation becomes simpler. The activity of these catalysts to affect the transesterification reaction diminishes with time. It also appears that many papers concerned with this kind do not address the question of catalyst leaching and how that may affect biodiesel storage and properties and meeting specifications, especially those addressing the heteroatoms Na, K, Mg, Ca, P and S (if the catalysts contain these elements) in biodiesel standards. Some catalysts may contain other heteroelements not addressed in biodiesel standards and the impact of these elements on fuel quality has not yet been fully addressed. Research on various catalysts for the transesterification has been so extensive that numerous reviews now deal with specialized aspects such as certain classes of catalysts and even catalysts containing specific metals, etc. Recent reviews cover most of the chemistry behind new heterogeneous catalysts. In these reviews and as in many other biodiesel heterogeneous catalysis papers mass-transfer effects are not considered extensively. If heterogeneous catalysts are used, the three phases arise: alcohol, oil and catalyst. Mass-transfer effects are often discussed only in the context of systems designed to eliminate or reduce mass-transfer-limitations, e.g. ultrasound. Notable exceptions are studies concerning CaO catalysts. Until the mass-transfer effects and leaching effects are addressed, it would be premature to discuss detailed kinetics of any of the other heterogeneous catalysts. Despite the innumerable reports on alternative catalysts for the transesterification reaction, it is unclear whether any have been used in commercial production due to a lack of reports in the open literature. Enzymatic catalysis shares many of the advantages of inorganic heterogeneous catalysts. Products are more easily recovered and, in general, product quality is improved. In addition, enzymes promise to be more environmentally friendly and are usually more tolerant toward moisture content and the quality of the feedstock. Reaction times are longer, however, and the enzymes are expensive. Costs are very systemdependent but it is worth mentioning a study that determined that a biodiesel produced via an immobilized lipase system was about twice as expensive as one produced with a conventional alkali system.

Direct Contact between Feedstock and Alcohol

Integration of the oil extraction step with the transesterification step has been investigated, a process called *in situ* transesterification or reactive extraction. This process could eliminate the use of hexane as extraction solvent for the oil feedstock. Some good results have been obtained but most of these processes have required high solvent-to-oil ratios, thus deviating from the "standard" condition, possibly because a large amount is necessary to physically cover dry feedstocks. It is a method, however, to be investigated in connection with the transesterification of feedstocks of aqueous origin like microalgae because it eliminates the drying step that is a major energy load on microalgal processes. Like the heterogeneous catalytic systems, *in situ* transesterification will yield a three phase system (alcohol, oil and feedstock solids), hence *in situ* transesterification is often combined with the methods to promote mass transfer mentioned earlier. These include co-solvents , ultrasound and operating at supercritical conditions.

Early Product Removal to Drive Equilibrium

In conventional transesterification, a large excess of alcohol, usually 100% more than theoretical, is fed in order to ensure that the equilibrium is driven forward and the limiting reactant (oil) is consumed. While the methanol may be recovered and recycled, this increases the cost for separation. One of the techniques being studied to avoid this is the use of membrane reactors, which allow continuous separation of the reactants from the products as they are formed. A similar concept is reactive distillation wherein a reactive middle section is sandwiched between a top section where recovery of solvents can be done and recovery of the heavier FAME product can be done. Because it also involves heat integration, reactive distillation has been shown to be an effective solution both in theory and in experiments.

Microwave Irradiation

The use of microwave irradiation for heating chemical reactions is not simply a more efficient method for heating. Microwaves promote selective heating of polar molecules which result in local temperatures that are actually higher than the bulk temperature. The *apparent* activation energy is thus lower and the overall reaction rate is higher. Catalyst requirements can also be reduced. The use of microwaves, however, places restrictions on the reaction vessel size and shape.

Biodiesel Feedstocks

The starting materials used for biodiesel production are vegetable oils (or more generally, plant oils) or other oils and fats consisting largely of triacylglycerols. The most common feedstocks in the past and up to the present have been commodity vegetable oils such as rapeseed (low-erucic variety; canola being similar to low-erucic rapeseed), palm, soybean and coconut. This observation is confirmed by the historical research described above carried out on oils such as peanut, palm and sunflower. The issue of expanding the base of feedstoks has led to significant interest in other potential source of triacylglycerol-based oils.

A common feature of most vegetable/plant oils is that most of their fatty acid profile is comprised of the five most common fatty acids palmitic (hexadecanoic), stearic (octadecanoic), oleic (9(*Z*)- octadecenoic), linoleic (9(*Z*),12(*Z*)-octadecadienoic) and linolenic (9(*Z*),12(*Z*),15(*Z*)-octadecatrienoic). The amounts of these acids vary among the oils though, and because their methyl esters have different properties the biodiesel fuels derived from these oils also show varying properties. Some plant oils, on the other hand, for example castor, coriander, cuphea and meadowfoam, exhibit fatty acid profiles with other fatty acids as major components, again significantly influencing the fuel properties of the biodiesel derived from these oils. Minor components, however, which may include other fatty acid methyl esters in the fatty acid profile, as well as steryl glucosides, monoacylglycerols and other acylglycerols remaining in the product after the transesterification reaction, and materials carried over from the feedstock often can significantly influence biodiesel fuel properties.

