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# Effect of Binary Fuel Blends on Compression Ignition Engine Characteristics: A Review

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Additional information is available at the end of the chapter

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## Abstract

Diversified research in alternate sources arises become necessity due to higher consumption of fossil fuels along with their adverse impacts on the environment, even to the point of complete elimination of diesel from compression-ignition (CI) engines. Binary fuel blend (a blend of low and high viscous fuel) is one of the best environmentally friendly alternative in CI engines. Blending of methyl ester with edible and nonedible oils in different volumetric ratios has the potency to give a stable mixture and that can be used as a fuel in diesel engines. The main motive for the blending of two fuels is that the inferior properties of one biofuel remunerate from improved properties of the other fuel considerably improves the physicochemical properties of the blend. The present study provides comprehensive information on the emission and performance characteristics of binary biodiesel-oil fuel blends. Most researchers had suggested optimum blends from their respective studies that support capability for complete elimination of diesel from CI engines. Some researchers have used this binary fuel blend with minor adjustments to the engine parameters. These investigations have provided positive results. The comprehensive review concluded that binary fuel approach has potential to completely eliminate diesel from CI engines.

**Keywords:** binary fuel blends, emission profile, fossil fuel depletion, performance analysis

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## 1. Introduction

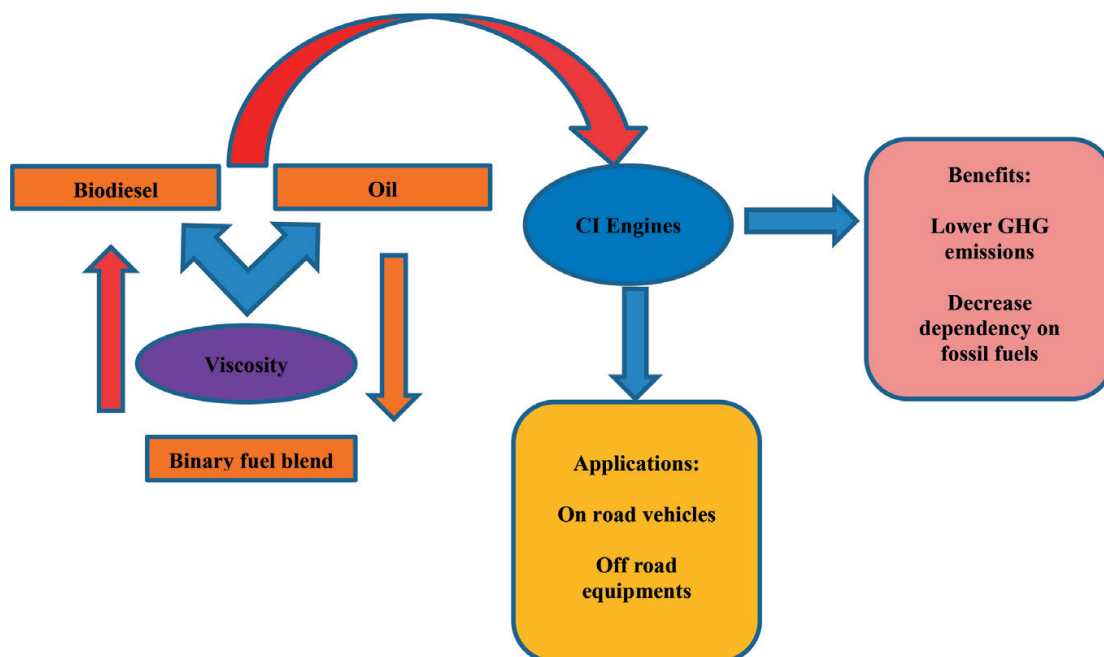
Demand of energy has been increased day by day due to the usage of nearly 600 million automobiles by 7 billion people throughout the world [1]. Today, the air contamination is also a severe concern as higher pollutants in today's environment are from internal combustion (IC)

