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An encompassing of two Biofuel – Diesel Blend's in D.I. Diesel Engine for reduced Air Pollution Emission

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Graphical abstract

Abstract

The study explores the usage of Diesel Fuel (DF) blends in conjunction with two biofuels, eucalyptus and turpentine oil, in diesel engines to address the reduction of air pollutants such as Carbon Monoxide (CO), Nitrogen Oxides (NO_X), Unburned Hydrocarbons (UBHC), and smoke density. Results indicate that while the use of Eucalyptus Oil Fuel (EOF 40) marginally increases brake-specific energy consumption by 1.03%, Turpentine Oil Fuel (TOF 40) decrease it by 3.05% compared to conventional DF. Furthermore, the Brake Thermal Efficiency (BTE) of TOF 40 blend surpasses that of EOF 40 blends by 4.91%. The analysis of Heat Release Rate (HRR) indicates a higher trend for higher proportions of EOF blend compared to TOF and base DF. TOF blends have lesser atmospheric pollution compared to EOF blends. Notably, the employment of TOF 40 blend results in a reduction of atmospheric pollutants such as Smoke Density, NO_X, CO and UBHC were 12.98%, 17.83%, 25.6% and 15.51%, respectively, in comparison with DF.

Keywords: Air pollution, turpentine oil, emission, biofuel, eucalyptus oil

1. Introduction

The recent surge in global oil prices, coupled with worries about energy security and growing public awareness of environmental concerns related to non-renewable fuels, has reignited interest in alternative fuels. Developing biofuel-based alternatives to diesel not only enhances fuel quality but also presents an attractive proposition. These biofuels can be readily used in engines or processed to closely mimic the essential characteristics of conventional Diesel Fuel (DF). However, previous attempts to utilize vegetable oils as fuel in engines have revealed several challenges, as numerous studies have shown. The main challenges arise from the low volatility and elevated viscosity of vegetable oils. The existence of oxygen in their molecular structure, along with the reactive nature of the unsaturated hydrocarbon chains, contributes to the gradual formation of gum and piston sticking, along with challenges related to elevated levels of smoke, hydrocarbon, and carbon monoxide emissions [Kowalewicz and Wojtyniak (2005), Barsic and Hunke (1981), Poola *et al.* (1994)]. Different methods have been employed to tackle these challenges, including preheating the oils, direct blending with diesel, transesterification, and thermal cracking. Past efforts have concentrated on developing appropriate techniques for incorporating vegetable oils into diesel engines. In this investigation, turpentine oil sourced from biomass and eucalyptus oil were selected as the primary constituents and directly mixed with DF. The study experimentally examined the performance, emissions, and combustion characteristics of a Direct Injection (DI) Diesel Engine utilizing turpentine oil, eucalyptus oil, and diesel as fuel sources.

2. Characterization and property analysis

This research focuses on employing oil extracted from biomass, specifically eucalyptus and turpentine. Turpentine oil has a well-established history as a commercially utilized fuel. It is predominantly sourced from pine trees, extracted as a fraction of resin. Through the distillation process of pine resin, two primary compounds are obtained: turpentine and rosin. Turpentine, a blend of functional isomers derived from pine gum or pine wood, is identifiable by its opaque, adhesive, volatile, and flammable properties, as well as its yellowish hue. It typically consists of gamma-pinene, beta-pinene, and other isomeric terpenes, which collectively make up 58–65% of turpentine oil. When turpentine oil is kept in a dark environment; its qualities can be preserved for years. It absorbs active oxygen at 100°C. Turpentine oil was appropriate for use in diesel engine operations due to its analytic qualities. It was unmodified when it was utilised in early engines. The abundant availability of DF eventually resulted in the cessation of turpentine oil usage in internal combustion engines. Nevertheless, there's a growing reconsideration of turpentine as an alternative fuel choice, owing to its capacity to yield minimal emissions of pollutants from exhaust systems. Although turpentine may be slightly more expensive than traditional petro-fuels, its cost remains lower than the expenses associated with global emission management. Eucalyptus oil, derived from biomass, presents another viable option for replacing conventional DF. Eucalyptus oil, sourced from the eucalyptus tree leaves, possesses a distinctive, fresh, and pungent scent, accompanied by its watery viscosity and pale-yellow hue. Unlike some other sources, eucalyptus leaves are available year-round, making eucalyptus oil production a continual rather than seasonal process. Studies have suggested that both eucalyptus and orange oils could serve as suitable alternatives for internal combustion engines Ramesh (1994). The direct blending of these oils with DF can be done without requiring any modifications. Table 1 outlines the fuel blends, variations in calorific value, and viscosities for various grades of Eucalyptus Oil Fuel (EOF), as well as blends of Turpentine Oil Fuel (TOF) and DF.