As the cost of biodiesel production is largely (about 75–80%) determined by the cost of the feedstock, less expensive feedstocks have been of interest for a considerable length of time. These low-cost feedstocks include used cooking oils, greases and animal fats. While their cost is lower, they also usually are of lower quality, almost always exhibiting high acid values and/or water content and presence of extraneous materials, necessitating quality improvement before biodiesel production.

The Case of Carbon in the Biodiesel

Biomass-derived fuels decrease the net atmospheric carbon in two ways: first, they participate in the relatively rapid biological cycling of carbon to the atmosphere (via engine tailpipe emissions) and from the atmosphere (via photosynthesis). Second, they substitute fossil fuels. Fossil fuel combustion releases carbon that took millions of years to be removed from the atmosphere. Combustion of biomass fuels participates in a process that allows CO2 to be rapidly recy cled to fuel. The main target for the use of bio-fuels is to decrease the emissions of gaseous pollutants to the atmosphere, mainly CO2 emissions, with the purpose of reaching the targets of the Kyoto Protocol. As already indicated, the use of biodiesel takes with itself a global emission decrease. A 1998 biodiesel life cycle study, jointly sponsored by the US Department of Energy and the US Department of Agriculture, concluded that biodiesel decreases the net CO2 emissions by 78.45% compared to mineral diesel. This is due to the biodiesel closed carbon cycle. Therefore, considering this aspect, in the case of the use of B100 (biodiesel pure form), the result is: 0.578 ton CO2 per m3 with biodiesel.

III. RESULTS AND DISCUSSION

A. Performance and emission characteristics of various biodiesel and its blend in C.I engine

Rakopoulos et al. investigated the performance and emission characteristics of a six cylinder turbocharged C.I engine fuelled with sunflower oil methyl esters blended with diesel and cotton seed oil methyl ester carried with diesel as base fuel. The engine was operated at two different speeds – viz., 1200 rpm and 1500 rpm – and at three different load conditions. As the percentage of biodiesel increased, the shoot density decreased, due to the presence of oxygen in biodiesel. The presence of oxygen in the biodiesel led to make less air fuel ratio area to oxygen rich area. This led to increase the local temperature and NOx. In contrast to other authors, this experiment produced higher HC in biodiesel than diesel. The authors stated that the BTE of biodiesel was almost equal to diesel.

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For all the fuels with increase in load, the BTE increased. With the increase in the percentage of biodiesel, the BTE decreased because of the higher fuel consumption and lower calorific value of biodiesel. B40 had the maximum BTE of 38.46%, i.e., 4.1% higher than diesel. With the increase in load, the exhaust temperature decreased. Due to the lesser calorific value of the biodiesel with the increase in the percentage of biodiesel in the blend, the EGT decreased. For all the blends of the waste cooking oil biodiesel used in this experiment, the mechanical efficiency increased with the increase in load. The blends had higher mechanical efficiency because of the high reaction activity of the fuel. The fuel with blend of biodiesel had higher NOx than diesel because the plant oil naturally had the nitrogen content along with it, and this would get involved in the production of NOx. The peak temperature produced during the combustion of the biodiesel was higher than diesel, so the NOx produced during the combustion of biodiesel was higher than diesel. The higher viscosity of the biodiesel blends led to poor atomization character and these resulted in an increase in HC compared with diesel. The ignition delay of biodiesel was higher than diesel, so more fuel was accumulated in the cylinder. This led to the production of more unburned hydrocarbons in the case of biodiesel. With the increase in load, the CO increased because more amount of fuel was injected during high load, and so CO emission increased.

Biodiesel–Alcohol Blend

Performance and emission characteristics of an engine was tested by Chang et al. using different blends and different ratios: soybean biodiesel–diesel–water containing acetone–butanol–ethanol (ABE). Water containing ABE solution blended with diesel–biodiesel produced 7.88% BTE higher than diesel and diesel–soybean biodiesel blends. At high load conditions, B50 and B75 produced almost equal BTE as that of diesel. Because of the lesser heating value of the biodiesel, with the increase in the percentage of biodiesel in the blend, the brake specific fuel consumption increased. At higher loads, the BTEs of fuel with the blends of bio-diesel with different proportions such as B25, B50, and B75 were almost equal, but at lower load, the BTE of B50, B75 had lesser efficiency than diesel. At higher loads, the lubricity of biodiesel led to produce efficiency equal to that of diesel, but at lower load conditions, the viscous factor of biodiesel led to poor atomization and eventually to lesser efficiency of biodiesel.

The blend containing biodiesel-50%, ABE-25%, and diesel-25% had the higher efficiency than diesel and blends with other combinations. This was because of the lower cetane number that helped to create more time for pre combustion zone and the lower viscosity led to higher atomization and more oxygen content facilitated better combustion.

