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Original Paper

A theoretical study of exhaust emission using biodiesel in diesel engine

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Abstract: Biodiesel is a renewable and oxygenated fuel which is exclusively derived from vegetable oil, animal fats, and tallow and waste product fossil oil. Many studies reported that diesel engine can be run using biodiesel without any modification in diesel engine due to similar properties to convenient fuel. So that, it's being considered as one of the best encouraging substitutes for combustion engines although having some physical and chemical limitations. Use of the heavy duty diesel engine is expected to increase and measures against emissions such as soot are a major factor. The major step towards improving the diesel engine performance and reducing the engine emissions biodiesel will be the proper substitute in a diesel engine as an alternative fuel. In this study, previous papers have been taken as a reference for analyzing parameters deeply. So far, the aim of this paper study is to reduce exhaust emission of internal combustion engine by using biodiesel and utilization of vegetable oil as an alternative fuel in a diesel engine. This paper also discussed the method of reduction of emission, emission standard, fuels, and effectiveness. From this review study, it can be stated that biodiesel could be used as an alternative fuel of diesel in a short term, but to get more details on the potentiality of a biodiesel as an alternative fuel more research requires reaching clear and fruitful conclusions and at the same time, it also requires advance research and improvement into engine.

Keywords: Diesel engine, Combustion, Emission, Lubricants, Biodiesel

1. Introduction

Fossil energy demand has been increased due to tremendous population growth over the last decades in the world. Luckily, predictions of fossil fuel exhaustion keep expanding, owing to the improvement of drilling technologies, and the emergence of large quantities of natural gas reserves. The improvement of alternative fuels, depletion of crude oil and price increasing of fossil fuels, bio diesel is being considered to be a reliable alternative fuel in terms of emission in diesel engine. For diesel engine, a great deal of research is still going on for using biodiesel as an alternative fuel for power, transportation and industrial sector.

Therefore, it is possible to say that human activities are greatly driven by and rely on fossil fuel energy and The usage of biofuels is anticipated to increment from 1.3 million barrels of oil per day in 2012 to 4.6 million barrels of oil per day in 2040, and their percentage of share will be roughly 8% of street transport fuel demand **[1][6]**. Due to fossil fuel depletions and high exhaust emission, Biofuel is one of the solutions as an alternative fuel because of its renewability, nontoxic and environmental friendly that can be used in a diesel engine with little or no modification in the diesel engine. Currently biodiesel seen as a solution and almost every country is preparing a policy on production and use of biodiesel in its transport sector **[2]**. This fuels also gaining worldwide acceptance as a solution for problem of environmental degradation energy security, restricting import, rural employment and agricultural economy. A large variety of alternative fuels are considered potential substitute to petroleum based diesel engine **[3]**. Rudolf Diesel, who developed the first engine and ran it with peanut oil vegetable fuel Vegetable oils are vital energy agent and sometimes create various problems in engine components,. This problem may be occurred due to their different volatility and molecular structure from diesel fuel as well as high viscosity compared to diesel fuel. This problem can be eliminated from bio-diesel by applying different chemical process such as Trans-esterify, supercritical and catalyst free process on vegetable oils. Through this process molecular structure and properties of vegetable oil is changed and fatty acid methyl esters is formed