Table 1. Test fuels properties

Sl.No.	Test Fuels	Blends of test fuels (% volume)	Density	Calorific value (kJ/kg)	Viscosity (cst)
1.	EOF 20	80% diesel fuel+20%Eucalyptus oil fuel	0.841	41814	2.8
2.	TOF 20	80% Diesel fuel + 20% Turpentine oil fuel	0.846	42916	2.8
3.	EOF 40	60% diesel fuel+40% Eucalyptus oil fuel	0.854	41928	2.6
4.	TOF 40	60% Diesel fuel + 40% Turpentine oil fuel	0.864	42732	2.6
5.	DF	100% diesel fuel	0.827	42700	3

3. Experimentation

The study was conducted using a Kirloskar TV-1 engine, which is a water-cooled, vertical cylinder engine with a four-stroke, single-cylinder, DI configuration, operating at a constant speed. Detailed technical specifications of the engine are provided in Table 1, and the setup for the experiment is depicted in Figure 1. Pressure measurements within the combustion chamber were taken using an AVL - manufactured transducer - a water-cooled piezoelectric pressure transducer with a sensitivity of 16:11 pc/bar. The electrical signals corresponding to the charge output from the piezoelectric transducer were generated using an AVL 3057 charge amplifier. Data collection for combustion parameters such as Heat Release Rate (HRR), in-cylinder pressure, and cyclic variations was facilitated by connecting a personal computer (PC) to an AVL 619 indimeter hardware, operating alongside medium-software version 2.2 data collection system. Engine speed was monitored using a frequency meter combined with a magnetic pick-up sensor. Emissions analysis for hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx) was conducted using an AVL 444 Di.

4. Results and discussion

4.1 BSEC–parameter related to performance

The Brake Specific Energy Consumption (BSEC) against brake power for DF blends containing TOF and EOF is shown in Figure 2. Compared to Brake Specific Fuel Consumption (BSFC), BSEC is an added significant statistic since it accounts for the fuel's calorific value as well as mass flow rate [Dickey (1989), Barie (1981), Canakci (2005)]. BSEC is a more useful metric for comparing fuels with varying values than brake specific fuel consumption. According to the results, BSEC for the TOF 40 and TOF 20 blend were 3.05% and 3.85% lower than DF respectively. This happens as a result of the higher heating value of TOF and diesel blends, which reduce the amount of energy the engine, must spend to keep the braking power constant. Augmenting the spray cone angle, facilitated by the high density and low viscosity of the turpentine oil and DF blend injected into the combustion chamber, can lead to enhanced premixed combustion. However, in contrast to DF, the BSEC for the blend containing 40% eucalyptus oil (EOF 40) increases by 1.03%. This can be credited to the increased density and decreased heating value of eucalyptus oil blends, necessitating a larger quantity of eucalyptus oil to sustain consistent braking power output [Canakci M (2005)].

