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Thermodynamic Investigation of a Modified Compression Ignition Engine Fueled by Diesel – Biodiesel – Ethanol Blends

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ABSTRACT

The present study contrasts the thermodynamics analysis of modified diesel engines with traditional diesel engines. Thermodynamics study is done by the use of energy and exergy analysis for diesel, B20 (blend of 80 per cent diesel by volume with 20 per cent mahua biodiesel) and LHR modification and LTC 15 per cent EGR fuelled with B20 blend and 5 per cent ethanol with various loads ranging from no load to full load. Implemented two technologies for increasing engine efficiency. One of the primary techniques is the Low Heat Rejection (LHR) concept (or the so-called "Adiabatic" engine) applied. In the engine cylinder, a ceramic layer of Alumina (Al_2O_3) was used to modify the Low Heat Rejection (LHR). Another technique is Low-temperature combustion (LTC) modes are added by joining the inlet and exhaust pipes through valves to control the exhaust gas at an optimal rate of 15 per cent. The findings of energy and exergy distribution in the engine were compared using optimum alterations with fuel blends such as 20 per cent mahua biodiesel and 5 per cent ethanol. From energy distribution, best shaft power (Q_{BP}) (2.8kW) is transformed from heat input observed in the optimum altered engine at full load conditions compared to others. Due to modifications employed in the engine and fuels. Maximum unaccounted energy (Q_{UN}) loss in diesel (44 %). And highest thermal efficiency (31.2 %) is revealed in B20E5 (LHR+15 % LTC). From exergy distribution, it noticed that the same trend of energy distribution and at 100 per cent load condition, maximum (12.54kW) in diesel and minimum (8.45 kW) in B20E5 (LHR+15 % LTC) has obtained input availability (A_{in}). The maximum conversion rate of availability in brake power (A_{bp}) (0.61 kW) in B20 (LHR). Compared to diesel, second law or exergetic efficiency more in B20E5 (LHR+15 % LTC). Finally, concluded the B20E5 (LHR+15 % LTC) is found to be best compared to diesel and other combinations (B20, B20 (LHR)) due to the used optimum modifications in engine and fuel.

Keywords: Energy; Exergy; Diesel engine; Biodiesel; Ethanol; Low heat rejection.

NOMENCLATURE

A_{in}	-	Availability of Input
A_{bp}	-	Availability of Brake power
A_d	-	Destructed availability
A_{ex}	-	Availability of Exhaust gas
Al_2O_3	-	Aluminium oxide
B20	-	20% Mahua Bio-diesel by Volume and 80% Diesel
B20E5	-	20% Mahua Bio-diesel, 5% Ethanol by Volume, and 75% Diesel
C_{pw}	-	Heat capacity of water
C_{pe}	-	Heat capacity of gases
CR	-	Compression Ratio
EGR	-	Exhaust gas recirculation
FAEE	-	Fatty acid ethyl esters
H_2SO_4	-	Sulphuric Acid
KOH	-	potassium hydroxide
LHR	-	Low heat Rejection
LHV	-	Low heating value
LTC	-	Low-Temperature Combustion
m_a	-	Mass of intake air
m_f	-	Fuel consumption
M_{eg}	-	Mass of exhaust gas
Q_{BP}	-	Brake power
Q_{ex}	-	Heat in the exhaust gas
Q_{in}	-	Heat input
Q_{cw}	-	Heat in cooling water
Q_{un}	-	Unaccounted heat losses
η_{II}	-	Second law efficiency or exergy efficiency