engine tailpipe emissions. Hence, the automobile industries are emphasizing on cleaner transport systems that decrease the environmental pollution and provide at least the same efficiency as normal diesel fuel [2]. Also, the pressure of environmental monitoring authorities forces the automobile companies to diminish the greenhouse gas emissions from the vehicles. These ever-increasing energy demand, rapid depletion of crude oil, and environmental pollution have an emphasis on a new feasible source of energy known as biofuel (mainly biodiesel). The another reason for emphasis on alternate fuel which can be produced from readily accessible resources is that the countries which do not have sufficient resources of fossil fuel and import crude petroleum are facing foreign exchange problem or energy crisis. Therefore, the exploration is focused on numerous feedstocks (edible/nonedible oils along with its methyl esters (biodiesel)) as a probable source of fuel for automobile sector [3]. It is better to use methyl ester instead of fossil-based diesel fuel due to its various benefits, that is, availability, high lubricity, low sulfur contents, low aromatic compounds, environmentally friendly nature, the existence of a carbon dioxide (CO<sub>2</sub>) cycle in burning period, viability, and biodegradability [4–9]. In general, biodiesel is clean burning mono-alkyl ester-based oxygenated fuel derived from long chain fatty acids of edible and nonedible oil, animal fat, microalgae, etc. [10]. The main application of biodiesel is in diesel engines as a fuel had shown that it lowers GHG emissions with the acceptable engine performance [11]. This finally leads us to the study of diesel engine characteristics of biodiesels, since they are the single most important contender in the area of future fuels.

Broad research has been carried out with the aim of using biodiesel and its blends as a feedstock for diesel engine. In this concern, B20 (80% diesel and 20% biodiesel by volume) is found to be the most suitable blend without any modification to the engine hardware [12]. Some researchers had used biodiesel-diesel-alcohol blends for increasing the biodiesel contents in the blend and conveyed that blending of 25% biodiesel-5% alcohol and 70% diesel give better result in terms of emission and performance in diesel engines [13]. However, with the application of 20 and 25% biodegradable realm in diesel engine, it is not presumable to attain the fossil fuel nondependence energy sources. Furthermore, the sustainability as well as the environmental friendliness of these blends decreases as the percentage of fossil-based diesel fuel is more in the blend as compared to diesel. So, it is imperative to take a step toward the total replacement of diesel from CI engines. In this regard, some work has been done on biodiesel-alcohol, biodiesel-oil, and biodiesel-biodiesel blends. The different approaches of the researchers who are working in the area of alternate fuels for engine application with the aim of partial and complete elimination of diesel is tabulated in **Table 1**. The applicability of neat biodiesel in diesel engine is also too low as it affects the engine performance and its running life due to high viscosity. One of the best possible ways to achieve the above stated requirement is to use binary fuel (biodiesel-oil) blends which possess properties as per American Society for Testing Materials (ASTM) specification for biodiesel. Using methyl ester (high viscous) in various proportions with nonedible oils (low viscous) have the ability to give a stable solution and feasible to completely replace diesel from CI engines [1]. The biodiesel can be a solubilizer and improve properties of the blend [14]. The major advantage of this binary fuel blend is that it can be used in CI engines without any major tweaking, and second, it

Elimination of conventional fuel from diesel engines	Partial elimination	Biodiesel + diesel blends Biodiesel + alcohol + diesel blends Biodiesel 1 + biodiesel 2 + diesel blends Biodiesel + alcohol blends
	Complete elimination	Neat biodiesel Biodiesel + oil blends Other mixed feedstock

**Table 1.** Overview of elimination of conventional fuel from CI engines.



**Figure 1.** Graphical representation of binary fuel approach.

produces less harmful gases as emission to the environment. Another advantage of using binary biofuel is that it also decreases our dependency on fossil fuels without compromising with the efficiency of the engine. Also, the feedstock used in binary fuel approach is renewable in nature. The graphical representation of binary fuel approach is shown in **Figure 1**.

The present study is to highlight the prospective of biodiesel with oil blend to be used as a feedstock for diesel engine in the automotive sector and can also make available effectively for the complete elimination of diesel from standing engine with these blends. This contributes to the constraints made by organizations like Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA) toward the replacement of fossil fuel and finding an alternative that is environmental friendly and biodegradable.

