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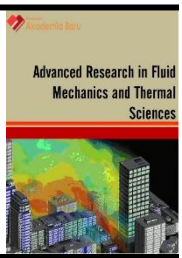

Exergy and Energy Analysis of Diesel Engine Fuelled with Diesel and Diesel – Corn Oil Blends

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ABSTRACT

Exergy and energy analysis of diesel engine fuelled with pure diesel and diesel – corn oil blends are the focus of this study. The analyses were carried out by using the results of experiments of fuels for different engine speeds. The obtained results revealed that the input exergy and energy of diesel – corn oil blends were lower than of that of conventional diesel at the same conditions. The exergy destruction is the major fraction of fuel exergy lost. Moreover, the exergy destruction increases with an increased engine speed for both conventional and diesel – corn oil blends. The destructed exergy of the test engine operating on diesel – corn oil blends was higher than that of conventional. It has been determined that exergertic efficiency and thermal decreases as the diesel – corn oil blends content in fuel increase so the highest values of exergertic efficiency and thermal efficiency were obtained for the diesel fuel. It was also observed that the exergertic efficiency value is lower than that of the thermal efficiency under the same conditions. Results also showed the diesel – corn oil blends can be used as a substitute for diesel fuel.

1. Introduction

Nowadays, energy sources are among the main issues in the world. Gradual depletion of energy sources has been increased due to the increasing demand for energy. Fossil fuels are among the most important energy sources that have a large share for demand. Alternative fuels have used to gradually replace fossil fuels. Various fuel types such as hydrogen, biogas, biodiesel, and their blends have been used in engines as an alternative fuel in order to achieve better engine performance and lower fuel consumption [1-5]. Biodiesel is one of the various alternative fuels that considered as the most suitable fuel for combustion engines [3]. There are numerous studies on using biodiesel as alternatives fuels, which revealed similarity in properties for both diesel and biodiesel, for instance, calorific value, cetane number, liquid nature, readily availability and renewability. Moreover, these studies indicated there are undesirable properties such as lower volatility and high viscosity [4].

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Several types of vegetable oils have been used as alternatives fuels in combustion engines [6-11]. The emissions and performance of an internal combustion engine that fuelled with biodiesels have studied based on the first law of thermodynamics. Decreasing the fuel consuming fuel and raising efficiency is the aim of most studies. Therefore, the characteristic of a compression ignition engine should be studied in more detail than measuring only the specification of emission and performance. Researchers have found that the analysis of internal combustion based on the first law of thermodynamics is not enough due to ignoring irreversibility processes that cause the losses in the systems. These losses and its location in the diesel engines can be considered in exergy analysis that based on the second law of thermodynamics [12]. Exergy is defined as the maximum useful work that obtained for a system when its equilibrium occurs with reference dead state [13]. The energy and exergy analyses are essential for improving the performance of the diesel engine as well as to redesign new engines with higher performances. Thereby, several studies have dealt with performance, emissions optimization, and improvement of engines based on the exergy analysis.

Alkidas [14] examined experimentally the exergy and energy balances to a compression ignition engine. They found that the combustion process and heat transfer were the most main sources of irreversibility. Rakopoulos *et al.,* [15] introduced an investigation for the destruction of exergy in a diesel engine based on experimental data. Canakci and Hosoz [16] introduced a comparative investigation for energy and exergy analyses of a diesel engine. They observed that the exergy losses were associated with exhaust gases, combustion, and heat transfer. Azoumah *et al.,* [17] investigated the effect of palm and cotton oils – diesel blends on the performance under exergy analysis conditions. They found that the exergy analyses are a very important tool for calculating the optimum loads that can be supplied by diesel engines. They revealed that heavy fuels has higher entropy compared with light fuel. Tat [18] found that the exergetic efficiency of engine increase with the increase in cetane number and delay period. Santos *et al.,* [19] indicated that the performance of the diesel engine decreases with using sunflower as an alternative fuel. Açıkkalp *et al.,* [20] studied the performance of the engine using sunflowers fuels. They found that the exergy destruction decreases with a decrease in the engine speed and the behavior of performance of the engine has closer to that of the pure diesel.

Yamık [21] reported that sunflower methyl and ethyl ester can be used as fuels in diesel engines because he found that the performance of the engine with using sunflower methyl was similar that of the pure diesel. Meisami and Ajam [22] found that exergy destruction increases with using biodiesels in their experimental study of the engine performance at various biodiesel blends. Aghbashlo *et al.,* [23] introduced an exergy analysis using 5% biodiesel blends. They revealed that exergy factors depend on engine speed and load. They also found that the exergetic efficiency depends on engine speed. Yamin *et al.,* [24] dealt with the influence of the cooking – oil and regular diesel on the performance of the diesel engine. They found that the performance of the engine that fueled with regular diesel fuel was higher than that of biodiesel fuel at high engine speeds.

The findings of previous studies associated with the exergy and energy analysis of biodiesel fuel in diesel engines indicated that the exergy analysis remarkably has a significant effect on improving engines. Moreover, biodiesel fuel is an attractive alternative for fuel that shares decreasing the depletion of energy sources. In all previous studies, despite considerable studies that examine the various types of biodiesel fuel types in diesel engine, there are types of biodiesel and its percentage blends with pure diesel have not yet been studied extensively under exergy and energy analysis. As distinct from the other previous studies, energy and exergy analysis were considered to analyze the quality and quantity of a diesel engine, which fuelled with 8% corn oil -92% diesel and 15% corn oil – 85% diesel. In this manner, the effects of the various percentage of diesel – corn oil blends on the energy distribution, energetic efficiency, energy losses rate, and exergy destruction rate can be observed, i.e., the performance of the engine. Therefore, the aim of the study is to indicate the effect of various percentage of diesel – corn oil blends on engine performance under exergy and energy analysis. The structure of this paper includes the description of the fuel preparation, engine test, mathematical model, results and discussion. The results of heat loss rate, output power, exhaust energy rate, exhaust exergy rate, exergy power, exergy destruction and exergy rate through heat transfer were calculated, and the results were introduced by comparing each of exergy and energy parameters.

2. Engine Setup

In this work, 8% corn oil- 92% diesel blends (CB8) and 15% corn oil- 85% diesel (CB15) blends beside of the reference diesel were used. All types of fuels were prepared in the research laboratories and quality control of north Refineries Company. The properties of the diesel – corn oil blends and conventional diesel as shown in Table 1.