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1. INTRODUCTION

Energy is unique of the greatest significant components in the world nowadays. A most critical obstacle, though, is the rising need for energy. The total global energy usage was 9.33x 1012 kW h in 2018. The rate of growth for energy seems to have increased impetus gradually[1]. Consolidation of the usage of fuel in India has resulted in a significant upsurge in imports of crude oil. Socio-financial structure of countries is influenced by rising imports of crude oil with the general price fluctuations[2]. A huge threat to the environment is also global heating due to the combustion of fossil fuels. This requires, for example, the use of renewable sources. Thanks to the accelerated degradation, rising costs, and environmental emissions of fossil fuels, biomass technology tends to be an appealing alternative to renewable energy sources for diesel engines[3]. Different processes are used to process biomass into energy in the form of liquid fuels, including anaerobic fermentation, transesterification, pyrolysis, and liquefaction of these methods, pyrolysis is known to be an actual humble and good-looking technique of extracting oil from all usable biomass types. A variety of research has been conducted on complex biomass pyrolysis[26]. Although there is extensive literature on the chemistry of pyrolysis and the processing of bio-oil from specific biomass, there are findings on this feature in the latest developments on seed biomass pyrolysis[4].

Biodiesel was mixed with various blend ratios like 5 per cent, 10 per cent, 15 per cent, and 20 per cent used to run the engine. They reported that the efficiency of the engine raised and fuel consumption was decreased due to using of fuel blend of KSPOlikened to pure fossil fuel. Then also, while using biofuel mixtures in the engine CO was reduced, but more HC, NO_x, and smoke emissions were obtained[7]. They also carried out the thermodynamic analysis of different biofuel mixtures through various load conditions. By way of per that likened to diesel, blended petroleum has more petroleum exergy rate and less exergetic efficiency. Finally, concluded that when increasing the engine load, exergetic efficiency also increases. The experiment was carried out with variable loads at a different compression ratio (CR) of 15 to 18[8]. The results indicated that the compression ratio 18 with FAEE B10 yielded 29.3 per cent maximum useful work and that diesel only yielded 26.3 per cent full load. And also found that at CR 18 engine exhaust pollutants are lower than the diesel. He was considered to be better than petrol in the FAEE B10[9]. During breakdown, the fuel studied has a maximum percentage of exergic destruction and a minimum of exergetic heat loss[11-14]. Compared to diesel, 1.4 per cent less energy is spent on biodiesel. The energy loss of biodiesel remained 12.9 per cent reduced linked to fossil fuel. They reported that 20 per cent of the biodiesel blend showed good combustion and performance with less irreversibility[15]. They specified the uncertainty and sensitivity analysis based on the temperature parameters. Finally, they decided that the 20 per cent blend of polanga oil methyl ester (POME) remained similar to diesel fuel[16].

Instead of a single injector, use dual injectors such as the primary and the pilot injectors. In this experiment, biogas as the main fuel and diesel as a pilot fuel accounted for between 10 per cent and 20 per cent of fuel consumption[17]. The experiment was conducted with varying compression ratios (CR) from 16 to 18 and the injection pressure used (IP) was 180 and 200 bar. The engines were found to provide maximum exergy efficiency at low and medium loads using a combination of CR 16 and IP 180 bar[18]. The result has been shown that the highest efficiency is 34.27 percent when combined with CR 17 and IP 180 bar at full load. And also noticed that 60 per cent of the exergy input was destruction exergy. Finally, it concluded that 20 per cent of jatropha biodiesel yields better results than other blends of biodiesel[19].

By using Taguchi's 'L 16' orthogonal array with Minitab software to compare the results of experiments. The engine was tested at various speeds, loads, and blend ratios[20]. They reported that based minimum brake specific fuel consumption and exergy destruction were achieved by optimum operating conditions is 40 per cent blend ratio, engine speed at 1900 rpm, and 75 per cent load[21,22]. The engine was tested with different loads conditions, the constant speed at 1500 rpm and standard compression ratio are 17:1. They concluded that heat carried out minimum in exhaust gas was 10 per cent at 15.37:1compression ratio and cooling water was 24 per cent at 16.4:1 compression ratio[23]. At compression ratio 14.5:1 showed the more unaccounted loss was 41 per cent, maximum availability of brake power was 27 per cent at 17.5:1 compression ratio, and 57 per cent destructive availability at 13.7:1 compression ratio[24]. Some researchers used biodiesel in a low heat rejection engine with alumina nanoparticles in various ppm ratios to conduct experiments to determine engine performance and emissions[27]. Biodiesel blends in proportions ranging from 20 per cent to 80 per cent are used in diesel engines. As a result, thermal efficiency has decreased and fuel consumption has increased. However, emissions such as CO and HC were reduced in a reasonable manner[28]. The fuel properties of biodiesel blends are compared using ASTM standards[29]. Recently, researchers have focused on biodiesel production, using microalgae as fuel to determine diesel engine performance and emissions[30]. The physicochemical properties of microalgae grown in wastewater were specifically investigated and compared to the fitment of conventional fuels[31]. After algae biodiesel is used, different nanoparticles are added to reduce harmful gas emissions and to determine the effect on engine performance[35].