With the addition of water containing ABE with biodiesel, the NOx production was reduced more when compared to biodiesel–diesel blends. With the addition of 25% of ABE with biodiesel–diesel blend, the NOx reduced up to 22.7% than soybean biodiesel–diesel blend. The water containing ABE had a similar character of biodiesel such as lower cetane number and higher oxygen content, but NOx was reduced due to the lower heating value and higher latent heat of vaporization of water that led to lower cylinder temperature eventually resulting in lower NOx. The cetane number for water containing ABE had lower value, so it led to higher ignition lag and increased the duration of higher temperature which is one of the main key factors in the NOx production, but the higher latent heat of vaporization of water containing ABE led to decrease in cylinder temperature and NOx production was decreased

Biodiesel–Synthetic Oil

Koc and Mudhafar Abdullah investigated the performance and emission characteristics of a four cylinder, water cooled C.I engine fuelled with blends of soybean biodiesel, tire oil, and diesel. The performance and emission characteristics were compared with those of diesel as a base line fuel. NOx and CO emissions for soybean biodiesel 10%–tire oil 10%–diesel 80% were significantly less than soybean biodiesel 10%–diesel 90%. Soybean biodiesel 10%–tire oil 10%–diesel 80% produced its maximum torque of 278 Nm at 1600 rpm. Pure diesel produced a torque of 247.4 Nm, which was the lowest torque produced compared with the other fuel blends used in this research. With the increase in the percentage of tire oil in the blend, the torque increased. The blends of tire oil produced higher torque than the blends of biodiesel–diesel. At no load condition, the BSFC at 2800 rpm for Diesel was found to be 450 g kW/h, and for the same running condition, the BSFC for soybean biodiesel 10%–tire oil 10%–diesel 80% was found to be 343 g kW/h. But, there was no significant difference in BSFC while comparing soybean biodiesel 10%–tire oil 10%–diesel 80% and soybean biodiesel 10%–diesel 90%. With the increase in the engine speed, the CO emission got decreased. At all operating conditions, the CO for soybean biodiesel 10%–tire oil 10%–diesel 80% was found to be lower than for diesel.

Biodiesel with Additive

Rashedul et al. reviewed many journals based on biodiesel and different additives that are used in C.I engine. Additives are used to improve the performance and emission characteristics of biodiesel. Higher viscosity and lower calorific value of the biodiesel are the main problem in the usage of biodiesel in C.I engine. Presence of oxygen content leads to produce higher NOx than diesel.

Storage of biodiesel for longer period leads to micro contamination and oxidation. It was found that the pore point is higher for biodiesel. Biodiesel is so corrosive that the fuel pipe line would be corroded in the longer usage. To solve the above problems, additives are used. Cerium oxide, platinum based additive, Isobutanol and antioxidants with biodiesel reduce BSFC. Cerium oxide, platinum based additives and thetmol-D improve the BTE.

Magnesium and nickel based additive in biodiesel reduces the flash point and viscosity. $FeCl_3$ as an additive with biodiesel leads to reduction in the flash point, thus improving the calorific value and the cetane number. TiO_2 with biodiesel increases engine power. Cerium oxide as an additive reduces the NOx. Oxygenated additive contains oxygen to improve the combustion process, so that the performance of the engine gets increased and the emissions such as CO and UBHC get decreased. Alcohol, ether and ester are some of the commonly used oxygenated additives. Methanol blend with biodiesel reduces the viscosity, flash point, and density. Blends of alcohol–biodiesel and kerosene–biodiesel are found to increase the cloud point and the pour point of the biodiesel. Diethyl ether as well as L-ascorbic acid reduces NOx. Ethanol with biodiesel reduces the CO_2. Amides, fatty acids and esters are commonly used as additives for improving the lubricity. The commonly used cetane improver is Alkyl nitrate. The cetane improvers significantly increase the cetane number in biodiesel, and the cold starting problem is avoided while using biodiesel.

Irrespective of the fuel used for the experiment, the NOx increased with increase in load. It is known that the NOx is directly proportional to the power; so, irrespective of the fuel used for the experiment, NOx increased with increase in load. The pure form of biodiesel produced higher NOx than diesel and other test fuels. Because of the presence of oxygen, better combustion took place, and it led to peak temperature; with the increase in the percentage of additive (dimethyl carbonate), NOx reduced. To reduce the pollution and to enhance the performance of a six cylinder, direct injection diesel engine, Mirzajanzadeh et al. used biodiesel–diesel and cerium oxide Nano particles-amides functional groups (CeO_2-MWCNTs). The engine used here was a variable speed engine, but the experiment was conducted at 1500 rpm at full load. The biodiesel used for this experiment was prepared from waste cooked oil. The different ratios of the blend used were,

Waste cooked oil Biodiesel 5%–Diesel 95%,
Waste cooked oil Biodiesel 5%–Diesel 95%–CeO_2-MWCNTs
30 ppm,
Waste cooked oil Biodiesel 5%–Diesel 95%–CeO_2-MWCNTs
60 ppm,
Waste cooked oil Biodiesel 5%–Diesel 95%–CeO_2-MWCNTs
90 ppm,
Waste cooked oil Biodiesel 20%–Diesel 80%,
Waste cooked oil Biodiesel 20%–Diesel 80%–CeO_2-MWCNTs
30 ppm,
Waste cooked oil Biodiesel 20%–Diesel 80%–CeO_2-MWCNTs
60 ppm and
Waste cooked oil Biodiesel 20%–Diesel 80%–CeO_2-MWCNTs
90 ppm.