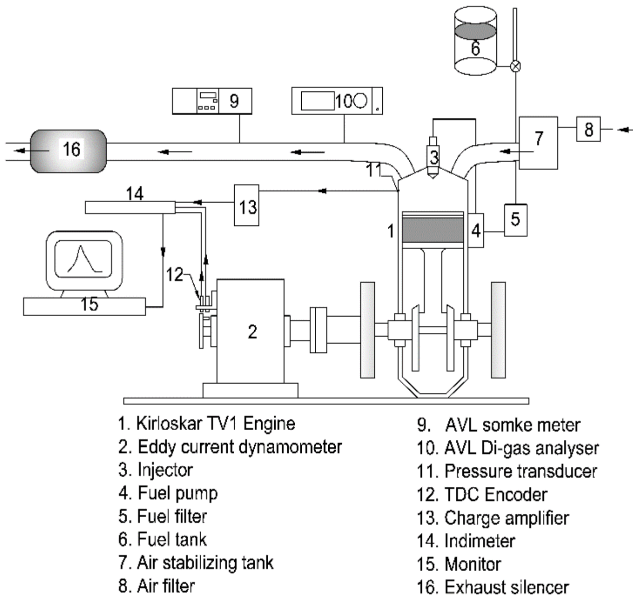

Figure 1. Experimental setup

4.2 BTE - Parameter related to performance

Figure 3 illustrates the trends of Brake Thermal Efficiency (BTE) against braking power for blends of DF with TOF and EOF. The results indicate that the BTE is superior for the engine operating with TOF blends at all loads in comparison to the baseline data. Compared to DF, the BTE of biofuel blends TOF 40 and TOF 20 were 4.04% and 6.4%

respectively. In comparison to DF, there is an improvement of BTE for the TOF blends. It is evident that with larger braking power outputs, the BTE improvement is more pronounced. Thus, it can be deduced that the BTE of the TOF blends exceeds that of both the pure DF and other combinations of EOF blend. This difference can be attributed to the higher cetane number and chemical composition of turpentine oil blends, which improve BTE and accelerate combustion.

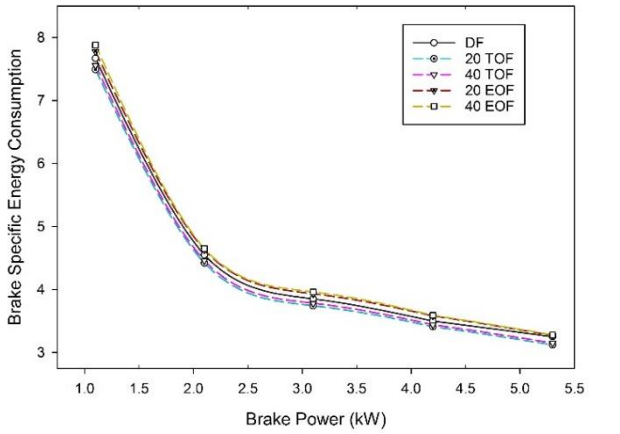

Figure 2. Comparison of BSEC of test fuels at different brake power

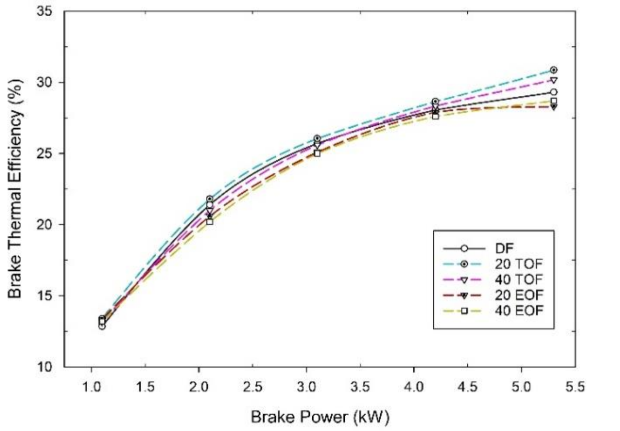

Figure 3. Comparison of Brake thermal efficiency of test fuels at various loads

4.3 Smoke Density- Parameter related to Emission

The smoke production in relation to different braking power is shown in Figure 4. When comparing TOF and EOF mixes to DF, it is discovered that the former produce less smoke at all loads. As the proportion of biofuel increases during the diffusive combustion phase, there is a corresponding rise in the HRR, leading to reduced smoke emissions. In comparison to DF, EOF and TOF mixes exhibit a noteworthy decrease in smoke emissions, ranging from 9.78% to 12.98%. According to the author [Lin CY and Lin HA (2006)], EOF and TOF blends' greater oxygen content could be the cause of this. TOF blends had a 10.76% and 12.98% lower smoke density at full load as compared base line DF respectively.