On these connections, the exergy method is used to assess the various input and output parameters of energy transfer. Exergy analysis was used specifically in IC engines to determine the loss of destruction in combustion, cylinder wall, friction, and so on. This method of evaluation provided the researcher with ideas for future IC engine developments[32]. Energy and exergy analysis is used in petrol engines as well, with different combination fuels such as petrol-ethanol, petrol-butanol, and petrol-butanol-ethanol blends used to conduct experiments and compare data with different engine speeds. According to thermodynamic research, a petrol-butanol-ethanol blend is an alternative fuel for petrol engines[33].

Low-Temperature Combustion (LTC) modes mitigate NO_x emission effectively by recirculating some exhaust gases like 0 per cent to 20 per cent. But this case compared LHR engine CO and HC were increased due to low oxygen concentration. The above emission problems can be minimised by using LHR concepts combined with LTC. Also 5 per cent Ethanol and using simultaneously 15 per cent LTC were used to decrease the NO_x. Only 5 per cent of Ethanol is used reason is ethanol's inability to get blended with diesel.

The current study's primary objective was to advance working compression ignition engine run as a fuel alternative to diesel by using LHR, LTC modification methods, and conventional fuel blend with mahua biodiesel (B20) and ethanol (E5)[5]. It has been found through the thermodynamic analysis of energy (first law) and exergy (second law) distribution of various experimental optimums of a diesel engine with specific load conditions (0%, 25%, 50%, 75%, and 100 %) [6].

2. METHODOLOGY

2.1 Engine Setup

The present study was done by using a compression ignition engine with two modifications. One is LHR (low heat rejection) method is done by ceramic (Al_2O_3) coating of engine combustion chambers like valves, cylinder liner, and head. Another one is the LTC (Low-Temperature Combustion) technique which is done employing circulation of exhaust gas (EGR) process through control valves to connect the inlet to exhaust pipe of engine. Only 15 per cent of LTC is used and it is optimum is proved in the previous experiment. The schematic diagram and experimental setup are exposed in Fig. 1(a) and Fig. 1(b). The specification of the CI engine used to conduct the experiments are presented in (Table 1). The engine remained attached toward an Eddy current dynamometer[2]. Thermocouples were mounted at different engine positions to test the water and exhaust gas temperature. Before the tests, most of the equipment was adjusted to maintain the uncertainty below the specified data indicated in the list.

Table. 1 specification of engine used

Type	Kirloskar Ltd, 4-stroke, single-cylinder
Model	AV1, DI
Fuel	Diesel
Diameter X piston displacement	8 X 11cm
CR	16.99 :1
Speed	1500 rpm
Valued Power	5.2kW
Injection Pressure	200bar
Injection timing	23^o BTDC
Dynamometer	Eddy current dynamometer