With the increase in the concentration of the CeO_2-MWCNTs, the power increased. The blend of waste cooked oil biodiesel 20%-diesel 80%–CeO_2-MWCNTs 90 ppm produced the highest Power of 165.7 kW, and the blend with waste cooked oil biodiesel 20%–diesel 80% produced the lowest power, 53.7 kW. It is known that the torque is directly proportional to the power and so the torque output has a similar trend to the power. The blend with 20% biodiesel produced higher power and torque than the blend with 5% of biodiesel. The BSFC for B5 was higher than the B20 additives.

Increasing the concentration of the cerium oxide reduced HC, CO, and soot, whereas NOx increased. Due to the presence of oxygen content in cerium oxide, the combustion quality improved; so, complete combustion took place. Cerium oxide prevented the precipitation of non-polar components, carbon and iron deposits. HC, CO, and engine friction reduced, whereas torque and power are increased while using cerium oxide with biodiesel.

Biodiesel-Nano Particles

Shaafi and Velraj conducted an experiment in a single cylinder constant speed C.I engine fuelled with blends of soybean biodiesel 20%–diesel 80%. The second blend consisted of a mixture of 80% diesel, 15% soybean biodiesel, 4% ethanol, and 1% isopropanol as a surfactant, and alumina nanoparticles of 100 mg/L and the performance and emission characteristics were compared with diesel. With the increase in the load, the BTE increased for all the fuels. Blending of biodiesel with the diesel increased the BTE. It was because of the oxygen content in the biodiesel. The blend with aluminium Nano particles had higher BTE of about 27% and the diesel produced the BTE of about 24%. The blend of aluminium nano particles had higher BTE because aluminium nano particles create micro explosion and improve the evaporation rate of the fuel. Pure diesel had the highest BSFC of about 0.35 kg/kW h, and the fuel with 80% diesel + 15% soybean biodiesel + 4% ethanol + 1% isopropanol + alumina nanoparticles of 100 mg/L had BSFC of about 0.32 kg/kW h. The BSFC for the fuel with aluminum nano particles is less because it enhanced the combustion quality. The fuel with aluminum nano particles produced higher NOx by 9.9% than neat diesel at full load condition. At full load condition, for the blend of aluminum nano particles, CO is less by 40% when compared with biodiesel blend and pure diesel. The heat released from the fuel with biodiesel blend and fuel with nano particles was higher than diesel, so NOx was higher than in diesel. The blends of ethanol– diesel had higher UBHC than diesel because some of the fuel got involved in the combustion process without evaporation. The fuel with aluminum nano particles increased the surface area of the fuel, so UBHC was less than the fuel without aluminum nano particles. EGT increased with the increase in load because at higher loads more fuel was injected so the EGT was higher. With the presence of aluminum nano particles, EGT decreased because the heat transfer coefficient was improved by aluminum nano particles.

Used Vegetable Oil Biodiesel

The performance and emission characteristics of four stroke, direct injection, variable speed, C.I engine with swept volume of 1318 cc fuelled with biodiesel–diesel and canola oil–diesel blends. For all the speeds, with the increase in the percentage of biodiesel and canola oil in the blend, BSFC increased. With increase in the speed of the engine, BSFC decreased for diesel, oil blends and biodiesel blends. With a blend of canola oil biodiesel 20%–diesel 80%, BSFC was higher by 1.1% than the neat diesel. Canola oil biodiesel 20%–diesel 80% blend had 2.55% lesser calorific value than diesel, but the BSFC of canola oil biodiesel 20%–diesel 80% blend was less than that of diesel. This indicated that the fuel conversion rate was higher than diesel. With the increase in the engine speeds, the percentage of the fuel conversion efficiency increased for all the fuel used in this research. Diesel had the lesser fuel conversion efficiency than canola oil biodiesel 20%–diesel and canola oil 20%–diesel blend because the biodiesel and oil had oxygen content, and so better combustion took place.

For all the fuels used in this research, with the increase in the engine speed, HC emission decreased. It was because of the better mixing of air and fuel at higher speeds. Due to the presence of oxygen in biodiesel, for all the engine speeds, with the increase in the percentage of canola oil biodiesel in the blend and used-canola oil biodiesel in the blend, HC emission decreased. Irrespective of the test fuels used, here, with the increase in the engine speed, CO decreased. It was because, at higher speeds, the turbulence increased and so better air–fuel mixture took place. Due to the presence of oxygen content in the biodiesel, with the increase in the percentage of the used canola oil biodiesel, the CO decreased.

Biodiesel–Water Blend

Koc and Abdullah studied the performance and emission characteristics of a four cylinder inline, naturally aspired, water cooled, variable speed C.I engine fuelled with biodiesel–diesel–water nano emulsions. Deionized water were used for emulsion; anionic surfactant, AOT (Dioctyl sodium sulfosuccinate) and 10.2 hydrophiliclipophilic balance (HLB) was used as an additive to form emulsion. The biodiesel used here was obtained from the transesterification process of soybean oil.