4.4 NOx (Oxides of N3itrogen)- Parameter related to Emission

Figure 5 illustrates the NOx reduction rate under various load conditions. Biofuel blends exhibit lower NOx emissions compared to pure DF. The results indicate approximately 3.8% to 17.83% reduction in NOx emissions for both EOF and TOF blends compared to baseline data. At full load, NOx emissions for the TOF 40 blend are reduced by 6.92% and 17.83% compared to the EOF 40 blend and DF, respectively. The decline in NOx emissions can be ascribed to the lower combustion temperature generated by TOF blends and oxygen content in the blend, as indicated by the author [Dennis *et al.* (1991)].

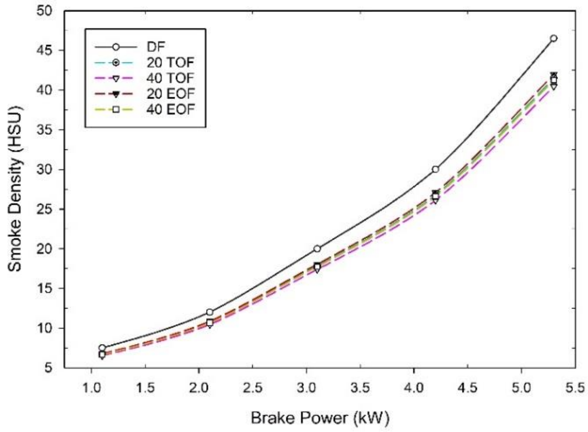

Figure 4. Comparison of smoke density of test fuels at different brake power

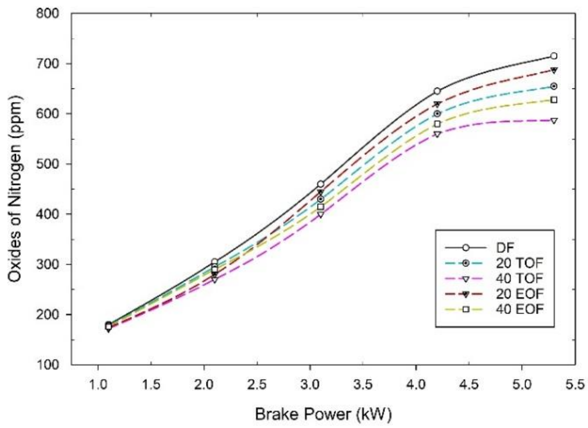

Figure 5. Comparison of NOx of test fuels at different brake power

4.5 Carbon monoxide - Parameter related to Emission

According to the authors [Heywood (1988), Sayin C and Uslu K. (2008)], the inadequate presence of oxygen during combustion leads to incomplete burning of carbon, resulting in the production of carbon monoxide (CO) instead of carbon dioxide (CO_2). Figure 6 depicts the variation of CO emissions across the entire brake power range for DF and different blends of TOF and EOF. The findings reveal that at full load, both the TOF 40 and EOF 40 blends display CO emissions that are 25.6% and 18.2% lower, correspondingly, compared to pure DF. This decline in CO emissions is accredited to the heightened after-combustion temperature induced by the blends. Elevated combustion kinetics and temperatures facilitate more thorough fuel conversion, resulting in reduced CO emissions.

