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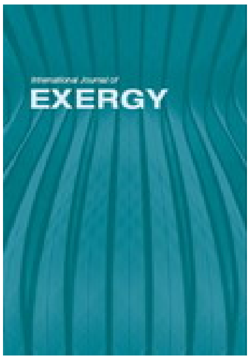

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Experimental investigation and analyses of CI engine fuelled with different blends of waste plastic oil and diesel

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Experimental investigation and analyses of CI engine fuelled with different blends of waste plastic oil and diesel

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Abstract: The present work focuses on the energy, exergy, and economic study of a compression ignition engine working with waste plastic oil (WPO). Blends like 10% to 30% by volume of WPO with diesel are prepared and investigated experimentally to evaluate the performance parameters. The thermal efficiency and exergetic efficiency are found to be increased by 3.38% and 6.92% with an increase in WPO blend up to 20% compared to the neat diesel case. The cost rate of inlet fuel for WPO20 is found to be decreased substantially from that of diesel. Moreover, the sustainability index (SI) of WPO20 by 1.38% higher than diesel ensured the extended durability of the engine and lesser damage to ecological factors.

Keywords: waste plastic oil; WPO; compression ignition engine; exergy analysis; economic analysis; sustainability index.

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1 Introduction

Improvement of techniques to develop resourceful and commercial energy agreements has become a major issue in the global context. It has become more crucial for upgrading power system design while minimising environmental impact amid limited conventional energy reservoirs and rising global challenges to meet energy demand (Ameri et al., 2009). The energetic analysis techniques involve thermodynamic evaluation of the efficiency of an energy transformation system. The exergy analysis explains the thermodynamic limitation, such as uninterrupted energy loss to the environment and identifying the position of occurrence (Bejan and Siem, 2001). A holistic investigation of a thermal system takes account of the quantitative and qualitative approach of thermodynamics equally representing energy and exergy analysis to acquire a further useful depiction of system performance (Das et al., 2020). In addition, an exergy study is very much essential to realise the thermodynamic principles including the reasons and effects of energy flow in an engine (Madheshiya and Vedrtnam, 2018). In this context, exergy analysis on fuels used in IC engines necessitates attention for improvement in thermal performance and reduction in exhaust emissions. Gouda et al. (2019) conducted the energy, exergy, and emission analysis of a blend of pyrolytic Kaner seed oil (KSPO) with pure diesel in a twin-cylinder CI engine. López et al. (2014) performed the exergy analysis in their study by using olive-pomace oil biodiesel in a diesel engine. The use of exhaust gas recirculation (EGR) to predict better exergy value is reported in various mass fractions with hydrogen fuel and diesel (Jafarmadar and Nemati, 2017). A significant decrease in exergy efficiency is found with an increase in exhaust exergy beyond induction of 30% EGR. Another approach of the investigation was to use pumpkin seed oil and moringa oleifera biodiesel in three modified combustion chambers of a diesel engine, namely toroidal, trapezoidal, and hemispherical, to perform higher energy and exergy balance. In comparison to diesel, they reported better engine performance and higher exergy efficiency when using a toroidal combustion chamber design with pumpkin seed oil biodiesel (Madheshiya et al., 2018; Karthickeyan, 2019). Similar efforts were also undertaken by Bengi Gözmen Şanli et al. by taking different fuel combinations of diesel, hazelnut, and canola biodiesel fuels and observed maximum thermal efficiency and exergy efficiency for canola biodiesel in comparison to other fuel mixtures (Şanli and Uludamar, 2020). Exergy and energy analysis of DI diesel engine was also performed using various blends of diesel, ethanol, and biodiesel, and claimed higher exergetic efficiency of fuel at higher engine load, speed, and blending proportion of biodiesel and bio-ethanol with diesel (Khoobbakht et al., 2016). The usage of Al_2O_3 nanoparticles as a fuel additive in biodiesel improved fuel economy enhanced BTE and reduced harmful exhaust emissions (Özcan, 2019). The impact of diethyl ether (DEE) on exergy parameters and emission concentrations on neem oil-based biodiesel was investigated and claimed an increase in exergetic efficiency and lower emission by the addition of 15%DEE with B45 to that of diesel (Chaudhary, 2021). Similarly, an emission analysis of a dual fuel diesel engine fuelled with different gaseous fuels generated from waste biomass was carried out (Nayak et al., 2021).