## 2. Performance analysis and emission profile of binary fuel blends

Blending of biodiesel with low viscous oil has a potential to completely replace diesel from the CI engine, and some work was already done on this type of blending.

Devan and Mahalakshmi [14] had used paradise oil methyl ester (PME) blends with eucalyptus (EU) oil in the proportion of 20, 30, 40 and 50% on a volume basis. Outcome revealed that 50% blend of PME and 50% EU is an optimum blend. The authors found that this blend shows a significant reduction in unburnt hydrocarbons (HC), carbon monoxide (CO), and smoke opacity at all load conditions. But, there is some increase in nitrogen oxide (NO<sub>x</sub>) observed. Although the enhancement in brake thermal efficiency (BTE), 2.4% at full load condition and decrement in most of the tailpipe emissions overshadow the slight increase in NO<sub>x</sub>. Vallinayagam et al. [15] had also assessed diesel engine characteristics fuelled with biodiesel oil blends. They had used blends of kapok methyl ester (KME), that is, high viscous and pine oil (low viscous) in the proportion of 25, 50, and 75% on the volume basis in single cylinder 4-stroke water cooled CI engine. Results revealed that 50% KME and 50% pine oil blend on volume basis (KME50P50) shows optimum result for engine performance and emission. With this blend as a fuel in diesel engine, they found 12.5, 18.9, and 8.1% decrement in CO, smoke, and HC emissions as compared to diesel, respectively. Results revealed that exhaust gas temperature (EGT) also reduced minimally at all the load conditions. And NO<sub>x</sub> emissions were found in line with diesel. They also found the performance of KME50P50 similar to conventional diesel fuel at high load condition perhaps its slight lower than diesel at low load conditions. Sharma and Murugan [16] had investigated Jatropha oil biodiesel with tyre pyrolysis oil (TPO) in composition as a fuel. They were found out that 80% Jatropha biodiesel-20% tyre pyrolysis oil blend provides better result in terms of performance and emissions and stated it as an optimum blend. Dubey and Gupta [17] had also used Jatropha methyl ester. They investigated diesel engine characteristics with Jatropha methyl ester blend and turpentine oil blends, that is, JB90TO10, JB70TO30, and JB50TO50. JB50TO50 shows improved results as compared to other tested blends. At full load condition, tailpipe emissions, that is, HC, CO, smoke, and NO<sub>x</sub> were found to be 42.5, 4.56, 29.16, and 4.72%, respectively, lower than conventional diesel although CO<sub>2</sub> emissions rises by 10.5%. Singh et al. [1] had used Amla seed oil biodiesel (AB) and EU in the various proportions of 9:1, 8:2, 7:3, 6:4, and 5:5 by volume. They concluded that among all the tested blends, AB70EU30 is optimum blend as it gives better results in terms of combustion, performance, and emission characteristics. AB70EU30 shows better results in terms of emissions and comparable performance as diesel at high load conditions.

All the authors used biodiesel-oil blends as a feedstock for diesel engine. They maximally found that the emissions decrease drastically with the use of biodiesel-oil blends, and one of the optimum blends from the tested blends has better combustion and emission characteristics. The effect on performance and emission characteristics of diesel engine with different binary fuel blends is due to variable properties of the fuels. The properties of the fuel used and their binary fuel blends are given in **Table 2**. The effect of operating conditions on performance and emission characteristics of different binary fuel blends is shown in **Table 3**, and the optimum blends suggested by the authors is tabulated in **Table 4**.