4.6 Unburned hydrocarbon- Parameter related to Emission

Figure 7 illustrates the unburned hydrocarbon (UBHC) emissions for DF, TOF, and EOF blends across various braking power levels. Lubricating oil contributes to UBHC emissions in the exhaust. During the ignition-delay phase, fuel evades combustion through processes such as valve overlap, bulk quenching, wall quenching of the flame, and lean mixing. Bulk quenching predominantly occurs at lower loads, whereas oil cracking dominates at higher loads. The results demonstrate an average decrease in UBHC emissions of 15.5% and 9.1% for EOF and TOF blends, respectively, in comparison to the baseline DF. This reduction is likely attributed to the oxygen content in the blends, which compensates for oxygen deficiency and fosters complete combustion.

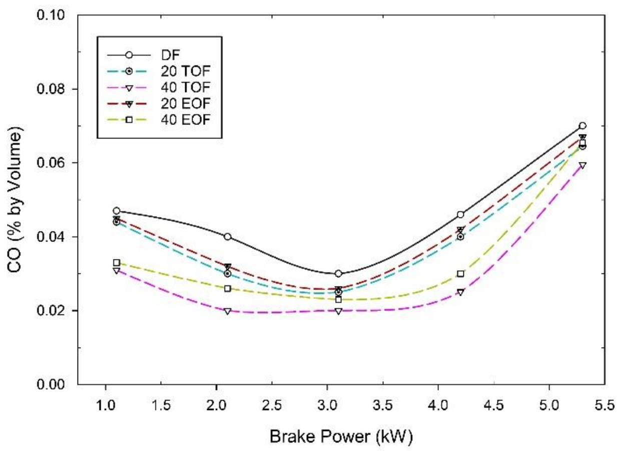

Figure 6. Comparison of CO of test fuels at different brake power

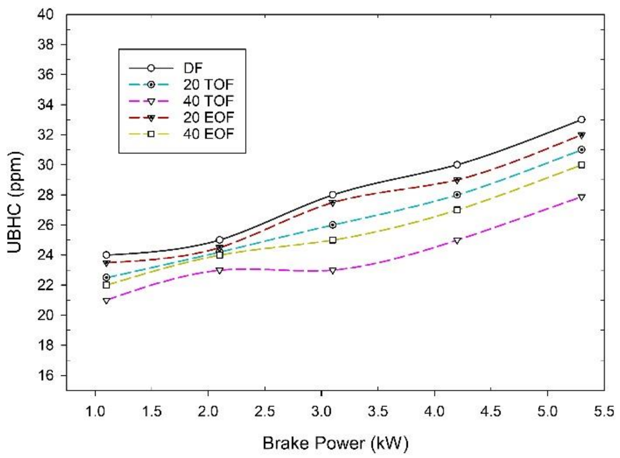

Figure 7. Comparison of UBHC of test fuels at different brake power

4.7 Cylinder pressure - parameter related to combustion

Figure 8 illustrates the P-θ diagram for DF alongside various blends of TOF and EOF. Peak pressure is affected by factors such as combustion chamber design, compression ratio, duration, energy content, fuel specific heat and fuel quality. As shown in the diagram, the in-cylinder pressure patterns generated by the TOF and EOF blends closely resemble those produced by DF. The maximum cylinder pressures such as 72.082 bar, 78.225 bar, and 74.305 bar are reported by TOF 40, EOF 40, and pure DF. It is observed that due to their rapid burning rate during the initial stage, the EOF and TOF combinations reach peak pressure between 5 and 15 crank angles after Top Dead Center (TDC). Thus, the conclusion is drawn that engine operation with these blends did not experience any issues associated to knock.