Table 1
Properties of the tested fuels

Test	CB15	CB8	Conventional diesel
Specific gravity @ 15.6 ^{0}C	0.8653	0.8512	0.8337
Color	1.0	1.0	1.0
Flash point ^{0}C	71	69	63
Pour point	-3	-3	-3
Viscosity (CST)@40^{0}C	3.81	3.65	2.98
Cetane	50.98	51.87	56.38

The properties of fuels types were calculated inside the laboratory by passing it through a series of tests that involve color test, flash point, distillation, viscosity, Cetane number, specific weight and pour test. The specific weight of the fuel sample was performed using manometer, which based on the American Petroleum Institute (API).

$$API = (141.5/Sg)-131.5 \quad (1)$$

where *Sg* is specific gravity. Lovibond Tint meter was used to measure color. The cetane number was measured for diesel – corn oil blends which were lower than that of pure diesel. The viscosity of all fuel types was also measured. It found that the viscosity for the pure diesel fuel is lower than of that diesel – corn oil blends. The flashpoint, viscosity test and pour test was carried out. The exergy and energy analysis were performed for four-stroke TD111 engine fueled with diesel – corn oil blends. The main specification of the engine as shown in Table 2.

TD115 a hydraulic dynamometer was coupled with a test to measure the load control and engine torque. Moreover, *TD114* instrumentation unit was used to measure many parameters. Consumption box viscous that was used to measure the air mass flow of the engine which was fixed with *TD114* instrumentation. Calibrated glass tube and stopwatch were used to measure the mass flow rate of the fuel. Type K thermocouples were used to measure the exhaust gases, inlet and outlet temperatures. Tachometer type Movistrobe was utilized to measure the engine speed. The schematic of the experimental set up is shown in Figure 1. Gas analyzer TD 156 was used to analyze the exhaust gases.

Table 2
Specification of the used engine

Type of engine	TD111 single cylinder
The No of stroke	4- stroke
bore	70mm
Stroke	60mm
Displacement volume	230 CC
Compression ratio	21:1
Mechanical efficiency	81%
Max. speed	3600 R.P.M
Max. power	3.5 kW

All the test of the engine was measured for the engine speeds 500 to 3000 r.p.m with an increment of 500 rpm. The tests were conducted for a sufficient amount of time to consume all the fuel from the previous test in order to start running the engine with a new type of fuel. Moreover, it was conducted the test until achieving the stabilizing of the conditions before the factors were a measure to achieve the accuracy for data test of the fuels. These procedures were repeated for all the fuel types. The exergy and energy analysis of the engine was performed based on the abovementioned measurement for all fuels types under similar condition.

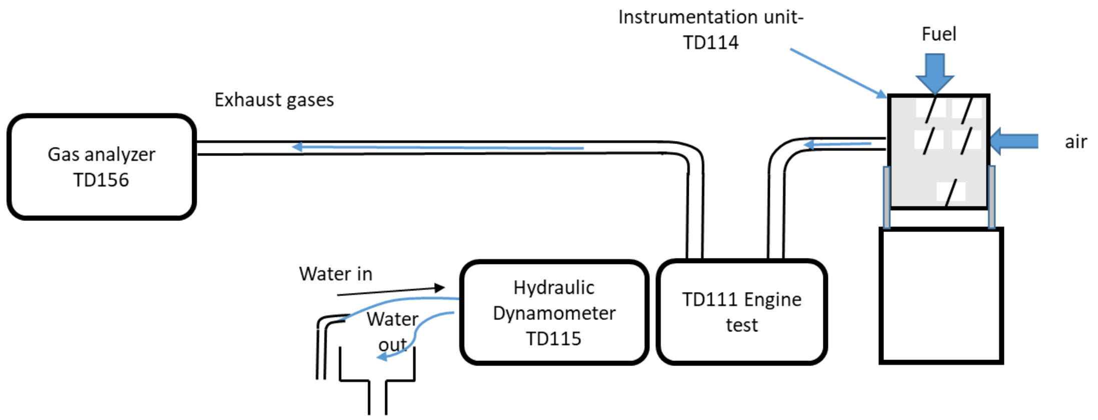

Fig. 1. Schematic diagram of the experimental setup

3. Engine Model for Energy and Exergy Analysis

While the energy analysis was carried out based on the first law of thermodynamics, the exergy analysis was based on the second law of thermodynamics. The schematic diagram of the engine balance was plotted to understand the energy balance of the test engine as shown in Figure 2. The air and fuel enter into the engine before mixes inside the combustion chamber. Before starting with exergy and energy analysis, assumptions were considered to simplify the calculations.

i. The gas mixture of all fuel types is an ideal gas.
ii. It was ignored the kinetic and potential energy of the exhaust gases and fuel mixtures [25].
iii. The reference environment conditions were assumed as in Reference with pressure P_0=1 atm and temperature T_0=25 °C.
iv. The energy losses rate of the engine and heat loss exit the control volume at a constant rate.
v. The combustion is complete and the exhaust gases are exit the control volume at pressure *Pp* and temperature *Tp*.

vi. The useful output of the engine is brake power.
vii. For both energy and exergy analyses, the engine was a steady-state open system.

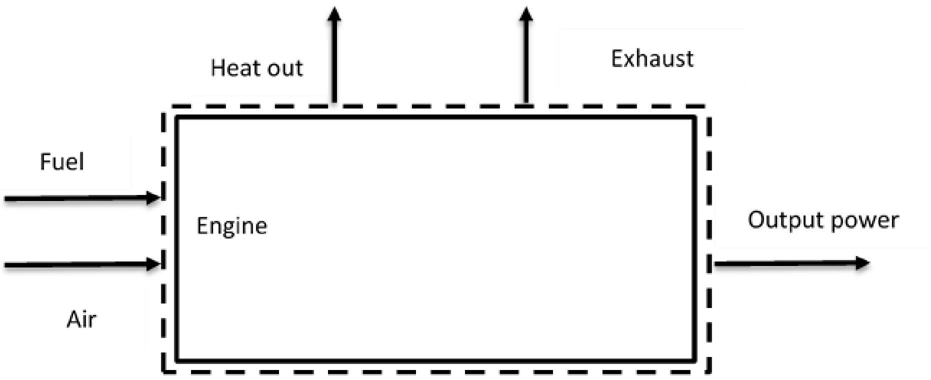

Fig. 2. Schematic the control volume of the engine test

The mass balance for the test engine as follows

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{2}$$

where $\dot{m}_{in}$ and $\dot{m}_{out}$ are the mass flow rate of the inlet and outlet respectively. The energy balance of the test engine was calculated as

$$\dot{Q} - \dot{W} = \sum \dot{m}_{out}\, h_{out} - \sum \dot{m}_{in}\, h_{in} \tag{3}$$

where $\dot{Q}$ and $\dot{W}$ are heat input rate and net work rate (output power) respectively while h_{out} and h_{in} are outlet and inlet specific enthalpy rate. The input energy ($\dot{E}$) was fuel energy that can be calculated based on the lowering heating value of fuel (Hu) and a mass fuel rate ($\dot{m}_{fuel}$) as follows