Properties Fuels	Density @40°C in kg/m <sup>3</sup>	Kinematic viscosity @ 40°C in CST	Conradson carbon residue	Fire point (°C)	Flash point (°C)	Pour point (°C)	Heating value (kJ/kg)	Sulfur wt%	Saponification value	Iodine value	Distillation recovery @90% min	Cetane number	Ref.
IS 1460– 1974	Nil	2.0–7.5	0.20	—	38 min	6 max	—	1.00 max	—	—	366°C	42	[14]
Diesel	0.84	3–4	—	—	74	–23	42,700	—	—	—	—	40–55	
PME	0.8752	5.4	0.18	150	141.2	2	40,285	0.13	191.5	46	369	51	
EU	0.8955	2.0	1.90	—	54	–5	43,270	—	—	—	—	—	
PME20EU80	0.8914	2.72	—	—	—	—	42,673	—	—	—	—	—	
PME30EU70	0.8894	3.08	—	—	—	—	42,374	—	—	—	—	—	
PME40EU60	0.8874	3.44	—	—	—	—	42,076	—	—	—	—	—	
PME50EU50	0.8852	3.8	—	—	—	—	41,778	—	—	—	—	—	
KME	0.875	5.4	—	—	156	—	36,292	<0.005	—	—	—	54	[15]
Pine oil	0.8751	1.3	—	—	52	—	42,800	<0.005	—	—	—	11	
KME25P75	0.875	2.3	—	—	78	—	41,173	<0.005	—	—	—	22	
KME50P50	0.875	3.3	—	—	104	—	39,546	<0.005	—	—	—	33	
KME75P25	0.875	4.4	—	—	130	—	37,920	<0.005	—	—	—	43	
JB	0.880	5.65	0.5	—	170	—	38,450	—	—	—	—	50–55	[16]
TPO	0.920	5.4	—	50	43	—	39,200	—	—	—	—	—	
JB90TPO10	0.883	5.73	—	78	64	—	39,240	—	—	—	—	—	
JB80TPO20	0.887	5.60	—	73	60	—	37,740	—	—	—	—	—	
JB70TPO30	0.892	5.41	—	69	55	—	36,400	—	—	—	—	—	
JB60TPO40	0.894	5.29	—	64	49	—	35,120	—	—	—	—	—	
JB50TPO50	0.897	5.15	—	59	44	—	33,890	—	—	—	—	—	
AB	0.884	—	0.04	—	152	–0.5	40,100	—	—	—	—	—	[1]
TO	0.920	4.12	—	—	38	–23	44,400	—	—	—	—	38	[17]
JB50TO50	0.900	4.01	—	—	—	—	41,950	—	—	—	—	—	
JB70TO30	0.892	4.08	—	—	—	—	40,480	—	—	—	—	—	
JB90TO10	0.885	4.12	—	—	—	—	39,990	—	—	—	—	—	

**Table 2.** Properties of the fuels and binary fuel blends.

Fuel blends used	Base fuel	Engine	Operating conditions	Performance			Emissions					Ref.	
				BSEC	BSFC	BTE	HC	NO <sub>x</sub>	CO	CO <sub>2</sub>	Smoke		EGT
PME20EU80	Diesel	1 cylinder 4-stroke air cooled diesel engine	At a constant speed of 1500 rpm and different loads	↓	-	⇒/↑	↓	↑	⇒/↓	-	↓	↑	[14]
PME30EU70				↑	-	⇒/↓	↓	↑	↑/↓	-	↓	↑	
PME40EU60				↑	-	⇒/↓	↓	↑	↑/↓	-	↓	↑	
PME50EU50				↓	-	⇒/↑	↓	↑	↑/↓	-	↓	↑	
KME100	Diesel	Single cylinder, 4 stroke, DI diesel engines	Constant speed of 1500 rpm and different loads	-	↑	↓	-	↑	-	-	↑	↑	[15]
KME25P75				-	↓	↑	-	↓/↑	↑/↓	-	↓	↓	
KME50P50				-	↑	↑	-	↓/↑	↑/↓	-	⇒/↑	↓	
KME75P25				-	↑	↓	-	↓	↑	-	↑	↑	
JB100	Diesel	Single cylinder, 4 stroke, air cooled DI diesel engines	Constant speed of 1500 rpm and different loads	↑	-	↓/↑/↓	↓	↑	↓	-	↑	↑	[16]
JB90TPO10				↑	-	↓	↓	↑	↓	-	↓	↑/↓	