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which is commercially known as Biodiesel fuel **[4][7]**.The effects of biodiesel are smaller and more variable for NO_x emissions, although generally NO_x increases slightly with use of biodiesel. This increase is referred to as the "biodiesel NO_x effect." **Figure 2** illustrate the effects of biodiesel blend level upon these four criteria emissions when used in heavy-duty (HD) diesel engines and research has also been going on to improve the fuel properties of biodiesel blends as well as optimize the performance and emission of diesel engine from optimum biodiesel blends ratios **[5][6]**. The physical properties of biodiesel such as viscosity and bulk modulus impact the injection and combustion behavior of the fuel as well. Biodiesel has a higher bulk modulus than conventional petro diesel, which has been shown to contribute to higher NO_x production. It is well known that the advancement of injection timing will increase NO_x emissions, and the fuel injection timing can be impacted by the bulk modulus, i.e., the compressibility of the fuel. The difference in compressibility between biodiesel and petro diesel fuel leads to an advance in injection timing which consequently can lead to a greater opportunity to form thermal NO_x **[7]**. Most of the organic compounds have found from the diesel engine which is main source of environment pollution such as carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x) and unburned hydrocarbons (HC) **[8]**. At the same time, other important properties affecting the flow of fuel spray characteristics and volatility with viscosity and flash point. Lower volatility and consequently poor combustion have been created in presence of higher the viscosity and flash point. The viscosity and flash point of biodiesel are higher while that of additives are lower as compared to diesel fuel **[9]**. **Figure 1** Global fuel demand has been plotted by using various kinds of gases. We observed that the global demand of gasoline is decreasing and on the other hands, the demand of other fuel such as natural gases, jet fuel are increasing day to day but the demand of diesel is increased slightly. So that, we can predict diesel demand will be decreasing due to environmental factors as well as depletion of fossil fuel.

Apart from biodiesel, researchers have conceived the idea of using vegetable oil as the lubricant alternative to mineral oil, as the disposal of mineral oil leads to pollution of ecosystem. Vegetable oil are perceived to be alternatives to mineral oil for the purpose of lubrication because of certain inherent technical properties like high flash point, high viscosity index, high lubricity, low evaporative loss and their ability of biodegradability but its poor low temperature behavior, thermal stability, inferior oxidation and gumming effect is one of the main disadvantages of vegetable oil **[10][11]**.

The aim of this study is theoretical study of exhaust emission in diesel engine throughout a review on the use of biofuel mainly biodiesel to reduce exhaust emission.

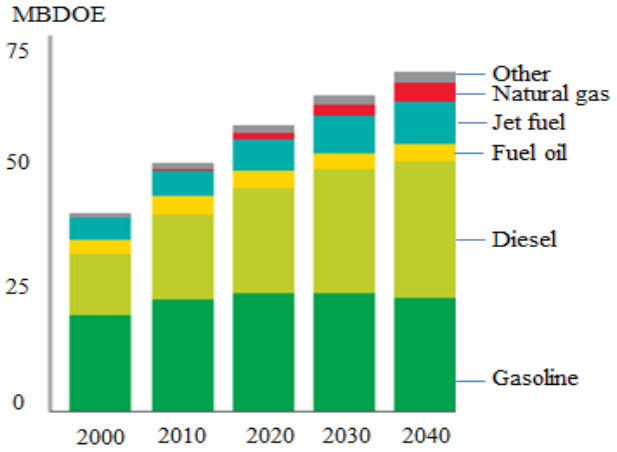

Figure 1: Global transportations demand by fuel **[1]**

Global oil reserve, production and consumption have been discussed in **Table 1**. Here we can see clearly consumption of fossil fuel is very high but the reservation is not high enough to support the demand.

Table 1: World Oil Statistics 2015 **[17]**

Region	Proved reserves (Thousand Million Barrels)	Production (Thousand Barrels Daily)	Consumption (Thousand Barrels Daily)
World	1700.1	88673	92086
North America	232.5	18721	23347
South and Central America	330.2	7613	7125
Europe and Eurasia	154.8	17198	18252
Middle East	810.7	28555	8706
Africa	129.2	8263	3800
Asia Pacific	42.7	8324	30856

Source: BP Statistical Review 2015

2. Significance and Properties of biodiesel

The significance of using biodiesel can be attributed to the following aspects: pursuing energy sustainability through the extended usage of those alternative fuels derived from renewable energy sources and mitigating the concerns of

limited fossil fuel energy; improving engine efficiency and engine out emissions with the aid of superior physical or chemical properties of alternative fuels compared to those of conventional fuels; and relieving the unbalanced usage of conventional petroleum based fossil fuel