Another such important method includes exergo-economics, also known as thermo-economics, which is a new field of engineering science that combines the exergy concept of thermodynamics with economic principles. It is thought to be a more effective and useful tool in identifying the sources, locations, types, and magnitudes of thermodynamic inefficiencies, as well as predicting the economics in any energy conversion system (Meisami et al., 2018). In addition, the study SIshows how to lower the environmental impact of thermal systems by minimising energy destruction/loss or boosting energy efficiency (Dincer and Naterer, 2010).

Recently energy, exergy, and emission study were conducted by fueling diesel engines with WPO and declared promising results by the author in his previous work (Das et al., 2020). An optimisation based on response surface methodology study on WPO fuelled engine performance has been carried out recently by us (Das et al., 2021a). From the literature survey, it is found that a little research work was mentioned on thermo-economic analysis on CI engines operating with different biodiesels (Meisami et al., 2018) but no work is yet being reported using WPO. Few works are reported on the performance, combustion, and emission studies of WPO in diesel engines and tried to develop different techniques to improve these aspects. However, no exergo-economic or sustainability analysis studies have been reported in the literature. With the motivation of mentioned research gaps, the objective of this research is to study the energy, exergy, economic, and sustainability analysis of the WPO blended diesel in CI engine. The brake thermal efficiency, fuel consumption, exhaust gas temperature, and outlet water temperature are measured and subsequently calculated as the exergetic parameters by using established equations. Finally, a thermo-economic study has been conducted to establish the techno-economic feasibility of WPO in comparison to pure diesel fuel. Furthermore, a sustainability analysis committed to the use of WPO with diesel in the correct proportion to achieve higher durability and less damage to the environment has been carried out. Thus, the present work is novel in terms of a complete study of energy, exergy, economic, and sustainability analysis of the WPO blended diesel in CI engine. The outcome will help manufacturers and suppliers along with users.

2 Experiments

2.1 *Test fuel preparation*

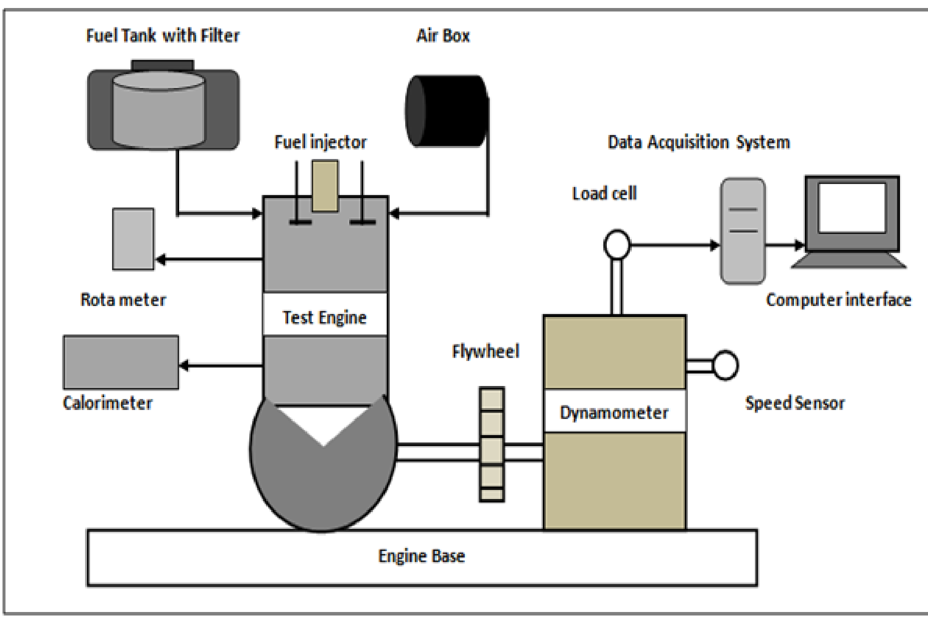
Discarded medical plastic wastes (syringes and saline bottles) made of polypropylene plastics collected from local hospitals, were shredded (to 1–2 cm size), dried well, and directly employed in the catalytic pyrolysis experiment using Zeolite A as a catalyst at an optimum temperature of 500°C in a semi-batch reactor. The test oil designated as WPO was analysed for its chemical composition and fuel properties. Detail about the reactor setup, the entire plastic to fuel conversion process, and GC-MS results of WPO are reported in our earlier paper (Das et al., 2021b).

WPO blended diesel was prepared by the splash blending technique used in the engine performance. Five different fractions (10%, 15%, 20%, 25% and 30%) of the WPO are mixed with diesel to obtain the fuel blend. These five blends are denoted as WPO10, WPO15, WPO20, WPO25, and WPO30, where the numbers denote the fraction of WPO and diesel in the volume fraction available in the fuel mixture).