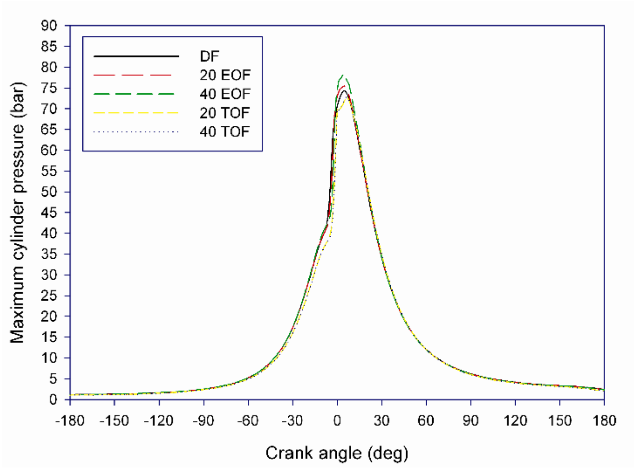

Figure 8. Comparison of maximum cylinder pressure of test fuels at different brake power

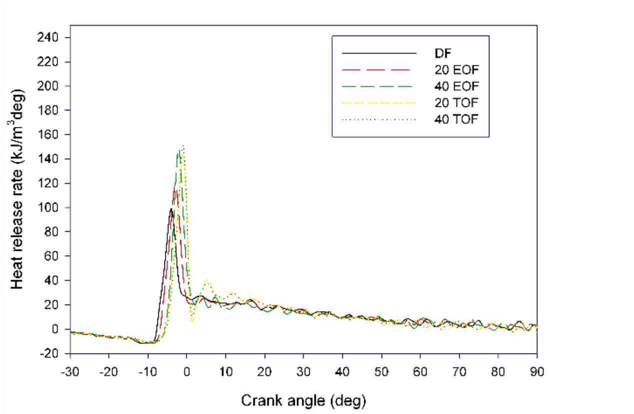

Figure 9. Comparison of heat release rate of test fuels at different brake power

4.8 Rate of heat release- Parameter related to Combustion

Figure 9 depicts the HRR of DF and blends of eucalyptus oil (EOF) and turpentine oil (TOF) at various crank angles spanning from -30° to 90°. It is evident that, in contrast to the blends, DF demonstrates a slower heat release. The HRRs for EOF 40 and TOF 40 blend at full load are 151.065 kJ/m3 deg and 153.057 kJ/m3 deg, respectively. Because of the decreased premixed combustion, the engine's HRR is somewhat off of the top dead centre. This phenomenon can potentially be elucidated by the slower burning rate and lower internal energy resulting from the slightly higher density and lower calorific value of the blends. Another researcher has also observed a similar pattern [Kamo *et al.* (1984)]. Furthermore, it is noted that eucalyptus oil (EOF) blends exhibit a longer ignition delay compared to TOF and DF, resulting in the emission of greater heat during the premixed combustion phase, as documented by the author [Huang Zuohua *et al.* (2004)].

5. Conclusion

Here are the primary findings from the experimentation on a DI Diesel engine running on DF and blends of TOF and EOF:

1. The BSEC is slightly increased for the EOF blends but decreased by 3.05% and 3.85% for TOF 40 and TOF 20 blends respectively in comparison to pure DF.
2. The BTE of the TOF 40 and TOF 20 blend surpasses that of the standard DF by 4.04% and 6.4% respectively.
3. The HRR for EOF blends is higher than that of TOF and DF, indicating a faster combustion process.
4. With the TOF 40 blend, emissions of atmospheric pollutants such as NOx and Smoke density are decreased by 17.83% and 12.98%, respectively compared to DF.
5. Both EOF and TOF blends exhibit lower UBHC emissions, with an average reduction of 9.1% for EOF40 blend and 15.51% for TOF40 blend compared to baseline DF.
6. The P-θ diagram shows comparable in-cylinder pressure patterns for TOF and EOF blends compared to DF. The maximum cylinder pressure is slightly lower for the TOF 40 blend compared to EOF 40 and DF.
7. Blends of TOF and EOF demonstrate reduced emissions of air pollutants including CO, NOx, UBHC, and Smoke Density when compared to pure DF.

From the research findings the TOF biofuel blend was found performing better than the EOF blend. Among the TOF blends, the TOF 40 was identified best blend as it allows for higher replacement of diesel, which is significantly notable in reducing polluting emissions.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper

Data availability statement

The raw/processed data required to reproduce these findings cannot be shared

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