The fuels used for the test purpose were:
Surfactant 7.5%–soybean oil Biodiesel 17.5%–water 5%–Diesel
70%;
Surfactant 7.5%–soybean oil Biodiesel 17.5%–water 10%–Diesel
65%;
Surfactant 7.5%–soybean oil Biodiesel 17.5%–water 15%–Diesel
60%;
Soybean oil Biodiesel 5%–Diesel 95%;
Soybean oil Biodiesel 20%–Diesel 80%; and
Diesel 100%

Power for all the fuels used in the test purpose was maximum at 2000 rpm. The water emulsion with biodiesel and diesel reduced the power; increase in the percentage of the water in the emulsion further reduced the power of the engine because the heating value of biodiesel and surfactant was less than diesel. The maximum torque was obtained at 1800 rpm. With increase in the percentage of water in the emulsion, the torque decreased. Diesel produced the maximum torque. For most speeds, blends of soybean biodiesel 5% and 20% produced same torque.

Diesel has a lower BSFC than the biodiesel and fuel with nano emulsion. With the increase in the percentage of water, BSFC increased. For most engine-speed ranges, the fuel with nano emulsion had the highest BSFC, and it was higher than biodiesel. It was because the calorific value of biodiesel and its emulsion with water is lesser than diesel. For most engine speed ranges, the BSFCs for

Surfactant 7.5%–soybean oil biodiesel 17.5%–water 5%–diesel 70% and soybean oil biodiesel 20%–diesel 80% almost were similar. The NOx emission for diesel and surfactant 7.5%–soybean oil biodiesel 17.5%–water 5%–diesel 70% was almost closer at most speeds. With the increase in the percentage of biodiesel in the blend, NOx increased, and with the increase in the percentage of the water in the emulsion, the NOx decreased. It was because the oxygen content in the biodiesel led to higher combustion temperature and the water content in the emulsion reduced the peak temperature of the combustion. With the increase in the engine speed, irrespective of the fuel used, CO2 emission decreased. With the increase in the percentage of the water content in the emulsion, the CO2 increased. It was because of the presence of higher oxygen content in the water emulsion fuel than in diesel and biodiesel. The biodiesel blend produced lower CO2 than diesel. Irrespective of the fuel, CO emission decreased with the engine speed. Diesel produced the highest CO, whereas surfactant 7.5%–soybean oil biodiesel 17.5%–water 5%–diesel 70% produced the lowest CO compared with the other fuels.

Microalga Biodiesel

Tuccar and Aydın conducted an experiment using 3970 cc engine, direct injection with glow plug, variable speed C.I engine and blends of microalgae biodiesel–diesel and diesel as a fuel. The performance and emission characteristics were compared. The blend ratios used for the test purpose were B5, B10, B20, B50, and B100. Irrespective of the blends used in this experiment, the maximum brake power was obtained at 2400 rpm. Power reduction increased with increase in the percentage of biodiesel in the blend, and it was because of the lower cetane number of the biodiesel. Irrespective of the fuel, increase in the percentage of the micro alga in the blends reduced the torque, whereas diesel produced the highest torque of about 236 Nm, and the lowest torque was produced by 100% microalga biodiesel, which was about 227 Nm. For all the engine-speeds, CO emission for micro alga was lower than for diesel. During the time of combustion, oxygen present in the micro alga reacted with CO to produce CO2, so the CO emission for the micro alga biodiesel was less than diesel. All the speeds of the engine, NOx emission for micro alga was lower than for diesel. In most cases, the usage of biodiesel increased the amount of NOx due to the presence of inbuilt oxygen content. In contrast to other authors in this experiment, the presence of oxygen in the microalga biodiesel reduced the NOx emission. It's because oxygen involvement from the atmosphere is reduced. So, the NOx produced during micro alga biodiesel was less than diesel and heat release rate for micro alga biodiesel was also mentioned as the reason for less NOx than diesel.

B. Engine Performance

The relationship among fuel properties, such as viscosity, calorific value, specific density, and surface tension are affected by engine performance. Fuel consumption increases with increasing biodiesel oil in blends and results in better combustion when injected into a combustion chamber. The performance of a diesel engine operating on sunflower oil as an alternative diesel fuel was examined for higher fuel consumption and lower torque generation. The low percentage of biodiesel (20% or less) blends provides higher brake power for completed combustion with lower fuel consumption. Engine performance has improved by having higher calorific value and lower viscosity in biodiesel. However, according to the results at maximum fuel delivery rates of the injection pump with standard calibration, this engine produced equivalent power or minor power increases when operating on biodiesel oils and biodiesel oil or a diesel fuel mixture.
Masjuki used coconut oil-blended diesel fuel to operate an IDI diesel engine. The brake power output per specific density was observed at speeds between 800 r/min and 3200 r/min for the various combinations of fuel. The coconut oil blends developed power per specific density similar to that of ordinary diesel (OD). Fuel consumption increases with an increasing amount of coconut oil in blended fuels. Overall lubricating oil analysis has shown that the results for 10–30% coconut oil blends are better than those for 40–50% blended fuels and comparable with the results from OD. Thus, the use of coconut oil blend in diesel engines is expected to become a reality in the near future.