2.2 Test engine specification and engine testing

The test engine comprised of a four-stroke, single-cylinder, and direct injection Kirloskar made system. The engine is facilitated with a water cooling system having a power rating of 3.5 kilo-watts at 1,500 engine rpm. The test engine is well equipped with calibrated rotameter and calorimeter to measure the rate of flow and heat loss respectively. Multiple thermocouples are employed in different parts of the engine for the measurement of inlet and exit temperatures of water and exhaust gas. The engine is linked to an AC dynamometer for the measurement and control of engine loads. All the sensors are connected to the data acquisition system. The instrumentation facilities provided in the experimental system layout are illustrated in Figure 1.

Figure 1 Schematic layout of the test engine



The load tests were conducted by fuelling the engine with neat diesel, WPO10, WPO15, WPO20, WPO25, and WPO30 at the steady crank speed of 1,500 rpm and 100% of rated loading, with no engine design alterations for preventing engine damage and fuel injection troubles. Engine idling was initiated with diesel and further switched over to different blended test fuels to record the experimental data.

2.3 Error and accuracy measurements

The operational errors associated with different parameters incurred during experimental studies are calculated in this part. The least possible errors for output results are anticipated by relying upon the calibration of the test instruments and accuracy of measurement. Since a measured quantity (M), is dependent on independent variables (i.e., X_1, X_2, X_3 … X_n), the measured error in the assessment of M is expressed by using the following equation (1),

$$\frac{\partial M}{M} = \left\{ \left(\frac{\partial X_1}{X_1} \right)^2 + \left(\frac{\partial X_2}{X_2}^2 \right) + \ldots + \left(\frac{\partial X_n}{X_n} \right)^2 \right\}^{\frac{1}{2}} \tag{1}$$

where $\left(\frac{\partial X_1}{X_1} \right), \left(\frac{\partial X_2}{X_2} \right)$, denotes errors associated with independent variables. ∂X_1 and X_1 represent the accuracy of measurement and least value of the output of the instrument throughout the test.

The range, accuracy and uncertainties of the apparatus associated with measurements such as dynamometer, fuel indicator, manometer were considered as (0–100 kg ± 0.01 kg ± 0.2), (0–100 cc ± 0.01 cc ± 1) and (0–50 mm ± 1 mm ± 1), respectively. The engine speed was maintained in the range of 0–1,000 rpm with ± 10 rpm accuracy and ±0.1% uncertainties. The cylinder pressure was maintained in the range of 0–345.5 bar with an accuracy of ±0.1 bar and ±0.1% uncertainties. In addition, the crank angle encoder was calibrated in the range of ±0.5 CA with uncertainties of ±0.2%.

2.4 Thermo-economic study

Thermo-economic study involves a combined analysis of governing laws of thermodynamics implicated in economic aspects. The prime objective of such economic analysis is to provide extensive information related to thermodynamics beyond the conventional approach. The present work focuses on the economic analysis of test engines with the aid of average cost theory and an exergy rate of costing approach used to allocate costs to different types of exergy related to engine performance. The information accessible during thermo-economic analysis regarding costing and performance of the thermodynamic system maybe employed for trade-offs among the economy of fuel, engine efficiency, and environmental sensitivity (Das et al., 2021b; Bejan et al., 1995).

2.5 Fuel energy analysis

The energy analysis of fuel is carried out to establish the importance of thermodynamics principles in explaining different types of energy liberated during the engine combustion process. Control volume theory in a thermodynamic system study explicates the importance of the energy generated and consumed in a system (Bejan et al., 1995). The test fuels obtained by pyrolysis methods are composed of aliphatic and aromatic hydrocarbons structured containing a small amount of oxygen. Stochiometrically standardised A/F mixture is also required to achieve improved combustion. The governing principles of any thermodynamic open system were enumerated in our previous works (Das et al., 2020, 2021a).

For a thermodynamically steady energy system, the molar fuel energy equilibrium may be stated as (neglecting potential energy and kinetic energy) (Cengel and Boles, 2007)

$$\frac{\dot{Q}_{in}}{\dot{n}_f} - \frac{\dot{W}_{out}}{\dot{n}_f} = \overline{h_p} - \overline{h_p} = \sum_{product} n_{out}\left(\overline{H_f^o} + \overline{\Delta H}\right)_{out} - \sum_{reactank} n_{in}\left(\overline{H_f^o} + \overline{\Delta H}\right)_{in} \tag{2}$$

The total quantity of energy derived through the combustion of fuel during a complete power cycle is partially employed for brake power and the remaining part of the energy is allocated as various forms of energy losses.