$$\dot{E} = \dot{m}_{fuel}.\, H_u \tag{4}$$

The output power was calculated based on the torque (*T*) and angular velocity of the engine $\omega\ (rad/s)$ as the following

$$\dot{W} = T.\omega \tag{5}$$

The losses energy ($\dot{Q}_{loss}$) from the system to the environment can be calculated as follows

$$\dot{Q}_{loss} = \dot{E}_{fuel} - \left(\dot{W} + \dot{Q}_{exh}\right) \tag{6}$$

where $\dot{E}_{fuel}$ is fuel energy rate. The rate of energy through the exhaust gases is defined as

$$\dot{Q}_{exh} = \sum \dot{m}_{out}\,\Delta h_{out} = \dot{m}_{CO}\Delta h_{CO} + \dot{m}_{CO_2}\Delta h_{CO_2} + \dot{m}_{NO}\Delta h_{NO} + \dot{m}_{NO_2}\Delta h_{NO_2} + \cdots \tag{7}$$

where $\Delta h_{out} = h - h_0$ and h_0 and h are the specific enthalpies of reference state and exhaust gases respectively. While the subscript CO, CO_2, NO, NO_2 are carbon monoxide, carbon dioxide, nitrogen monoxide, and nitrogen dioxide respectively. The ratio of the output power rate to the input (fuel) energy rate defined as the thermal efficiency (η) which can be estimated as

$$\eta = \frac{\dot{W}}{\dot{E}_{fuel}} \tag{8}$$

During any process, a fraction of energy is destroyed due to irreversibilities processes [26, 27]. Thereby, the exergy analysis was utilized to analysis to estimate these energy losses rate in the systems. However, the main assumptions of the energy analysis are also applied for exergy analysis. Thus, the exergy balance for the engine can be calculated as follows

$$\sum \dot{m}_{in}\, \varepsilon_{in} = \sum \dot{m}_{out}\, \varepsilon_{out} + \dot{E}x_{heat} + \dot{E}x_{work} + \dot{E}x_{dest} \tag{9}$$

where ε_{in} and ε_{out} are the input and output specific exergy while $\dot{E}x_{heat}$, $\dot{E}x_{work}$ and $\dot{E}x_{dest}$ are exergy losses rate through heat transfer, output power exergy, and exergy destruction rate respectively. The input exergy rate involves the chemical exergy of the input fuel, which can be estimated as

$$\dot{E}x_{in} = \dot{m}_{fuel}\, \varepsilon_{fuel} \tag{10}$$

The specific exergy of the fuel ε_{fuel} is estimated as follows

$$\varepsilon_{fuel} = H_u \varphi \tag{11}$$

The factor of chemical exergy(ϕ) is estimated as [28]

$$\varphi = 1.0401 + 0.1728\frac{h}{c} + 0.0432\frac{o}{c} + 0.2169\frac{a}{c}\left(1.216901\frac{h}{c}\right) \tag{12}$$

where *h, c*, *o* and *a* are the mass fraction of hydrogen, carbon, and oxygen and sulfur content of the fuel respectively. While $\dot{E}x_{work}$ is exergy work rate, which is calculated based on the rate of energetic work.

$$\dot{E}x_{work} = \dot{W} \tag{13}$$

The rate of exergy transfer refers to the heat transfer rate to the environment, which can be estimated as follows

$$\dot{E}x_{heat} = \sum \left(1 - \frac{T_0}{T_{cw}}\right) \dot{Q}_{loss} \tag{14}$$

where T_{cw} is the average of the cooling of outlet temperature (T_{cwout}) and inlet temperature (T_{cwin}) while T_0 is the temperature of dead state.

The exhaust exergy rate is calculated as follows

$$\dot{E}x_{out} = \sum \dot{m}_i\, (\varepsilon_{tm} + \varepsilon_{chem}) \tag{15}$$

where the exhaust specific thermo-mechanical exergy (ε_{tm}) is calculated as follows

$$\varepsilon_{tm} = (h - h_o) - T_o(s - s_o) \tag{16}$$

where *s* is the specific entropy of the exhaust gases, *h* is the specific enthalpy, T_0 is the environment (reference) temperature and the subscript zero denotes properties of the dead state. While ε_{chem} is the chemical exergy of the exhaust gases can be estimated as follows

$$\varepsilon_{fchem} = \bar{R}\, T_o \ln \frac{y_i}{y_r} \tag{17}$$

where $\bar{R}$ is the constant of gas y_i is the mole fraction of exhaust gases and y_r is the mole fraction of the given component in reference environment as 0.03450% CO_2, 0.00070% CO, 0.00020% SO_2, 3.03000% H_2O, 0.00005% H_2, 20.3500% O_2, 75.6700% N_2, and 0.91455% other gases [29].

The exergetic efficiency (η_e) is more accurate than that of the thermal efficiency which can be calculated as ratio exergy work rate to fuel exergy as follows [30]

$$\eta_{u} = \frac{\dot{E}x_W}{\dot{E}x_{fuel}} \tag{18}$$

4. Results and Discussion

4.1 Energy Analysis

In the energy analysis, the fuel energy rates, the losses energy rate, and energy rate of flow exhaust gases were calculated for all fuel types at different engine speeds. While, for the exergy analysis, the exergy destruction rate was also included in the calculations. All the obtained results were introduced in terms of conventional diesel and the volume percentage of diesel – corn oil blends at different speed engines (500 -3000 rpm).

Energy distribution for all fuel types was plotted to provide insight into how the energy distribution for the test engine. Figure 3(a), (b) and (c) illustrate the energy balance (Sankey) for all fuel types at 2500 r.p.m. It can be noticed that for the conventional diesel, the mean output power is 2.82 kW, the rate of energy losses through exhaust gases is 2.64 kW and the energy losses rate are 3.87 kW while energy input rate of the fuel was 9.33 kW. In terms of the percentage of the input energy rate, these were approximately 30.2% of the input energy rate was converted to output power while the energy losses rate was 41.5% of the input energy and energy transfer rate through exhaust gases was 28.296%. This trend is consistent with the finding results obtained by several studies such as Kul and Kahraman [31] Hoseinpour *et al.,* [32]. Those researchers found that approximately 30% of the input energy was converted to output power while the highest exergy was energy losses. Energy distribution for CB8 and CB15 were plotted to provide comprehensive information about the influence of fuel type on the energy fraction. As shown in figure (b) and (c) at engine speed 2500 rpm, the input energies rate of CB8 and CB15 were 9.08 kW and 8.9 kW that were slightly lower than of that of the conventional diesel as 2.06% and 4.6% respectively. Moreover, the output power for CB8 and CB15 was less than that of the conventional diesel as 5.6% and 10.2% respectively. The highest output power was observed to be 2.82 kW for the conventional diesel fuel while the lowest output power was measured to be 2.53 kW for CB 15 fuel. This explanation of this trend due to the decrease in the lower heating value for the blends of diesel – corn oil blends compared that of the conventional diesel, i.e., the fuel exergy rate for the diesel –corn oil blends is lower than that of the pure diesel [28].