A stationary engine test was conducted at the UTM. The test employed a Ricardo E-6 and a traditional slow-speed singlecylinder Lister stationary engine. The short-term performance of both engines fuelled with palm oil have shown that palm oil is technically suitable for use in diesel engines. Studies have shown that POME is much safer because of its high-storage ability. When palm oil was stored for about 12 months in a storage tank, palm oil methyl ester showed a high flash point. The properties of kinematic viscosity increased, oxidative stability decreased, and acid value, iodine value, cloud point, and pour point were unaffected during extended storage of palm oil methyl ester. When palm oil methyl ester was stored for around three months, the properties of acid value and viscosity increased and the induction period decreased. Palm oil also has higher specific fuel consumption; thus, it reduced emission from another fossil fuel used
in light-duty diesel engines.

Palm oil blends and diesel fuel are used in KIR-LOSKAR TV-1, a four-stroke diesel engine at varying loads. The maximum output of the engine is 5.2 KW with a varying load of 20–100% by maintaining constant speed at 1500 rpm. The brake thermal efficiency of 25%, 50%, 75%, and 100% of palm biodiesel were 30.895%, 30.56%, 29.22%, 29.58%, and 28.65%, respectively. At full load, the brake specific fuel consumption (BSFC) for 100% palm oil and diesel were 274.90 g/KW h and 314.91 g/KW h, respectively. The BSFC for 25%, 50%, and 75% of palm oil were observed to be 2.59%, 8.93%, and 9.25% higher than that of diesel respectively. When the engine is operated by palm oil or palm oil blends, the BSFC is slightly higher at 2–6% for palm oil blends, 14–17% for preheated palm oil, and 17–25% for palm oil methyl ester.
The performance of an Isuzu 4FBI diesel engine was studied using palm oil fuel with conventional diesel at percentages of 25%, 50%, and 75% by volume. The brake power output at speeds between 900 rpm and 3000 rpm for various combinations of fuel were examined. Pure palm oil fuel and its blends developed power similar to that of pure conventional diesel. The maximum power for all fuels was observed at 1250 rpm, with conventional diesel fuel producing 9.2 kW, followed by fuel blends of 25%, 50%, and 75% for palm oil, and 8.79%, 7.75%, and 7.25% for pure palm oil fuel. The brake power of palm oil blends was 0.83% higher than that of canola blends. The lower viscosity of preheating CPO did not affect the injection system and also provided smooth fuel even at 100 _C heating. CPO has shown high peak pressure of approximately 6% and low period ignition delay of about 2.6_; a lower amount of heat was released compared with petroleum diesel. Various engine problems such as engine deposit, sticking of piston ring, and injector conking were found

by using high viscosity and low-volatility raw vegetable oils in diesel engines. The higher viscosity of palm biodiesel can be caused by poor atomization in fuel, which leads to injector deposits and conking of valves. Observed the performance and durability of diesel engines with fuelled CPO. A longer period of combustion was observed in CPO than in diesel fuel. According to the study, CPO showed a heavy amount of carbon deposits from the combustion chamber; piston ring wear, scuffing of fuel consumption in the cylinder, and irregular spray formed when palm oil biodiesel was used in the diesel engine. Palm oil reduced the amount of unsaturated molecules that could cause oxidation stability to engine performance. Oxidation stability can be caused by harmful effects of filter plugging, deposits, and corrosion. Injector deposits of PB20 blend was higher than those of diesel fuel at the end of the 150 h endurance test. PB20 blend showed that overlapping deposits were relatively thick at the tip and the injector hole exit along the shrinkage of the injector hole diameter.

C. Exhaust Emissions

When a diesel engine is operated with fossil fuel, it emits exhaust gases such as hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO2), particulate matter (PM), and nitrogen oxide (NOx).

Based on numerous studies conducted in the last 20 years, vegetable oils derived from fuel can be used in a diesel engine to reduce engine-exhaust emission components, such as unburned Fuel, HC, CO, and PM emissions. However, unlike petroleum diesel, biodiesel or vegetable oil contains oxygen, which can contribute to lower levels of PM emissions. The ability of biodiesel to reduce emissions was recognized by the national biodiesel board, which developed a program to commercialize biodiesel as an alternative fuel.

In the study conducted by Shehata, exhaust temperature was recorded for diesel, palm oil, cotton oil, and flax oil with or without exhaust gas recirculation (EGR) for a Deutz F1L511-type diesel engine. The gaseous emissions were measured at full load at the speed of 1600 rpm without EGR and at 75% load at the speed of 1400 rpm with EGR. Exhaust gas temperature increased with the increase in engine speed and also decreased with the increase in EGR for diesel, palm, cotton oil, and flax oil. The highest exhaust gas temperature was found from palm oil at high engine speed without EGR and the exhaust gas temperature decreased by 7% for palm oil with the increase in EGR by 0–15% at 1400 rpm speed compared with diesel, cotton, and flax. The higher ignition delay and unburnt portion to burn at the later diffusion combustion phase causes higher exhaust-gas temperature.