2.6 Fuel exergy analysis

The exergy analysis of fuel explains the degree of degradation of energy in quality and eventually reaching a balanced state with surroundings. During exergy analysis, the primary state is taken specifically with the final system attained thermodynamic equilibrium with the surroundings, termed as a dead state.

The exergy rate of any thermodynamic system can be expressed as; rate of change in exergy = rate of fuel exergy transfer – rate of exergy destruction

$$\frac{\Delta E_{Syst}}{dt} = \left[\dot{E}_{in} - \dot{E}_{out}\right] - \dot{E}_{dest} \tag{3}$$

Fuel exergy, shaft exergy, cooling exergy, exhaust exergy, and exergy of destruction are evaluated for the test fuels. The utmost power output is attained in a reversible process with an exhaust stream at a dead end.

The exergy efficiency can be expressed as follows:Z denote

$$\eta = \frac{\dot{E}_{work}}{\dot{E}_a + \dot{E}_f} \tag{4}$$

2.7 Fuel economy analysis

For a balanced condition control volume of a test engine, the fuel economic equilibrium equation can be expressed as (Meisami et al., 2018)

$$\sum \dot{C}_f + \dot{C}_W = \dot{C}_Q + \sum \dot{C}_g + \dot{Z} \tag{5}$$

The above correlation consists of $\dot{C}_w$ and $\dot{C}_q$ which point out cost rates of work done and heat transfer.

$$\dot{Z} = \dot{Z}_{CI} + \dot{Z}_{OM} \tag{6}$$

where, $\dot{Z}$ denotes total of the rate of assets investments $\left(\dot{Z}_{CI}\right)$ and operating and maintenance $\left(\dot{Z}_{OM}\right)$ expenditures.

The rate of principal investment is described by the ratio of yearly input of principal investment cost per number of time units of system function per year.

$\dot{Z}$ can be computed from the subsequent equation (Barzegar Avval, 2011)

$$\dot{Z} = \frac{Z\ X\ CRF\ X\ \varphi}{N\ X\ 3600} \tag{7}$$

where Z is taken as procurement cost of test engine in terms of US dollars with φ as a maintenance issue, indicates a deficiency of comprehensive information, assumed to be 1.06 (Massardo and Scialo, 2000). N is regarded as yearly engine operating hours, assumed to be 1,200 hours per year. So, the capital recovery factor (CRF) can be calculated by the subsequent equations (Meisami et al., 2018).

Assuming the annual rate of interest as 20% (i = 0.2) and the monthly compounding rate (p = 12), the successful return rate and capital return aspect were calculated to be 21.93% and 23.1%.

To calculate this value, an average international price per unit mass of fuel for a life span of 2005–2020 (15 years) was regarded as the price of diesel fuel and WPO with diesel. Thus, the average prices of the fuels are 1.34 the US dollars ($) and 0.47 the US dollars ($) per kg for diesel and WPO, respectively (US yearbook 2016).

2.8 Fuel sustainability analysis

Sustainability is associated with the synergy of environmental, economic, and social characteristics involved with an effective energy conversion system for the comprehensive improvement imparting responsibility for better energy management. The ecological effects and lower production costs are considered prime features for performing sustainability analysis (Aydin et al., 2012). In the current study, the sustainability analysis is done by estimating the sustainability index, the sustainable cost index (SCI), and the economic profits of improvement potential.

2.8.1 Sustainability index for test fuels

The SI evaluates the rank of sustainability for both individual fuel and fuel mixtures. The value assigned to the SI lies in between the range of 0 to ∞. The higher sustainability of fuel efficiency indicates lower exergy destruction and exergy losses from any combustion system. The energy system producing high exergetic efficiency signifies a reduction in the environmental effect and subsequently raises the SI value (Sahu et al., 2018). Exergy analysis facilitates establishing efficiency enhancements and control in the thermodynamic irreversibility related to the combustion process. In addition, the SI of any thermal system explains the significant impact of exergy value on the environment (Balli and Hepbasli, 2014). The SI can be evaluated as follows:

$$SI_n = \frac{1}{DN_n} = \frac{\dot{E}_F}{\dot{E}_D + \dot{E}_{loss}} = \frac{\dot{E}_F}{\dot{E}_F - \dot{E}_W} = \frac{1}{1 - \eta_{II,n}} \tag{8}$$

where, SI is designated as the fuel SI and DN as depletion number, which is taken as the integral of exergy destruction and other exergy loss.