It was also observed that the energy losses rate for CB8 and CB15 were higher than that of the conventional diesel as 4.18% and 8.08% respectively. The energy loss rate through exhaust gases for rate for CB8 and CB15 was lower than that of the conventional diesel. The trend is attributed to the several factors such as oxygen content of the fuel, exhaust temperature, viscosity of fuel and lower heating value. The abovementioned factors led to a drop in the energy of the exhaust gases for CB8 and CB15 respect to that of the pure diesel. Moreover, the exhaust energy and losses energy rate have also similar the trend for both diesel – corn oil blends and conventional diesel. These trends were consistent with previous studies, for instance, Kul and Kahraman [31] reported that for pure diesel, the value output power was 27.6% net power while and 52.39% of energy rejected to the environments and 19.99% of energy lost through the exhaust gases. In addition, they found that the losses energy rate of biodiesel is higher than that of the pure diesel.

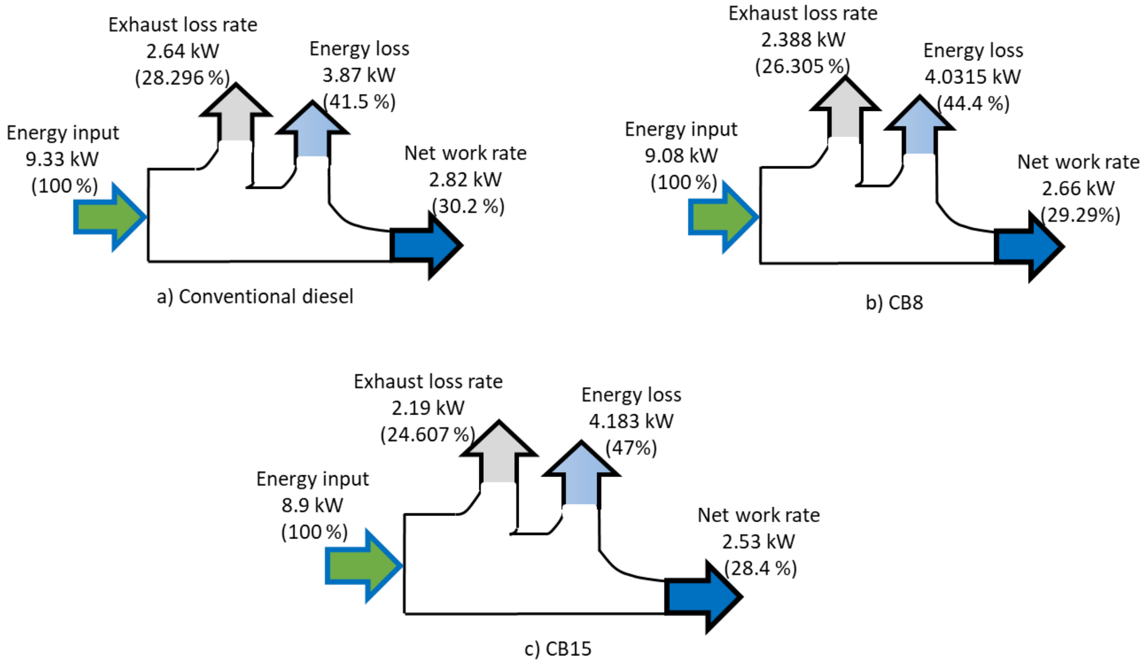

Fig. 3. Energy distribution of the engine fuelled with (a) diesel fuel (b) CB8 and (c) CB15 for the engine speed of 2500 rpm

Brake thermal efficiency is output power to the input fuel. Brake thermal efficiency for all fuels types was plotted together with engine speeds as shown in Figure 4. It can be noticed that the brake thermal efficiency firstly increases with increasing the engine speed before it decreased for all the fuel types. When comparing diesel – corn oil blends with conventional diesel, it has been determined that brake thermal efficiency decreases as the corn content in fuel increases so the highest power has been obtained for pure diesel at all the engine speeds. Where the thermal efficiency of pure diesel is higher than of that CB8 and CB15 as 0.91% and 1.8% for the corresponding engine speed of 2500 r.p.mm. The reason for low exergy efficiency was brake power of most of the diesel – corn oil blends is lower than that of the conventional diesel. This is also attributed to the decreasing in cetane number, which has an influence on increasing in the ignition delay, thereby brake power decreased for all the diesel – corn oil blends. This was proved by previous studies of [28, 31, 32].

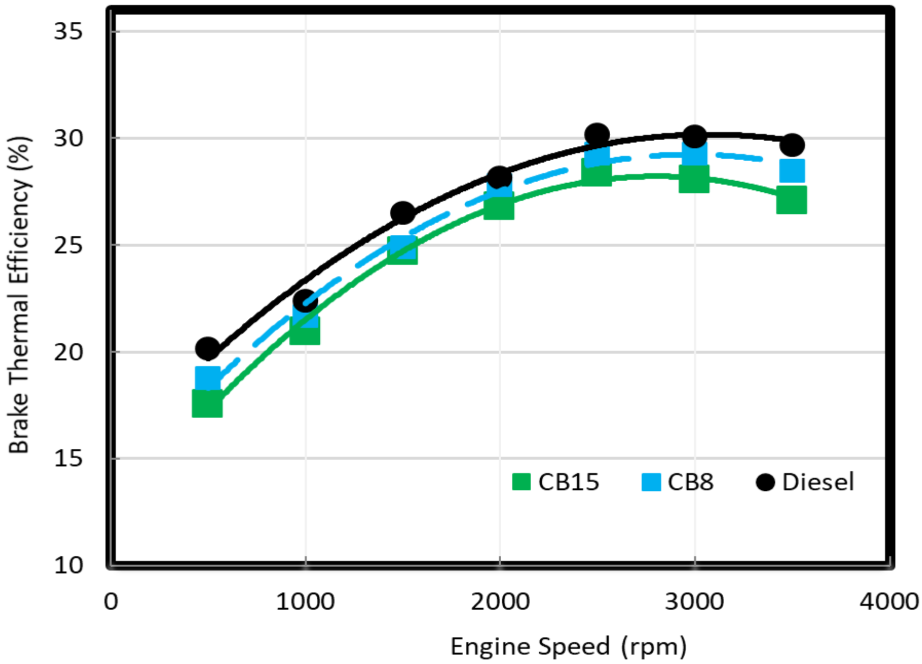

Fig. 4. Variation of brake thermal efficiency with engine speeds for fuel blends types