Biodiesel gives better lubricity and more complete combustion thus increasing the engine energy output. According to, cetane ratings compared to low Sulphur diesel fuels and it has good lubricating properties. Variations in biodiesel energy density are more dependent on the feedstock used than the production process. Usually color ranges of biodiesel from golden and dark brown, based on the production method. It has a low vapor pressure, high boiling point and slightly miscible with water. Biodiesel often used as an additive to low Sulphur diesel fuel to aid with lubrication and it contains virtually no Sulphur. The best biodiesel properties can be obtained using transesterification process. This process of the vegetable oils reduces viscosity and making it similar to the petroleum diesel. This makes biodiesel more suitable to use in diesel engine than the raw vegetable oils. In unmodified diesel engines, fuel flow and ignition problems cause due to high viscosity of the fuels and also decrease in power output.

Till date a plenty of biodiesel has been tried in diesel engine as an alternative fuel. Properties of few such diesel and biodiesel are shown in **Table 2**. It is observed that the density is higher and calorific value is lower of the biodiesel as compared to diesel fuel. The lower calorific value is due to lower hydrogen content in biodiesel. Surprisingly, the conventional diesel fuel does not contain oxygen while biodiesel contain a considerable amount of oxygen in the structure. Due to oxygen content, the biodiesel is promising option to reduce emission from diesel engine.

Table 2: Properties of diesel and biodiesel are given below

Properties	Diesel	Biodiesel
Fuel composition	C_{10-21} HC	C_{12-22} FAME
Heating value (MJ/ kg)	42.5	37.5
Viscosity at 40℃	2.86	5.28
Density @20℃(kg/㎥)	840	871
Cetane number	52	52
Viscosity @ 40℃(mPa s)	2.95	4.57
Flash point (℃)	70	126
Oxygen (wt %)	0	10.8

From **Table 3** we have seen that the leading country in biofuel production has been discussed in this statistic. In USA, production reached around 64 thousand barrels per day of oil equivalents. That means, USA is among the global top 12 countries in biofuel production but the production of biodiesel is also increasing in rest of the world based on the concern of environmental degradation as well as fossil fuel depletion.

Table 3: Global biodiesel production by country 2016 **[16]**

Rank	Country	Production (in billion liters per)
1	United States	5.5
2	Brazil	3.8
3	Germany	3
4	Indonesia	3
5	Argentina	3
6	France	1.5
7	Thailand	1.4
8	Spain	1.1
9	Belgium	0.5
10	Colombia	0.5
11	Canada	0.4
12	China	0.3

3. Different kinds of biodiesel tested and outcomes

Two bio-diesels and petroleum diesel: Two types of bio-diesel, type A – 80% tallow (beef, pork and sheep) and 20% canola oil methyl ester and type B – 70% chicken tallow and 30% waste cooking oil methyl ester were used for the experimentation. Bio-diesels were chosen fuel types such as B5, B10, B20,B50 and B100 are analyzed (note: B100, 100% bio-diesel; B20,20% bio-diesel + 80% diesel; B40, 40% bio-diesel + 60% diesel; B60,60% bio-diesel + 40% diesel; B80, 80% bio-diesel + 20% diesel) **[4]**. Several parameters such as specific fuel consumption, torque and power and exhaust emissions have been determined. Fuel consumption for bio-diesel B is higher than bio-diesel A. Bio-diesel A has lower exhaust emissions and better performance compared to bio-diesel B due to the higher energy content. Biodiesel A shows a decreasing trend with increasing blend ratio while biodiesel shows increasing trend with increasing blend ratio for NOx emission **[4]**.