2.8.2 Sustainable cost index (SCI) for test fuels

It is measured as the ratio of the unit exergy cost of fuels $\left(\dot{C}_f\right)$ to the SI. The SCI can be evaluated as follows:

$$SCI_n = \frac{\dot{C}_{f,n}}{SI_n} = \dot{C}_{f,n} * \left(1 - \eta_{II,n}\right) \tag{9}$$

Here, SCI_n is designated as the SCI for n_{th} type of the fuel mixture. The significance of SCI is to correlate the cost flow with the exergetic efficiency of different fuels. It depends upon the unit exergy $\left(\dot{C}_f\right)$ and *SI*. The higher value of SCI indicates higher exergy cost and lower SI with lower exergetic efficiency of the fuel.

2.8.3 Economic profits of improvement potential (EPIP) for test fuels

The EPIP value represents the probability of economic profit by the improvement potential rate of exergy of destruction and exergy loss rate of fuels. The EPIP of fuels is expressed as follows:

$$EPIP_n = \dot{C}_{P,n} * IP = \dot{C}_{P,n} * \left(1 - \eta_{II,n}\right) * \left(\dot{E}_D + \dot{E}loss\right) \tag{10}$$

3 Results and discussion

3.1 Test fuel composition and fuel properties

The major chemical components of the oil are saturated and unsaturated hydrocarbons with a carbon chain range from C10 to C18. The major components are 3,7-dimethyl-2-octene, 2,5,5-trimethylheptane, 4-methyl decane, 2,3,7-trimethyl-2-octene, 7-methyl-4-undecene, 2,4-dimethyl-2-decene, 7-methyl-1-undecene, 2,2-dimethyl-3-decene, 1-dodecene, 1,5-diethyl-2,3-dimethylcyclohexan, 2,3,5,7-tetramethyl-2-octene and 1-octadecene. The physical properties of pyrolysis oil and different blend with diesel are summarised in Table 1.

Table 1 Different fuel properties of WPO blended diesel

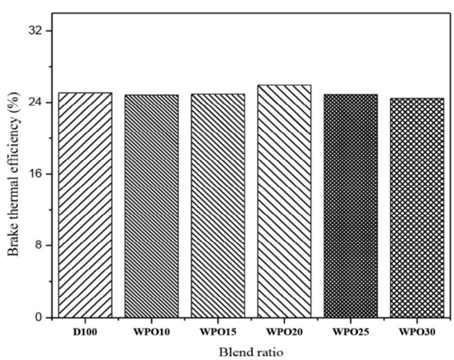
Test fuels	*Volumetric concentration, (%)*		*Fuel Density at 15°C (g/m³)*	*Flash point (°C)*	*Fire point (°C)*	*Gross calorific value (MJ/kg)*	*Kinematic viscosity (cSt) at 30°C*
	Diesel	*WPO*					
Diesel	100	-	835	52	57	45	2.15
WPO10	90	10	830.8	47.3	52.2	45.1	2.31
WPO15	85	15	828.7	44.95	49.8	45.15	2.39
WPO20	80	20	826.6	42.6	47.4	45.2	2.47
WPO25	75	25	824.5	40.25	45	45.25	2.55
WPO30	70	30	804.34	37.69	41.96	45.73	3.31

This study estimates three major outcomes of thermo-economic analysis such as energy, exergy, and economics. The energy analysis results in BSFC and BTE, whereas exergy analysis results in exergetic efficiency and rate of exergy destruction, and in the conclusion part, the cost rates of fuel, work losses, and exergy destruction for different WPO diesel blends are stated as the economic results.