4.2 Exergy Analysis

A major part of the supplied energy to the engine is destructed due to the system irreversibility. Thereby, exergy analysis was utilized to deal with this energy losses rate of the system. Exergy analysis was performed by calculating exergies related to the input exergy, output power exergy, and exhaust exergy rate, exergy rate through heat loss and system destruction or irreversibility. The diagrams (Sankey) of exergy distribution were utilized to represent distribution for the input and output exergy. Figure 5(a), (b) and (c) show the diagram of exergy distribution of conventional diesel, CB8 and CB15 respectively at 2500 r.p.m. For the conventional diesel, the rate of output power was approximately 28.16% of the input exergy while exergy losses through the exhaust gases was 15.29% of input exergy, the rate of heat rejected is 7.05 % of input exergy and 49.48% of input exergy rate is lost as exergy destruction as shown in Figure 5(a). This behavior is consistent with previous studies such as Kul and Kahraman [31] Hoseinpour *et al.,* [32]. These studies showed that about 30% of the input energy was converted to output power while the most the input exergy was exergy destruction. Compared with the fuel energy rate, the exergy fuel rate for all fuel is higher than that of the fuel energy rate. This behavior due to the factor of chemical exergy that is greater than unity. Considering the fuel type, the diagram of exergy distribution deduced that the input exergies rate for conventional diesel, CB8 and CB15 were 10.01 kW, 9.74 kW and 9.54 kW respectively. This trend can be explained due to the lowering heating value of conventional diesel is higher than those of the CB8 and CB15, i.e., decreasing fuel consumption. Moreover, the trend of fuel exergy for pure diesel is the same as that of the CB8 and CB15. It can also be seen the output exergy for conventional diesel, CB8 and CB15 were 2.82 kW, 2.66 and 2.53 kW respectively. These figures also indicated that the exergy destruction of CB8 and CB15 was higher than that of conventional diesel fuel at 2500 r.p.m. It can be deduced that the exergy destruction is the major fraction of fuel exergy losses, which were 49.485%, 52.965% and 56.02% for the conventional, CB8 and CB15 respectively. Moreover, the highest exergy destruction was for CB15 fuel. This is explained due to the presence of additional oxygen atoms in the diesel – corn oil blends which lead to an increase in exergy destruction of the blends. This was also proved by the Kul and Kahraman [31] Hoseinpour *et al.,* [32] whose found that the exergy destruction for pure diesel was 51.60% and for other biodiesel blends were within the range 54.4% to 55.13%.

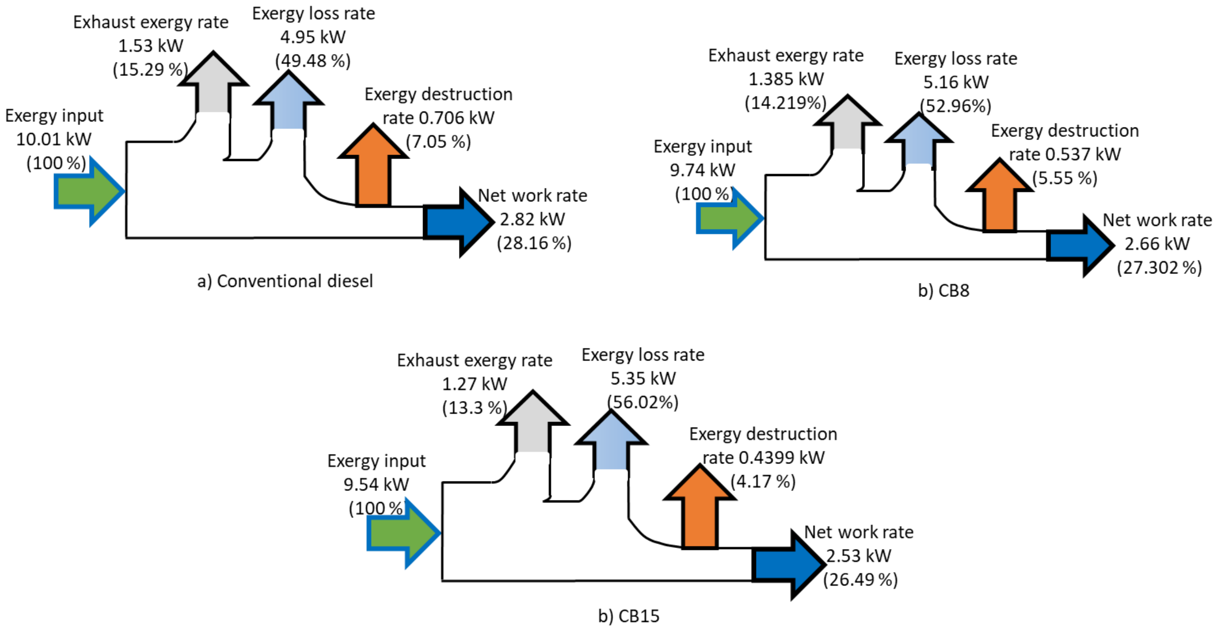

Fig. 5. Exergy distribution of the engine fuelled with (a) conventional diesel fuel (b) CB8 and (c) CB15 for the engine speed of 2500 rpm

When comparing fuel types in terms of the exhaust exergy rate, it has been determined that exhaust exergy rate decreases as the corn blend content in fuel increase so the highest exhaust exergy rate has been found for conventional diesel as can be seen shown in Figure 5(b) and 5(c). The explanation of these trends is explained by many factors like a decrease in viscosity and decrease in the lower heating value of diesel–corn oil blends. For the losses to the surrounding excluding exhaust, it was also observed that the rate of exergy loss through heat transfer of CB8 and CB15 was lower than that of the conventional diesel at the same engine speed of 2500 rpm. The lowest value of the exergies losses was observed for the exergies lost through heat transfer were approximately 7.05%, 5.55% and 4.17% for conventional diesel, CB8, and CB15 respectively. This difference between the pure diesel and corn –diesel blends occurred due to that the lower heating values of diesel –corn oil blends were less than that of the pure diesel fuel. As results, the fuel exergy of the pure diesel is greater than that of the diesel–corn oil blend. This trend was consistent with the previous results of Hoseinpour *et al.,* [32].

Rate of input exergy depends on the factor of chemical exergy beside of the mass flow rate and the lower heating value of fuel that affects the input energy. Thereby, the rate of fuel energy and exergy have a similar trend. Chemical exergy factor is greater than one, thus the value of fuel exergy rate greater than the fuel energy rate at the same conditions. Figure 6 illustrates that the fuel exergy rate increases as engine speed increasing for all fuels types. This is explained by the fact that the engine consumes more fuel with an increase in the engine speed. When evaluated in terms of the fuel type, the fuel exergy rates of CB8 and CB15 are lower than that of the pure diesel as 2.69% and 4.69% respectively at the corresponding speeds 2500 rpm. Moreover, the highest input exergy rate was obtained when a test engine with reference diesel at all speeds engine. While the lowest input exergy rate was obtained for the CB15. This explanation of this trend because the dropping in the lower calorific value of the diesel – corn oil blends, i.e., the energy input of the diesel – corn oil blends is lower than that of the conventional diesel. This behavior was consistent with previous studies of [16, 32].