Ndayishimiye and Tazerout observed minimal difference among HC, CO, and NOx emissions when running on any of these fuels. The emission results for the CI engine (Model Lister–Petter TS1 at maximum speed of 3500 rpm) illustrated minimal difference in the level of emissions from the combustion of these fuels. Palm oil fuel gives nearly constant HC emissions over light load range, whereas petroleum-based fuel exhibited worsening light load emissions. At middle and full loads, HC emission was significantly reduced with the edition of methyl esters in biodiesel. The higher viscosity and lower cetane number of palm oil compared with diesel fuel leads to higher HC emission. In another study by Liaquat using palm oil fuel in a four-stroke direct injection (DI) diesel engine, exhaust emissions were measured with a Bosch exhaust gas analyzer (model ETT 0.08.36) for emission characteristics and Bacharach (Model CA300NSX) for emission concentrations. The test was conducted for about 250 h at an engine speed of 2000 rpm. Both CO and CO2 emissions indicated decreasing trends as the percentage of palm oil fuel increased in various fuel blends compared with diesel. These observations showed that palm oil fuel was environment-friendly as far as the two gases were concerned.

Canakci reported that exhaust gas emission was measured using a Bilsa MOD 500 exhaust gas analyzer as an emission device. Percentages of CO2, CO, and O were determined. This study was conducted only on a 1.8 VD Diesel BMC diesel engine. The result showed that CO2 decreased with increasing speed. With palm oil, the percentage of CO2 was higher compared with that of conventional diesel. However, the percentage of CO was negligible because improved combustion took place in the engine fuelled with palm oil. In general, palm oil fuel is not expected to cause environmental problems because results gathered from the trial had shown that the levels of pollutant concentrations and smoke were generally comparable or less and were lower at high engine speed.

D. Discussion

Nowadays, globalization and industrial developments in the world require more fossil fuel while aiming to reduce environmental pollution through green technology. Production and consumption of fossil fuel has increased by about 5–6% every year. Palm biodiesel is one alternative fuel that can reduce environmental pollution and meet the demand for fossil fuel. Compared with other vegetable oils, palm oil is a more sustainable and affordable fuel that is environment friendly and has greater potential energy and economic benefits. Malaysia is a developing country that is also the second highest producer of palm oil in the world, with major markets in Europe and the US. Palm oil is also used as cooking oil and many food manufacturing factories use about 74% of palm oil for food processing. Developing countries spend most of their money on imported petroleum diesel. According to MPOB economic statistics in 2014, Malaysia produced 19.667 million tonnes of palm oil, which was approximately 5.392 million ha. Malaysia earned RM 63.618 billion revenue by exporting 25.07 million tonnes of palm oil in 2014. In low-temperature countries, palm oil is very suitable for diesel engines and can be used under _21 _C to 0 _C temperature conditions. Many studies illustrate that better diesel engine performance is achieved by using palm oil biodiesel. Higher specific fuel consumption was observed in palm oil biodiesel and its blends is higher than in diesel fuel. In diesel engines, exhaust emissions, such as HC, CO, CO2, smoke, and PM were reduced because of palm oil biodiesel compared with diesel. Engine fouling components, such as fuel injector, fuel pump, piston ring, filter plugging, and various sliding engine parts are required for lubrication. Palm oil and blends have better lubrication properties than diesel in a short-term engine run. When an engine has been running for long periods, palm oil does not provide better lubrication and can be a cause of carbon deposits, piston-ring sticking, and changing lubricity problems of the engine. Palm oil contains a lower amount of metal compositions, such Fe, Pb, Cr, and Si, compared with diesel. Production of palm oil biodiesel is more profitable for farmers and small holders and also develops livelihood, education, and medical facilities in developing countries. In summary, palm oil and its blends have better engine performance, lower exhaust emission, good lubrication properties, and economical sustainability.

E. Advantages of Biodiesel

1) Biodiesel is a renewable energy source, and it is available in a wide range in most parts of the world.
2) HC, CO, particulate, soot and sulphur emissions are less while using diesel.
3) Most biodiesel and biodiesel–blends with diesel can be used in conventional engines without major modifications.
4) The viscosity of biodiesel improves the lubrication, so the life time of engine increases.
5) Since the flash and the fire point of most of the biodiesel forms are higher than those of diesel, they are safer to handle.
6) Biodiesel is a carbon neutral fuel.
7) Octane number of biodiesel is higher than that of diesel.

F. Disadvantages of Biodiesel

1) Due to the presence of oxygen in biodiesel, the fuel line may get corroded.
2) Presence of oxygen in biodiesel reduces calorific value of the fuel, but on the other hand, oxygen presence improves the combustion property.
3) In most cases, the use of biodiesel increases NOx. Additives can be used to reduce the NOx.
4) Biodiesel produced from different crops have different physical and chemical characteristics, so the engine should be designed in such a way as to operate in this range.
5) It requires energy to harvest, transport the harvested seeds and extract oil from the seeds, and, during biodiesel production, heating is done for which energy is required too.
6) The by-product glycerol formed during production pollutes the environment.
7) The waste water with catalyst used for washing the biodiesel pollutes the environment.