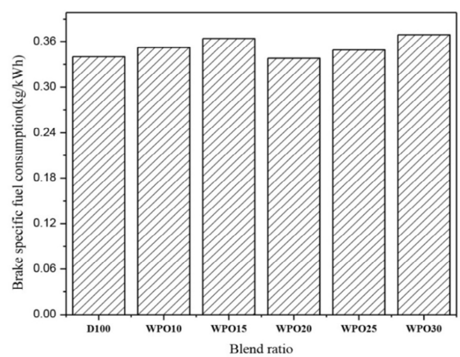
3.2 Engine performance

Figure 2(a) exhibits the effect of various blends of WPO with diesel on the thermal efficiency of the engine. It is clear from the graph that the thermal efficiency of the engine increases with an increase of WPO concentration in fuel mixture up to 20% by volume and decreases on further increment. The brake thermal efficiency is 25.08% at maximum load for diesel fuel. It is found that the efficiencies for WPO10, WPO15, WPO20, WPO25, and WPO30 fuel mixtures are having minimum and maximum values of 24.46% and 25.91% respectively. The reason for the higher efficiency of blended fuels is owing to the higher heating value of WPO and its mixtures in comparison to diesel. However, further addition of WPO in fuel mixture reduces thermal efficiency which is due to superior density and viscosity of blended fuels resulting in poor fineness of atomisation. Figure 2(b) illustrates the effect of various mixtures of WPO with diesel on the BSFC of the engine. The BSFC is 0.34 kg/kWh at maximum load for diesel fuel. It can also be observed that the efficiencies for WPO10, WPO15, WPO20, WPO25, and WPO30 fuel mixtures are having minimum and maximum values of 0.341 kg/kWh and 0.364 kg/kWh respectively. Enhancement of the volume of WPO in fuel mixtures raised an increment of fuel calorific value resulting in lower consumption of fuel to produce equivalent power from the test engine as compared to diesel. In addition, the superior density of WPO facilitates a better mass of fuel injection that leads to increasing brake-specific fuel consumption for fuel mixtures in comparison to diesel.

Figure 2 (a) BTE and (b) BSFC of different WPO diesel blends



(a)

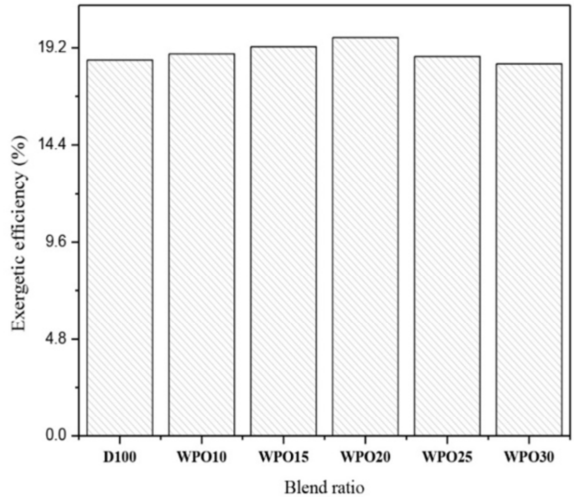


(b)

3.3 Exergetic efficiency of different blends of WPO

Figure 3 shows the effect of different blends of WPO with diesel on the exergetic efficiency of the engine. The exergetic efficiency followed a similar trend as BTE. The exergetic efficiency of different blended fuels is found to increase with the increase in the concentration of WPO in diesel up to 20% and decrease on further blending. WPO at 20% blend with diesel showed 6.92% higher exegetic efficiency than that of diesel. The higher calorific value of WPO attributed to higher BTE and lower BSFC and subsequently improved the exergetic efficiency in comparison to diesel.

Figure 3 Exergetic efficiency of WPO diesel blend



It has also been observed that though the fuel exergy of WPO is higher as compared to diesel, the exergy efficiency is maximum for 20% WPO, followed by 10% WPO, 0% WPO (pure diesel), 25% WPO, 30% WPO and 15% WPO. This may happen due to higher fuel exergy input at 20%WPO as compared to diesel.

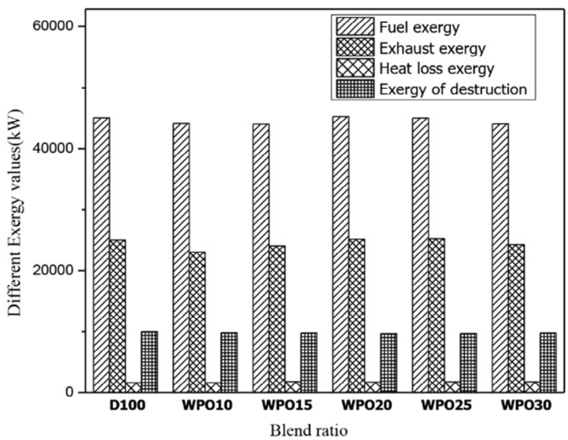
3.4 Various exergetic values of WPO blended diesel fuels

Rate of fuel exergy, heat loss exergy, exhaust exergy, and destructive exergy are depicted in Figure 4. Fuel exergy increases with the increase of WPO blend up to 20% and marginally declines on further add up to 30% of WPO by volume with diesel owing to irreversibility in combustion, mechanical friction, and fuel mixing. From Figure 4, it is evident that the fuel exergy of WPO20 is maximum and highest by 6.7% to that of diesel. It is higher than other blends of WPO with diesel by 2.23%, 2.56%, 5.96%, and 8.59% for WPO10, WPO15, WPO25, and WPO30 respectively. Fuel exergy rate is a function of the mass flow rate, heating value of fuel, and chemical exergy factor (Rosen et al., 2008). The reason for higher fuel exergy is due to the higher calorific value of WPO as compared to diesel.