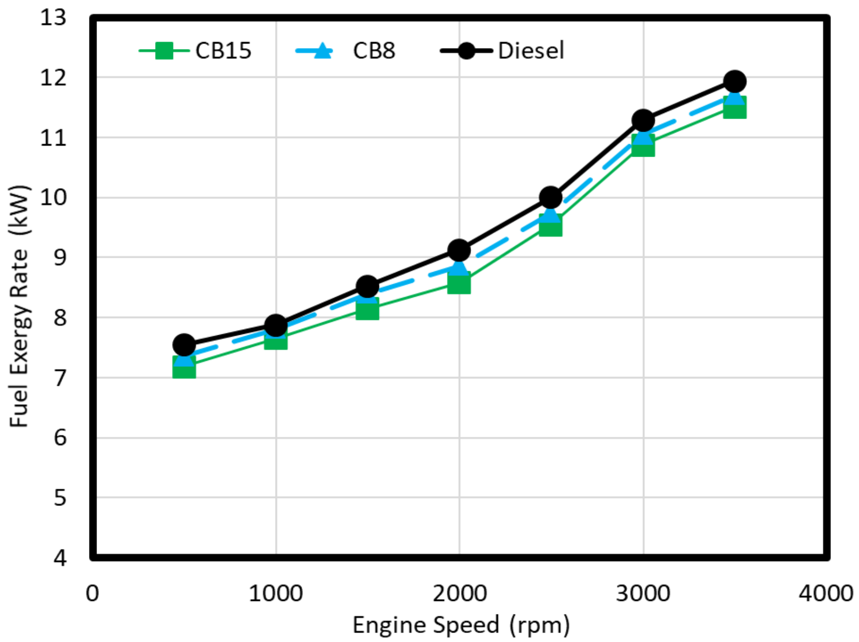

Fig. 6. The thermal efficiency versus the engine speed for all fuel types

A fraction of the input exergy is destructed due to many irreversible processes which involve the turbulence within the combustion chamber, the pressure drops, mixing of the air with fuel, gases expansion, etc. [33]. The rate of exergy destruction increases with the increase in the engine speeds for all fuel types as shown in Figure 7. This is explained due to the high irreversibility in the combustion process causes high values of exergy destruction. Moreover, the cylinder temperature and rate of fuel consumption increase with an increase in engine speed. It was also found that the exergy destruction of the CB8 and CB15 is slightly higher than that of the exergy destruction rate for pure diesel at all engine speeds. At 2500-rpm engine speed, the exergy destruction rate for the CB8 and CB15 increase as 4.2% and 8.08% compared with that of the conventional diesel. It can be observed that the behavior of exergy destruction rate indicated a similar trend with each other. This is explained by the fact the incomplete combustion, which occurred with diesel – corn oil blends i.e. dropping in combustion efficiency [34]. This trend was also consistent with Gogoi [35] who found that the rate of exergy destroyed for diesel fuel was lower than that of the exergy destroyed for biodiesel fuel.

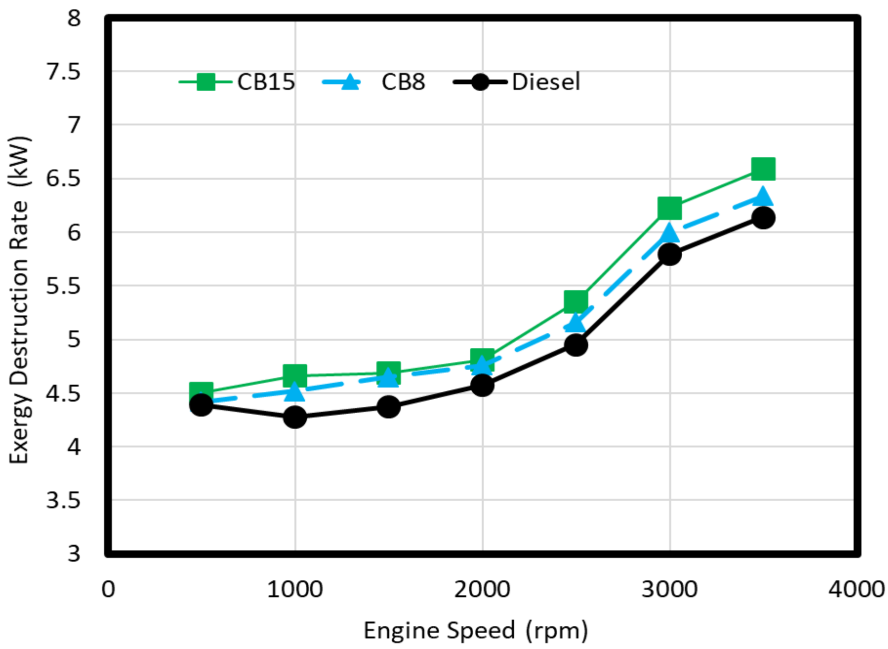

Fig. 7. Variation of exergy destruction of tested fuels with engine speed for all fuel types

The exergetic efficiency (Second law efficiency) is more accurate than the thermal efficiency and has used to measure the performance of the engines [28]. Figure 8 shows the exergetic efficiency firstly increases with the increase in the engine speed to the maximum value before again decreased for all the fuel types. It was determined for conventional diesel fuel, the exergy efficiency increased to 3000 rpm and decreased after 3000 rpm. It can be observed that the exergetic efficiency and thermal efficiency has similar behavior. Moreover, the exergetic efficiency is lower than that thermal efficiency at all engine speeds. The difference between thermal and exergetic efficiency was about 1.8%. The reason for dropping in exergetic efficiency was the conversion of small amounts of input exergy to the output power and the destruction most of the inlet exergy rate [22]. Moreover, when evaluated in terms of fuel types, the exergetic efficiency of pure diesel got the highest exergetic efficiency for all engine speeds. It can also be observed that the exergetic efficiency of conventional diesel is higher than that of the CB8 and CB15 as 0.86% and 1.67% respectively. This explanation of this behavior due to decreasing in the lower calorific value of the diesel – corn oil blends. The reason of low exergy efficiency was brake power of most of the diesel – corn oil blends is lower than that of the conventional diesel. The abovementioned finding was also agreed with the previous studies of [31, 36].