2.2 Biodiesel Production

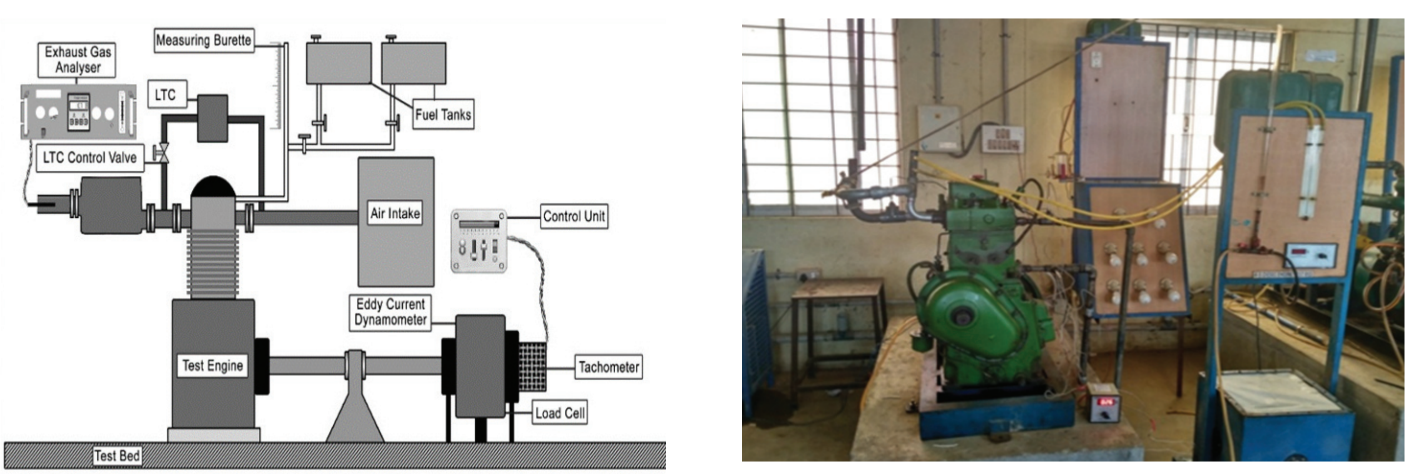
Mahua is a member of the Sapotaceae family. The plant grows to around 20 m tall with a trunk between 50 cm to 80 cm in diameter. The life cycle of the tree is roughly 70 years. The Mahua tree can be found in a variety of locations throughout India[34]. It's so versatile to use the engine as a fuel source. In this study, used fuel was mahua biodiesel, ethanol, and diesel, and biodiesel is produced by using a two-stage process[6]. One is esterification and another one is transesterification. Esterification is used to reduce mahua oil's Fatty acid level percentage through acid catalyst (H_2SO_4). After that, transesterification is done by using chemical catalyst potassium hydroxide (KOH) and methanol is used with heating temperature 60 ^{o}C[25]. Then blended with diesel and ethanol. For this test fuel is prepared by B20 (Diesel 80 %, Biodiesel 20 %) and B20E5 (Diesel 80 %, Biodiesel 20 %, and Ethanol 5 %) and compared to reference fuel (diesel 100 %). Table 2 displays the possessions of fuel used trendy of the investigation like flash point, cetane number, density, viscosity, etc.

Table 2. Properties of tested fuels

Property	Density	kinematic viscosity	Heating value	flash point	Cetane Number
Units	kg/m^3	cSt	MJ/kg	^{o}C	-
Diesel	850	3.52	42	49	55
Mahua Oil	960	24.58	36	232	45
Ethanol	794	1.1	28.4	-	4
Mahua biodiesel	880	3.98	37	208	47
B20	860	3.62	38	80	52.5
B20E5	869	3.49	40	77	52

3. THERMODYNAMIC ANALYSIS

This research is done with founded on the First Law of Thermodynamics the Second Law of Thermodynamics. The First Law of Thermodynamics was rummage-sale to find out the energy supplied and the energy distribution of engine. It is



(a) (b)

Figure 1. (a) Line diagram (b) Arrangement of experiment

called energy analysis. The Second Law of Thermodynamics was used to realise available energy then unavailable energy of the engine. It is called exergy analysis. The following formulae were used for calculations of thermodynamic analysis

4. ENERGY INVESTIGATION

Energy Investigation is founded upon the First Thermodynamics theorem. For every IC engine heat inlet (Q_{in}) was composed of fuel. This supply of heat was then transformed into several types[5]. Engine, the inlet fuel was organic energy was divided into the succeeding forms useful shaft energy (Q_{BP}), Heat in cooling water (Q_{CW}), Heat in outlet gas (Q_{ex}), and Unaccounted heat losses (Q_{un})owing to radiation, friction, transfer of heat to surroundings of the system. The mass fractions of fuel utilised in this investigation are shown in Table 3.