The exhaust exergy also follows the same trend and increases with the increasing concentration of WPO in diesel blends. The higher exhaust gas exergy in the blends is due to an increase in the exhaust gas temperature and rate of fuel consumption (Aghbashlo et al., 2015). Total heat loss exergy of all fuels is found higher than diesel irrespective of the concentration of blend. It was found that the total heat loss is increased by 13.2%, 15.84%, 15.96%, 20.59%, and 21.51% for WPO10, WPO15, WPO20, WPO25, and WPO30 blend of fuel respectively in comparison with diesel. This could be related to higher heating value and higher viscosity of WPO as compared to diesel.

Exergy of destruction depends on some important factors including rate of heat transfer, fuel exergy, exhaust exergy, and turbulence in the fuel mixing process (Das et al., 2021a). It was also observed from the graph that the exergy of destruction rises with an increment in the concentration of WPO in diesel blends as shown in Figure 4. It can be observed that the exergy destruction of diesel is increased by 2.22%, 5.47%, 7.89%, 11.22%, and 17.11% for WPO10, WPO15, WPO20, WPO25, and WPO30 blends of fuel respectively in comparison with diesel.

Figure 4 Different exergy values of WPO blends



The cost rate of exergy destruction is exhibited in Figure 4. The cost rates of losses and exergy destruction are quite proportionate to the cost rate of fuel. As the percentage of WPO in the blends increases, the fuel cost declines, but the rate of losses and exergy destruction enhances.

3.5 Cost analysis of different WPO-diesel blended fuels

The cost-effectiveness of WPO compared to diesel makes fuel cost reduction with rising WPO concentration. Conversely, the BTE increased and BSFC decreased with the increment of the WPO blend fraction. Considering all such parameters, there is an increment in fuel cost in anticipation of attaining the highest value at WPO20 and then reduces with superior blends of WPO, as depicted in Figure 5. It shows power generation at a low price at the expense of a lower cost of fuel. It can be seen from Figure 5 that, the cost rate of power follows the analogous trend to the cost rate of inlet fuel. The engine exergy losses are measured when different losses are encountered by transfer of heat at different engine positions such as cylinder wall, exhaust gases, and exergy of destruction. So, the cost incurred with different exergy losses is depicted in Figure 5.

The lower price of WPO than diesel leads to fuel cost reduction with increasing WPO concentration. Conversely, the specific fuel consumption increased with the increase of the WPO blend ratio, as discussed in Figure 2(b). Combined, these two factors lead to decreases up to WPO20, as shown in Figure 5. The lower fuel price leads to the lower price of power generation. Thus, the cost rate of power follows a similar trend to the cost rate of inlet fuel. The main terms of engine exergy losses are heat transfer from the cylinder wall, exhaust gases, and exergy destruction, of which the last one is most important.

The cost rates of losses and exergy destruction are directly proportional to the cost rate of fuel. As the percentage of WPO in the blends increases, the fuel cost decreases up to

WPO 20, but the rate of losses and exergy destruction increases. Combined, these effects lead to a maximum value in WPO20 for both the cost rates of losses and exergy destruction.

Figure 5 Different cost ratings of WPO blends

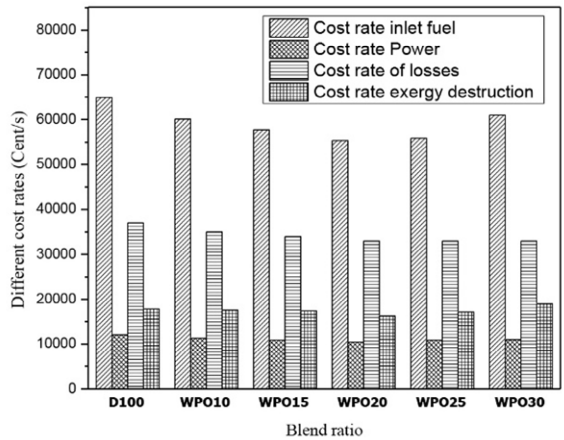
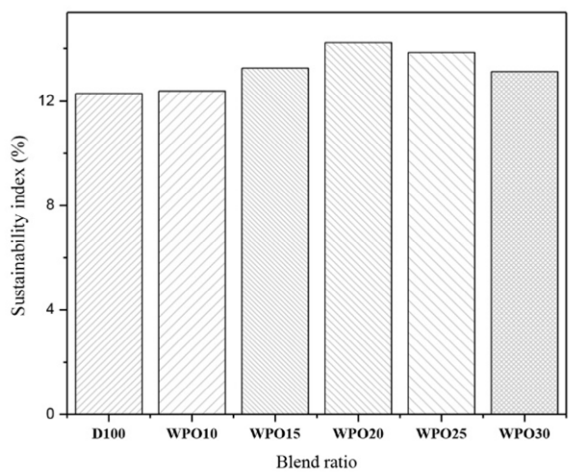