Fuel blends used	Base fuel	Engine	Operating conditions	Performance			Emissions					Ref.	
				BSEC	BSFC	BTE	HC	NO <sub>x</sub>	CO	CO <sub>2</sub>	Smoke		EGT
JB80TPO20				↑	-	→/↑/→	↓/↑/↓	↑	↓	-	↓	↑	
JB70TPO30				↑	-	↑/↓	↑	↑/↓/↑	↑	-	↑/↓	↑	
JB60TPO40				↑	-	↑/↓	↑	↑/↓/↑	↑	-	↑	↑	
JB50TPO50				↑	-	↑/↓	↑	↑/↓/↑	↑	-	↑	↑	
JB100	Diesel	Single cylinder, DI, water cooled, naturally aspirated engine	Constant speed and different load conditions (no load, 35%, 65% and full load)	-	↑	↓	↓	↑	↓	↑	↓	-	[17]
JB50T50	-			↑	↓	↓	↓	↓	↑	↓	-	-	
JB70T30	-			↑	↓	↓	↑	↓	↑	↓	-	-	
JB90T10	-			↑	↓	↓	↑	↓	↑	↓	-	-	
AB100	Diesel			Single cylinder, DI, water cooled, naturally aspirated engine	Constant speed and variable load	-	↑	↓	↑	↓	↓	-	↓
AB90EU10	-	↑	↓			↑	↓	↓	↓	-	↓	↓	
AB80EU20	-	↑	↓			↓	↓	↓	↓	-	↓	↓	
AB70EU30	-	→	↑			↓	↓	↓	↓	-	↓	↓	



Fuel blends used	Base fuel	Engine	Operating conditions	Performance			Emissions					Ref.	
				BSEC	BSFC	BTE	HC	NO <sub>x</sub>	CO	CO <sub>2</sub>	Smoke		EGT
AB60EU40				–	↓	↑	↓	↑	↓	–	↓	↑	
AB50EU50				–	↓	↑	↓	↑	↓	–	↓	↑	

First arrow/second arrow shows the change at low load and high loads.

First arrow/second arrow/third arrow shows the change at low, medium and high loads.

Single arrow shows the overall effect from lower to higher loads.

**Table 3.** Performance and emission characteristics of dual biofuels.

Authors (Ref.)	Devan and Mahalakshmi [14]	Vallinaygam et al. [15]	Sharma and Murugan [16]	Dubey and Gupta [17]	Singh et al. [1]
Optimum blend	PME50EU50	KME50P50	JB80TPO20	JB50TO50	AB70EU30

**Table 4.** Optimum blend that have capability to completely eliminate diesel from CI engines.

### 3. Effect of minor modification on performance of optimum binary fuel blend

The most important parameter is the air-fuel mixing that affects the performance of biodiesel and its blends. A way to improve the air-fuel mixing is to alter the engine parameters. In this regard, some researchers have used this binary fuel blend with minor adjustments to the engine parameters.

There is very less literature available with biodiesel-oil blend as a feedstock in a diesel engine with minor tweaking. Authors [18–21] had performed experiments to study the behavior of a diesel engine running on the optimum binary fuel blends at varying compression ratio (CR), injection timing (IT), and injection pressure (IP).

CR has been altered without changing the geometry of combustion chamber with the provision of arrangement provided in variable compression engine [21]. In a simple diesel engine, CR of the engine has been changed by altering the clearance volume, by the replacement of gaskets of variable thickness in between the cylinder and the cylinder head. The fuel injection strategy is an important parameter in diesel engines to optimize the combustion, performance, and tailpipe emissions. Three IP values were used for experimentation, that is, 180, 210, and 240 bar. IP was adjusted by regulating spring tension of needle provided in injector. Injection timing was adjusted on three different values of 20, 23, and 26° bTDC by introducing required shims at the position between the fuel pump and engine. To advance the fuel IT, the shims under the pump were removed, and to retard additional shims were introduced under fuel injection pump. At standard IT, the number of shims placed under the pump was three. The thickness of the each shim is 0.3 mm and removing one shim advanced IT about 1.5° CA IT and introducing a shim retard the timing by 1.5° CA.