Almond and Palm oils: Blend ratios as 0%A (0% almond biodiesel – 100% diesel fuel), 10%A (10% almond biodiesel – 90%diesel fuel), 30%A (30% almond biodiesel – 70% diesel fuel), and 50%A (50% almond biodiesel – 50% diesel fuel) and 0%P (0% palm oil biodiesel – 100% diesel fuel), 10%P (10% palm oil biodiesel – 90% diesel fuel), 30%P (30% palm oil

biodiesel –70% diesel fuel), and 50%P (50% palm oil biodiesel – 50% diesel fuel). In this experiment, single cylinder diesel engine were done and several parameters such as specific fuel consumption (bsfc), brake thermal efficiency (gb), exhaust gas temperature (Tg), carbon monoxide (CO), nitrous oxide (NOx), particulate matter, and unburned fuel emissions have been determined. A comparison between the almond biodiesel blends and palm oil biodiesel reveals that the almond biodiesel, in general, performed better **[8]**.

RME (Rapeseed Methyl Ester) has been used in this study for seed oil bio fuel test. Arranged of load settings up to maximum power was used at constant speed 1500 rpm with fixed injection timing (24.51 BTDC) at constant compression ratio of14:1 for each of the fuels examined. Because of earlier injection timing, ignition delay is longer and nitrogen oxide levels higher, whereas smoke levels are lower, than for atypical commercial multi cylinder engine **[16]**. Diesel fuel (Derv) and edible-grade seed-oil (equal volumes of rapeseed and soya oils) base fuels and blends of these containing 25% and 75% seed oil, were tested. Tests were made at steady conditions after the engine had reached normal operating temperatures with diesel fuel and shown better performance during testing **[11]**.

Jatropha oil: In this article, our investigation and to test the tri-biological characteristics and compatibility of non-edible Jatropha oil based bio-lubricant for the automotive application. The reason for selecting Jatropha oil as a feedstock is it does not contend with the food and can be grown on marginal land as well. Five types of Jatropha oil (10–50%) were mixed with the commercial lubricant SAE 40.The lubricant SAE 40 was used as a base lubricant and comparison purpose. Four ball tri-biodiesel tester, Viscosity, Element analysis, coefficient of friction and Friction and wear characterization were used with the standard test methods of ASTM D2783 to investigate the tri-biological properties of bio-lubricants. Due to oxidization and chemical reaction little number of elements such as phosphorus, calcium and magnesium were decreased during element test. Overall, it can be said that to get optimum efficiency for the automobile application the addition of 10% Jatropha oil in the base lubricant is the best performer in terms of wear, COF, viscosity, rise in temperature, WSD and FTP **[12]**.

Jatropha biodiesel and turpentine oil: Blend has been separated by transesterification process in the presence of sulfuric acid and sodium hydroxide. Experimental work is carried out to examine combustion performance and emission characteristics using Jatropha methyl ester with turpentine oil blends (dual fuel blends) and conventional diesel. BT50 gives lower NO_x, CO, HC and smoke emission as compared to mineral diesel fuel. Moreover, at full load condition, reduction of emissions4.72%, 4.56%, 42.5% and 29.16% respectively while CO_2 emission is increases 10.5% as a dual fuel **[13]**.

4. Emission Analysis

Figure 2 shows the average percentage of change in NO_x emission for B20, B40, B60, B80, and B100 that are taken from graph are 2%, 4%, 6%, 8%, and 10%, respectively. Using proper engine tuning or catalytic converter, NO_x can be reduced. Moreover, the use of EGR system could help to reduce NOx. Also Biodiesel blends B20 and modified engine with different injection Timings could affect the variation of NO_x emission for standard engine. At full load with B20, The NOx was 9.2% increased as compared to standard engine with advance injection timing. The compressibility of the fuel leads to an advance injection timing which can consequently lead to a chance of greater NO_x formation. However, NO_x emission decreases during retard injection timing. At retard injection timing, high cylinder pressure and temperature could contribute to the shorter ignition delay which leads to slow burning rate and slow rise in pressure and temperature.