8) Most biodiesel forms have less calorific value than diesel, so biodiesel mostly produces less torque, less power and higher BSFC.
9) In most cases, NOx emission is higher than diesel.
10) Pour point of most biodiesel forms is higher than that of diesel, so it makes it less feasible to be used in colder region.
11) Biodiesel is less stable than diesel. Biodiesel gets oxidized easily; so, to reduce oxidation process, antioxidant has to be mixed, and this makes the fuel costlier.
12) Special fuel supply line material has to be manufactured because biodiesel with the conventional material like rubber gets corroded and reacts with the metals and corrodes the fuel line.

IV. CONCLUSION

Diesel engine using vegetable oil as alternative fuel (e.g., palm oil methyl esters) is potentially highly attractive and performs much better than other types of fuel. The properties of palm oil fuel are not significantly different from those of conventional diesel except that the former has a higher specific gravity and viscosity and a slightly lower cetane index. According to the present study, performance and exhaust emissions using palm oil fuel and its blends with conventional diesel fuel in stationary diesel engines are comparable to those of conventional diesel fuel. Moreover, palm oil fuel is environment-friendly and exhaust emission is much cleaner with reduced black smoke, CO, HC, and absence of SO_2 excluding NOX. Wear analysis also showed that palm oil does not seriously affect engine and bearing components, does not degrade lubricating oil, and produce comparable amounts of carbon deposits. Palm oil and its blends improve the anti-wear characteristics of the engine components. Compared with pure conventional diesel fuel, palm oil and its emulsion with ordinary diesel fuel show a slightly higher specific fuel consumption. The high fuel consumption of palm oil fuel and its blends can counteract the lower heating values such that the engines consume an equal amount of energy. The ignition delays for palm oil fuel are shorter than those for diesel fuel.

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. The carbon released by petroleum diesel was fixed from the atmosphere during the formative years of the earth, whereas the carbon released by biodiesel gets continuously fixed by plants and may be recycled by the next generation crops. Therefore, the main advantage of the biodiesel is that CO_2 emissions can be considered as recyclable by the growing plants. Then, the emission levels using this kind of bio-fuel are 78.45% lower in comparison with the diesel fuel. The calculated parameter is 0.578 ton of CO_2/m^3 of biodiesel (B100). The emissions for internal combustion engines using pure biodiesel (B100) are: 0.658 kg/kg of fuel for CO_2, 0.042 kg/kg of fuel for NOx and 0.009931 kg/kg of fuel of particulate material (PM). In the case to use 20% of biodiesel mixed with 80% diesel (B20), the emission levels are: 2.61 kg/kg of fuel for CO_2, 0.024 kg/kg of fuel for SO_2, 0.0404 kg/ kg of fuel for NOx and 0.01421 kg/kg of fuel of particulate material (PM). The total emissions for diesel in comparison with the biodiesel (B100) are 4.4 times higher, based in kg/kg of fuel relation. The ecological efficiencies, for the analysed fuels, natural gas, gasoline, diesel, biodiesel B100 and biodiesel B20 are, respectively, 91.95%, 82.52%, 77.34%, 87.58% and 78.94%. This study shows that the use of biodiesel as alternative fuel, from an ecological point of view, is better than the use of diesel fuel, presenting higher values of ecological efficiency.

Almost all forms of biodiesel and their blends with diesel have higher viscosity than diesel. Due to the higher viscosity of biodiesel, the atomization property may be affected and the combustion efficiency get reduced, but biodiesel acts as a lubricator; so, it improves the mechanical efficiency.

Biodiesel has higher cetane number than diesel, so the ignition delay for biodiesel will be less than diesel. Due to the less ignition delay of biodiesel than diesel, accumulation of the fuel inside the cylinder is reduced, so vibration and knocking is reduced. The higher cetane number also reduces the UBHC produced during the injection of fuel before the starting of the combustion. Lower calorific value, lower volatility, higher density, and viscosity of biodiesel reduce combustion quality. In most cases, exhaust gas temperature of the engine is less while using biodiesel. Since the calorific value of biodiesel is less than mineral diesel in most cases, the BSFC for biodiesel is higher than diesel. The presence of oxygen content in biodiesel improves the combustion quality, so this leads to increase in NOx. In most cases, CO emission for biodiesel is less than diesel. Blending of water containing acetone-butanol-ethanol with biodiesel would be a good idea to reduce NOx and particulate matter which is considered as the main problem while using biodiesel. To reduce NOx, ethanol can be injected in the inlet manifold or blend with biodiesel. It has been stated by many researchers that biodiesel can be used in the conventional engine without modification. Increase in the injection pressure while using biodiesel as fuel in C.I engine decreases UBHC. Increase in compression ratio while using biodiesel as fuel decreases UBHC. The presence of oxygen content in the biodiesel reduces CO emission. Usage of biodiesel in low heat rejection engines increases BTE and NOx, whereas SFC, UBHC, and CO decreases when compared with the conventional engines.

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