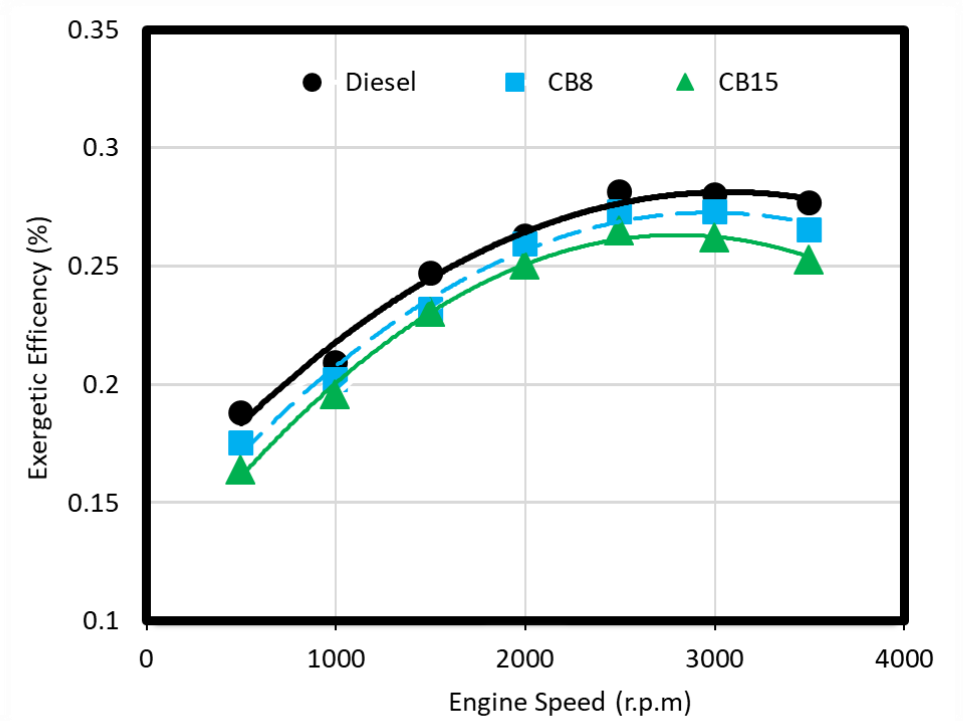

Fig. 8. The exergetic efficiency versus engine speed for all fuel types

5. Conclusions

In this study, the energy and exergy analysis of a diesel engine using conventional diesel, CB8 and CB10 were investigated. The experimental tests were performed at various engine speeds in order to indicate the energy and exergy distribution with changing the fuel type. The analyses were performed by estimating brake power, fuel energy rate, fuel exergy rate, exhaust exergy rate, heat losses rate, and exergy destruction. Moreover, exergetic efficiency and thermal efficiency were evaluated. It can be drawn from this study the following conclusions:

The fuel exergy increases with an increase in the engine speeds for both conventional and diesel –corn oil blends fuels. The Exergy destruction increase wit increase in the engine speed for both conventional and diesel-corn oil blends. The losses of exergy and energy transfer through exhaust gases for CB8 and CB15 fuel are lower than that of conventional diesel fuel. Moreover, the percentage of exergy and energy rate through heat transfer for CB8 and CB15 are lower than that of the conventional diesel. While the exergy destruction percentage of CB8 and CB15 are higher than this of conventional diesel fuels at different engine speeds. The outcomes result also indicated that the brake power of the conventional diesel was greater than that of the diesel-corn oil blends. This is a trend due to the decrease in the lowering heating value of the diesel –corn oil blends. It can be drawn that the engine speeds significantly influence exergy destruction, thermal efficiency, and exergetic efficiency. Considering the fuel types, the highest values of exergetic efficiency and thermal efficiency were obtained for the diesel fuel. It was also that the exergetic efficiency value was lower than that of the thermal efficiency under the same conditions. The explanation of this trend due to the exergy destruction, i.e., small amounts of fuel exergy was converted into work exergy. Furthermore, the trends of the results finding were consistent with the previous studies [26, 33]. According to the results of the outcomes of the energy and exergy analysis for the engine, as the engine speed increases, more quantity of fuel given to the engine was consumed by the engine.

The obtained results indicated that the major fraction of fuel exergy is exergy losses through exergy destruction. For this reason, eliminating destruction reasons is necessary when high efficiency is required. Furthermore, the exergy losses through the exhaust gases are second reason for exergy losses. For that reason, recycling exhaust gases is also essential for raising the exergetic efficiency. Moreover, exergy losses due to the heat transfer is another contributor in decreasing the output exergy power. Based on the exergy results, it can be concluded that engine optimization based on the exergy analysis can serve as an essential tool (together with energy analysis) for the engine design. It can also be concluded that form the finding results, the tested CB8 and CB15 offer competitive exergetic and thermal efficiency for conventional diesel fuel. Thereby, according to the outcomes of the results, CB8 and CB15 can be used instead of the conventional diesel fuel as a substitute fuel since both it has a similar energy and exergy distribution with that of the conventional diesel fuel.