CR is the most valuable factors for diesel engine operation because of its high anti-knocking property. Sharma and Murugan [18] had altered the CR and compared the results of optimum Jatropa biodiesel-tyre pyrolysis oil blend. They operated the engine with diesel as a fuel at original condition and JB50TPO50 blend at altered CR conditions. They found that BTE improves unrelatedly of the engine load at higher CR. The consumption of energy at higher CR reduces at higher CR as compared to the original conditions. This may be due to the reason of better fuel spray characteristics and improved air-fuel mixing at higher CR. As compared to original CR conditions, the tailpipe emissions, that is, CO and HC to the environment from diesel engine exhaust fueled with biodiesel oil blends reduces. Smoke opacity also reduces as

compared to original conditions. This is also due to the fact that air move in during the suction stroke at higher CR is compressed, which escalates the air temperature. Higher air temperature helps for better atomization of fuel which improves fuel combustion inside the combustion chamber. But  $\text{NO}_x$  emissions increase at higher CR as compared to original conditions. This is due to the higher temperature inside the combustion chamber at higher CR conditions as compared to original CR conditions. This is also due to the higher oxygen contents in the biodiesel-oil blends which improves combustion and hence increases  $\text{NO}_x$  formation. The exhaust gas temperature also found to be higher due to the higher intake temperature and then better combustion rate. Similarly, Dubey and Gupta [19] had also altered CR with the aim of better performance of binary fuel blends in diesel engines. They found that the JB50TO50 gives the better result as compared to other blends and BTE efficiency improved by 2.17% a full load condition and higher CR. The tailpipe emissions CO, HC, and  $\text{NO}_x$ , and smoke opacity were decreased by 13.04, 17.5, 4.21, and 30.8%, respectively, while there is some increment was noticed in  $\text{CO}_2$ , that is, 11.04%. Overall, they stated that JB50TO50 has better option at higher CR condition as a fuel for CI engines.

Fuel IT is undoubtedly an important parameter that influences the combustion, performance, and emission characteristics of any diesel engine. Advanced IT results in increase in maximum cylinder pressure and heat release rate, while the reverse trend is noticed in the case of retarded IT. Ignition delay was found to be longer with shorter combustion duration at advanced IT as compared to that with the original and retarded ITs. BSEC at advanced IT is lower than that with the original IT. Advancing the IT results in reduced CO, HC, and particulate emission. This is due to the fact that more time is being available for the complete combustion in the case of advanced ITs.  $\text{NO}_x$  emission was higher at the advanced IT in comparison to that with the original IT and lower at retarded IT compared to original and advanced ITs. This is due to the fact that at retarded IT, fuel is injected near the top dead centre (TDC) and most of the fuel burn after TDC. It causes higher amount of heat going to the exhaust which results in lowering of maximum cylinder pressure and temperature [20].

Sharma and Murugan [21] used JB50TPO50 as a fuel at altered IP conditions. Outcome revealed that the IP up to 220 bar gave good engine performance as compared to those of original IP and also 230, 240, and 250 bar. At 220 bar IP, the BTE was found to be higher. HC and CO emissions were also lower at this IP as compared to original IP at full load. The smoke opacity was lower at full load compared to original IP.

#### **4. Tribological aspects associated with binary fuel blends**

There are two different types of tribological studies available in the literature for binary fuel compatibility in engines, that is, short-term bench tests and long-term endurance test. Before conducting the endurance test, some bench tests on four ball tester (FBT), high frequency reciprocating rig (HFRR), and pin on disc tester (POD) were carried with binary fuel blends

to endow the convenient basic information about the fuel lubricity behavior, effect of oxidative stability, and engine oil dilution. The effect of temperature and load on friction and wear were investigated with the help of FBT [4]. As biodiesel is subjected to oxidation and has highly affected lubricity at higher temperature and load, so the effect of oxidation was also studied. The effect of dilution in lubricating oil was also evaluated by means of HFRR and POD friction monitor [5]. The effect of engine oil dilution on pin and disc as well as on cam and tappet in valve train combination were studied. The effect of binary fuel blend on injection system of engine was also discussed by Singh et al. [22]. Result revealed that biodiesel and its oil blends show improved lubricity as compared to diesel, and hence increase the life of injection system of the engine.