Figure 6 Sustainability index for different blends



3.6 Sustainability analysis of fuel mixtures

The assessment factors for better sustainability include the SI, SCI, and the economic profits of the improvement potential rate (EPIP). From such analysis, the significance of WPO has been performed and shown in Figures 6, 7 and 8. The SI is directly related to the exergy efficiency of the engine. Therefore, the effect of operating parameters showed similarity with their effects on the exergy efficiency under the same operating conditions. From Figure 6, it is evident that the SI for WPO20 reached maximum value as compared to other fuel mixtures. This is due to higher exergetic efficiency contributing to better performance and lesser environmental impact. Figure 7 shows, the highest values of SCI for diesel and decreases gradually after blending with WPO. The lowest value of SCI is found at WPO 20 and increases on further blending. The economic profit of the improvement potential of different fuels is shown in Figure 8. It shows that values of EPIP increase by increasing the blending of WPO with diesel. The increment in EPIP is due to higher exergy destruction and other exergy losses.

Figure 7 Sustainable cost index for WPO-diesel blend

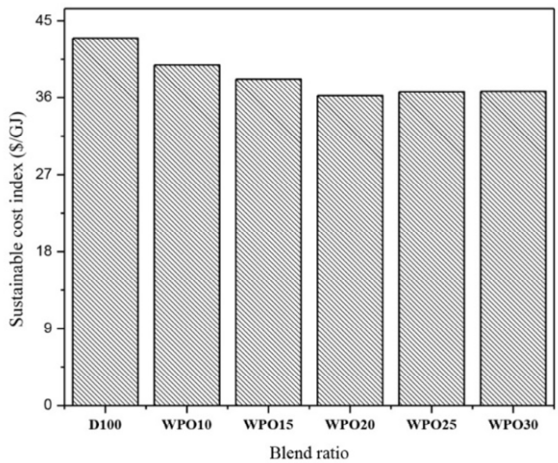
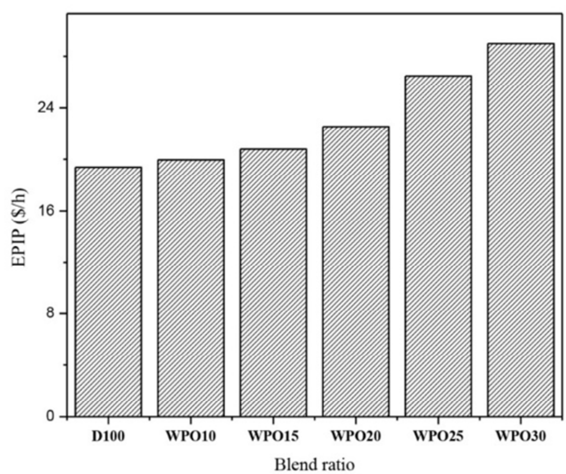


Figure 8 EPIP for WPO-diesel blends



4 Conclusions

Energy, exergy and economic analysis of CI engine fuelled with WPO blended diesel was carried out and presented in this paper. Experimental method and analytical methods were adopted to find performance in the present case having maximum volume range WPO as 30%. The thermodynamic analysis explained the highest values of energy and exergy efficiencies found at WPO20 fuel mixtures are 25.91% and 68.89%, respectively as compared to diesel. The lowest values of BSFC and exergy of destruction were also found atWPO20. Under economic analysis, it was revealed that the most cost-effective condition occurred at the fuel combination of WPO20. The sustainability analysis recommended the use of WPO with diesel at an optimum blend of 20% due to the highest SI value. SI value was agreed with WPO20 due to the lower cost rate of power production and EPIP exhibited an increasing trend of economic profit by the addition of WPO with diesel. Hence, WPO blended diesel could be used for CI engines for reducing waste for sustainable progress.

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