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References
[1] Bart, Jan CJ, Natale Palmeri, and Stefano Cavallaro. *Biodiesel science and technology: from soil to oil*. Elsevier, 2010.
[2] Rahman, M. M., M. K. Mohammed, and R. A. Bakar. "Air fuel ratio on engine performance and instantaneous behavior of crank angle for four cylinder direct injection hydrogen fueled engine." *Journal of Applied Sciences* 9, no. 16 (2009): 2877-2886.
[3] Murugesan, A., C. Umarani, R. Subramanian, and N. Nedunchezhian. "Bio-diesel as an alternative fuel for diesel engines—a review." *Renewable and Sustainable Energy Reviews* 13, no. 3 (2009): 653-662.
[4] Agarwal, Avinash Kumar. "Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines." *Progress in Energy and Combustion Science* 33, no. 3 (2007): 233-271.
[5] Kamil, Mohammed, Khalid Ramadan, Abdul Ghani Olabi, Chaouki Ghenai, Abrar Inayat, and Mugdad H. Rajab. "Desert palm date seeds as a biodiesel feedstock: extraction, characterization, and engine testing." *Energies* 12, no. 16 (2019): 3147.
[6] Nazal, Ibrahim T., and Hussain H. Al-Kayiem. "Experimental characterization of diesel engine performance fuelled by various sunflower oil-diesel mixtures." *Journal of Applied Sciences* 12, no. 24 (2012): 2604-2609.
[7] Azad, Abul Kalam, M. G. Rasul, Mohammad Masud Kamal Khan, Subhash C. Sharma, and M. A. Hazrat. "Prospect of biofuels as an alternative transport fuel in Australia." *Renewable and Sustainable Energy Reviews* 43 (2015): 331-351.
[8] Efe, Şükran, Mehmet Akif Ceviz, and Hakan Temur. "Comparative engine characteristics of biodiesels from hazelnut, corn, soybean, canola and sunflower oils on DI diesel engine." *Renewable Energy* 119 (2018): 142-151.
[9] Nabi, M. N., and M. G. Rasul. "Influence of second generation biodiesel on engine performance, emissions, energy and exergy parameters." *Energy Conversion and Management* 169 (2018): 326-333.
[10] Kamil, Mohammed, Khalid Mustafa Ramadan, Omar I. Awad, Thamir K. Ibrahim, Abrar Inayat, and Xiao Ma. "Environmental impacts of biodiesel production from waste spent coffee grounds and its implementation in a compression ignition engine." *Science of the Total Environment* 675 (2019): 13-30.
[11] Kamil, Mohammed, Khalid M. Ramadan, Abdul Ghani Olabi, Abdallah Shanableh, Chaouki Ghenai, Amna K. Al Naqbi, Omar I. Awad, and Xiao Ma. "Comprehensive evaluation of the life cycle of liquid and solid fuels derived from recycled coffee waste." *Resources, Conservation and Recycling* 150 (2019): 104446.
[12] Ptasinski, Krzysztof J. *Efficiency of biomass energy: an exergy approach to biofuels, power, and biorefineries*. John Wiley & Sons, 2016.
[13] Li, Yaopeng, Ming Jia, Sage L. Kokjohn, Yachao Chang, and Rolf D. Reitz. "Comprehensive analysis of exergy destruction sources in different engine combustion regimes." *Energy* 149 (2018): 697-708.
[14] Alkidas, A. C. "The application of availability and energy balances to a diesel engine." *J. Eng. Gas Turbines Power* 110, no. 3 (1988): 462-469.
[15] Rakopoulos, C. D., E. C. Andritsakis, and D. K. Kyritsis. "Availability accumulation and destruction in a DI diesel engine with special reference to the limited cooled case." *Heat Recovery Systems and CHP* 13, no. 3 (1993): 261-276.

[16] Canakci, Mustafa, and Murat Hosoz. "Energy and exergy analyses of a diesel engine fuelled with various biodiesels." *Energy Sources, Part B* 1, no. 4 (2006): 379-394.
[17] Azoumah, Yao, Joël Blin, and Tizane Daho. "Exergy efficiency applied for the performance optimization of a direct injection compression ignition (CI) engine using biofuels." *Renewable Energy* 34, no. 6 (2009): 1494-1500.
[18] Tat, Mustafa Ertunc. "Cetane number effect on the energetic and exergetic efficiency of a diesel engine fuelled with biodiesel." *Fuel Processing Technology* 92, no. 7 (2011): 1311-1321.
[19] Santos, Bjorn S, Sergio C Capareda, and Jewel A Capunitan. "Sunflower methyl ester as an engine fuel : performance evaluation and emissions analysis." *ISRN Renewable Energy* 2013 (2013): 1–12.
[20] Açikkalp, Emin, Hasan Yamik, and Yakup İçingür. "Performance of a compression ignition engine operated with sunflower ethyl ester under different engine loads." *Journal of Energy in Southern Africa* 25, no. 2 (2014): 81-90.
[21] Yamık, Hasan. "Energetic and exergetic assessments of an internal combustion engine with sunflower ester blends." *International Journal of Exergy* 20, no. 4 (2016): 482-495.
[22] Meisami, Farshad, and Hossein Ajam. "Energy, exergy and economic analysis of a Diesel engine fueled with castor oil biodiesel." *International Journal of Engine Research* 16, no. 5 (2015): 691-702.
[23] Aghbashlo, Mortaza, Meisam Tabatabaei, Pouya Mohammadi, Navid Pourvosoughi, Ali M. Nikbakht, and Sayed Amir Hossein Goli. "Improving exergetic and sustainability parameters of a DI diesel engine using polymer waste dissolved in biodiesel as a novel diesel additive." *Energy Conversion and Management* 105 (2015): 328-337.
[24] Yamin, Jehad A., Eiman Ali Ehsan Sheet, and Ismail Hdaib. "Exergy analysis of biodiesel fueled direct injection CI engines." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 40, no. 11 (2018): 1351-1358.
[25] Sayin, C., M. Hosoz, M. Canakci, and I. Kilicaslan. "Energy and exergy analyses of a gasoline engine." *International Journal of Energy Research* 31, no. 3 (2007): 259-273.
[26] da Costa, Yoge Jeronimo Ramos, Antonio Gilson Barbosa de Lima, Celso Rosendo Bezerra Filho, and Laerte de Araujo Lima. "Energetic and exergetic analyses of a dual-fuel diesel engine." *Renewable and Sustainable Energy Reviews* 16, no. 7 (2012): 4651-4660.
[27] Kotas, Tadeusz Jozef. *The exergy method of thermal plant analysis*. Elsevier, 2013.
[28] Hürdoğan, Ertaç. "Thermodynamic analysis of a diesel engine fueled with diesel and peanut biodiesel." *Environmental Progress & Sustainable Energy* 35, no. 3 (2016): 891-897.
[29] Moran, J. M., and N. H. Shapiro. "Fundamental of Engineering Thermodynamics. New York: John Willey & Son." (1988).
[30] Çengel, Yunus A., and Michael A. Boles. *Thermodynamics: an engineering approach,-PDF*. McGraw-Hill, 2008.
[31] Sayin Kul, Bahar, and Ali Kahraman. "Energy and exergy analyses of a diesel engine fuelled with biodiesel-diesel blends containing 5% bioethanol." *Entropy* 18, no. 11 (2016): 387.
[32] Hoseinpour, Marziyeh, Hassan Sadrnia, Mohammad Tabasizadeh, and Barat Ghobadian. "Energy and exergy analyses of a diesel engine fueled with diesel, biodiesel-diesel blend and gasoline fumigation." *Energy* 141 (2017): 2408-2420.
[33] Zheng, Junnian, and Jerald A. Caton. "Second law analysis of a low temperature combustion diesel engine: effect of injection timing and exhaust gas recirculation." *Energy* 38, no. 1 (2012): 78-84.
[34] Şanli, Bengi Gözmen, and Erinç Uludamar. "Energy and exergy analysis of a diesel engine fuelled with diesel and biodiesel fuels at various engine speeds." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* (2019): 1-15.
[35] Gogoi, Tapan Kumar. "Exergy analysis of a diesel engine operated with koroch seed oil methyl ester and its diesel fuel blends." *International Journal of Exergy* 12, no. 2 (2013): 183-204.
[36] Gharehghani, A., Hosseini, R., Mirsalim, M. and Yusaf, T.F. "A comparative study on the first and second law analysis and performance characteristics of a spark ignition engine using either natural gas or gasoline." *Fuel* 158, (2015): 488-493.