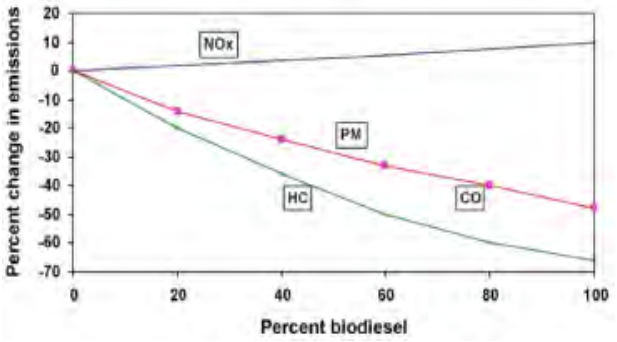

Figure 2: Average impact of biodiesel for heavy duty engines **[2]**

Meanwhile, the average percentage of change in PM emission for B20, B40, B60, B80, and B100 is −12%, −23%, −32%, −40%, and 48%, respectively. The negative sign is indicating the reduction of the percentage change in emission, whereas the average percentage of change in CO emission for B20, B40, B60, B80, and B100 is −13%, −24%, −33%, −40%, and−48%, respectively. Meanwhile, the average percentage of change in HC emission for the same biodiesel blends B20, B40, B60, B80, and B100 is −20%, −37%, −49%, −59%, and−67%, respectively. The reduction of PM

and HC is due to the additional oxygen content in the fuel, which helps to oxidize these combustion products and improve combustion in the cylinder. On the other hand, the reduction of CO and HC is due to the oxygenated fuel of biodiesel, it leads to a more complete combustion. The higher cetane number of biodiesel fuel reduces delay period leading to lower HC emissions. Thus, the higher oxygen content and cetane number of biodiesel-diesel fuel blends tend to reduce HC emissions when compared to conventional diesel.

For heavy trucks and buses, the emissions standard have stric tly implemented in all over the world specially in United States, Europe and Japan over the past 20 years which is described in **Table 4**. Many countries outside of Europe follow the Europea n model for engine emission certification, including Brazil, Chi na, India, Russia, South Korea and Thailand. Mexico has histor ically followed the U.S. model, but has recently changed to allo w either U.S. or European-certified engines. Developing countri es' technology paths to compliance with Euro IV and Euro V st andards are expected to mirror those of Europe.

Table 4: Global comparison: for heavy duty engine emissions **[17]**

Average limit values of heavy duty engine emission standards			
Region	Regulation and Year	Average Standard Values(g/kwh)	
		NO_x	PM
USA	2002-2004	2.7	0.13
	2007	1.6	0.013
	2010	0.27	0.013
European Union	Euro III(2000)	5	0.1
	Euro IV(2005)	3.5	0.02
	Euro V(2008)	2	0.02
	Euro VI(2013	0.2-1.0	0.01-0.02
Japan	2003-2004	3.38	0.18
	2005	2	0.027
	2009-2010	0.7	0.01

5. Method of NOx reducing

From the previous research showed that bio diesel generally gives advantage emission with respect to HC, CO and PM but slight NO_x emission is one of the threatening issues for using alternative fuel in conventional engine and negative impact on environmental sector as well. The NO_x can be reduced by using two methods: 1. Modifications of engine 2. Modifications of fuel **[5]**.

5.1 Modifications of engine

Better way by retarding injection timing by 1 to 4 degree, the reduction of NO_x emissions in both two stroke and four stroke engines would be. Also EGR system will help to reduce NOx emissions in engine. The major effect of EGR is reduced cylinder temperature, due to introduction of diluent gas of high specific heat (containing substantial levels of H_2O and CO_2). Additionally, introduction of EGR reduces the oxygen content in the cylinder. Both factors are believed to contribute to reduced NO_x emissions. Several other investigators have reported on the benefits of EGR in reducing NOx emissions when using biodiesel in laboratory test engines. EGR is also commonly employed to reduce NO_x emissions when using conventional diesel fuel. Thus, to be effective in a biodiesel situation, a greater degree of EGR would be utilized. The combination between EGR and diesel particular filter could also be a promising way to reduce both NO_x and PM from exhaust. Finally, more effective than either injection timing or EGR alone is the combination of both approaches, utilizing a control system to maximize the overall benefit **[5]**.