The outcome of the four ball tester gives an idea about the impact of binary fuel blend used in the experiment on wear and friction under different operating conditions. The operating loads and temperatures were 147–392 N and 45–60–75°C, respectively. The changes in load and temperature highly influenced the wear and friction between sliding surfaces. Higher load and higher temperature adversely affect the tribological performance of the used feedstocks. The existence of both abrasive and adhesive wear has been observed at this condition, while only abrasive wear occurred at low temperature and load condition. The oxidation of methyl ester blends at higher loads and temperature conditions lead to higher corrosive wear. However, the aged (oxidized) methyl ester shows better results in terms of lubricity in short-term test [4].

The effect of 10% dilution of fresh AB70EU30 oxidized AB70EU30 and diesel by volume in the engine oil by means of HFRR and POD. The results revealed that the 10% dilution AB70EU30 showed promising results after dilution with lubricating oil as compared to diesel and oxy-biodiesel and provided much smoother mating surfaces. It is due to the existence of palmitic acid, tocopherol, etc. in the biodiesel and oil blend [23]. The lubricating oil diluted with oxy-biodiesel shows higher COF and WSD as compared to fresh biodiesel contaminated lubricating oil. This is because of complex interactions between polar molecules of anti-wear additives and biodiesel after the oxidation. This shows the poorer results as compared to fresh biodiesel but rather it is better than diesel. AB70EU30 diluted lubricating oil shows lower change in the value of total acid number (TAN) after the test as compared to diesel contaminated lubricating oil. This also justified the better condition of the lubricating oil after the dilution of AB70EU30. The ferrography also showed the less wear debris in the AB70EU30 contained lubricating oil. In modern diesel engine, additional late in-cylinder injection strategy is implemented to raise the EGT in order to check the particulate emission. During late injection, piston moves toward BDC exposing more cylinder surface area to the fuel, causing lubricating oil dilution as fuel readily passes through to the crankcase [24]. Crankcase dilution can decrease viscosity and lubricity of engine lube oil, and at the same time, it can diminish the performance of anti-wear additives. Sharma and Murugan [25] have assessed the use of 20% tyre pyrolysis oil with 80% Jatropha oil methyl ester in CI engine for long term, that is, 100 hrs. They reported that the deposition of carbon on injector tip and inside the combustion chamber was higher for this blend. But, they did not find any problem with the use of JB80TPO20 for 100 hrs in diesel engine with modified conditions.

## 5. Conclusion

Though, difference results in terms of performance and emission characteristics obtained from binary fuel blends due to their different physico-chemical properties, however, some general conclusions were drawn:

- Suitable selection and blending of two biofuels (biodiesel or oil) are an effective way to overcome the operative issues in engine associated with the neat oil and biodiesel. Typical issues such as viscosity and calorific values can be suitably adjusted with the blending.
- It can be drawn from the above observations that optimum biodiesel-oil blend suggested gives satisfactory result in terms of performance and emission.
- Minor tweaking in engine parameters can be a better option for the utilization of binary fuel blend. It provides the better efficiency and lower emissions for binary fuel blends as compared to diesel.
- The optimum blends also have better performance in short-term and long-term tribological tests as compared to diesel.
- In future, these optimum blends are environmentally friendly alternate for diesel without compromising the efficiency and the consumption of fuel as compared to diesel. Hence, these blends play a vital role to reduce the environmental impact of fossil energy sources.

## Nomenclature

AB	amla biodiesel
ASTM	American Society for Testing Materials
BSFC	brake specific fuel consumption
bTDC	before top dead centre
BTE	brake thermal efficiency
CA	crank angle
CI	compression ignition
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
CR	compression ratio
DI	direct injection
EGT	exhaust gas temperature
EGT	exhaust gas temperature

EU	eucalyptus oil
GHG	greenhouse gas
HC	hydrocarbon
IC	internal combustion
IP	injection pressure
IT	injection timing
JB	Jatropha biodiesel
KME	Kapok methyl ester
NO <sub>x</sub>	nitrogen oxide
PM	particulate matter
TO	turpentine oil
TPO	tyre pyrolysis oil

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