Emission regulations for engines and vehicles are adopted by the Ministry of Environment, South Korea. Depending on the application, Korea adopts either European or US-based emission standards. Here, Emission standards for heavy-duty truck and bus engines are based on European regulations which are discussed in **Table 5**. In 2006, emissions for diesel vehicles were equivalent to Euro IV until 2009, when the Euro V level was adopted. Since 2014, diesel emissions have been regulated under Euro VI limit values.

Table 5: Global emission comparison for heavy duty diesel engines in South Korea **[18]**

Date	CO	NOx	HC+NOx	PM	Smoke	Test Cycle
	(g/kWh)					
Jan., 2006	1.5	3.5	0.46	0.02	<10%	ND-13
	4	3.5	0.55	0.03	—	ETC
Sep., 2009	1.5	2	0.46	0.02	<10%	ND-13
	4	2	0.55	0.03	—	ETC
Jan., 2014	1.5	0.4	0.13	0.01	—	WHSC
	4	0.46	0.16	0.01	—	WHTC
Notes: ↓						
1.Manufactures should meet the standard for the both test cycle ↓						
2.ND-13 cycle is identical to the European Stationary Cycle in Europe						

5.2 Modification of fuel

Selective non catalytic reduction (SNCR) process with some

amines under certain conditions could be reduced NO_x emissions, although NO_x increased under other conditions. Fuel formation changing is one of the ways to reduce the NO_x emission from the bio diesel. Recently, reported on addition of amine compounds at relatively high concentrations (2–4%) to both conventional diesel and biodiesel fuels. However, challenges with respect to insolubilities and costs are likely to restrict commercial application of this SNCR approach. Changes in fuel composition have long been suggested as ways to mitigate the NO_x increase resulting from use of biodiesel (and biodiesel blends), while still benefitting from the reductions in HC, CO, and that such fuels offer. In 1996, Graboski et al. tested a variety of biodiesel blends in a 1991 DDC Series 60 engine, using the EPA Transient test protocol. The authors concluded that the NO_x increase resulting from B20 usage could be eliminated by reducing the base fuel's aromatic content (from 34.3% to 29.7%) or by increasing the cetane number (from 46.2 to 52.8). To improve the effectiveness and durability of modern diesel emissions control systems, use of ultra-low sulfur diesel (ULSD) is now required. [5]

6. Conclusions

Biodiesel not only can provide to engine efficiency development and reduce exhaust emission but also to find alternative solutions of diesel and environment sector. Various kinds of conclusions can be made from the above discussions are following at the below

(1) Engine has got some problems such as lower volatility, poor atomization, incomplete combustion, could and pour points are high which may cause problems in cold condition, ring sticking, and high carbon deposits while using biodiesel. Slightly chemical modification is required to overcome these problems.

(2) Study shows that NO_x emission is increased while CO and HC emissions are reduced for all the blends as compared to that of diesel fuel. So, the proper adjustment of injection timing and by using exhaust gas recirculation (EGR) may be possible to reduce NO_x emission.

(3) The presence of higher oxygen content in bio diesel with increasing blend ratio leads to complete combustion in the diesel engine. As a result, Less CO emissions can be produced.

(4) It is also reported that injector choking, moving parts failure, filters plugging, and fuel pump damage identified during cold weather. This problem can be eliminated by using anti-freeze blend additives or heated fuel lines in cold conditions.

(5) A large amount of unburnt fuel is created due to higher viscosity and density of biodiesel and to avoid this problem engine oil need to change at shortened time especially while using biodiesel at high concentrations.

Above all, In general agreement on the biodiesel helps to reduce hydro carbon (HC), carbon monoxide (CO) and smoke emissions but it increases oxide of nitrogen (NO_x) as compared to diesel fuel and also further advance research requires improving quality of biodiesel and engine.

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