4.1 Heat Input (Q_{in})

$$Q_{in} = mf * LCV \text{ KW} \tag{1}$$

Let, mf -- Fuel Fonsumption -- Kg/s

LCV= Lower Calorific Value of Fuel-- KJ/Kg

4.2 Brake Power (Q_{BP})

(2)

Let, N-- speed - rpm

T= Torque - KNm

4.3 Cooling Water Heat (Q_{CW})

$$\boldsymbol{Q_{cw} = m_{cw}\left(T_2 - T_1\right)} \text{ kW} \tag{3}$$

Where T_1, T_2 are in and outof temperatures of cooling water

C_{pw}- Specific Heat of Cooling water (4.2 KJ/KgK)

4.4 Heat in the Exhaust Gas (Qex)

$$Q_{ex} = M_{eg}\, C_{pe}\left(T_4 - T_3\right) \text{ kW} \tag{4}$$

M_{eg} - Mass of Exhaust gas in Kg/s

$$\boldsymbol{M_{eg} = m_f + m_a}$$

Where T_3, T_4 are in and out temperatures of Exhaust

C_{pe} - Specific heat of exhaust gases

m_a - Mass of inlet air- Kg/s

4.5 Unaccounted Heat Losses (Q_{un})

$$\boldsymbol{Q_{un} = Q_{in} - \left(Q_{BP} + Q_{cw} + Q_{ex}\right)} \text{ kW} \tag{5}$$

5. EXERGY ANALYSIS

Exergy analysis was used to find out Second law efficiency or exergy efficiency. Possibility of finding the irreversibility associated with combustion, mixing, heat transfer, friction, etc.

5.1 Availability of Input (A_{in})

$$A_{in} = \left[m_f LHV\right]\Phi \textbf{ kW} \tag{6}$$

$$\phi = 1.0401 + 0.\frac{1729\mathbf{H}}{\mathbf{C}} + 0.\frac{0431\mathbf{O}}{\mathbf{C}} + 0.\frac{2169\mathbf{S}}{\mathbf{C}} * \left(1 - 2.\frac{0629\mathbf{H}}{\mathbf{C}}\right)$$

Let take, H, C, and O & S is the mass fraction of Hydrogen, Carbon, and Oxygen & Sulphur

m_f - Mass flow rate of fuel- kg/s

LHV -Low Heating Value- kJ/kg

Table 3. Mass fraction of fuels

Chemicals		Bioethanol (C_2H_5OH)	Diesel ($C_{12}6H_{24}$)	Biodiesel ($C_{19}H_{35}O_2$)
By weight (%)	C	52	85.29	77.06
	H	13	13.64	12.13
	S	-	1.07	-
	O	35	-	10.81

For diesel mode

$$A_{in} = \left[1.0338 m_f LHV\right]\Phi \text{ kW} \tag{7}$$

For Biodiesel blend (B20) mode

$$A_{in} = \left[1.046584 m_f LHV\right]\Phi \text{ kW} \tag{8}$$

For Biodiesel blend with ethanol (B20E5) mode

$$A_{in} = \left[1.05631 m_f LHV\right]\Phi \text{ kW} \tag{9}$$

(1) Availability of Brake power(A_{bp}), $A_{bp} = Q_{bp}$ kW (10)
brake power of the engine,

(3) Availability of cooling water (A_{cw}),

$$\boldsymbol{A_{cw} = Q_{cw} - \left[m_{cw} C_{pw} T_a ln\{\frac{T_2}{T_1})\right]} \text{ kW} \tag{11}$$

T_a -Ambient temperature

(2) Exhaust gas availability (A_{ex}),

$$B20E5\left(LHR + 15\%LTC\right), \text{ kW} \tag{12}$$

R_e-Specific Gas Constant.

P_a-Ambient Pressure

P_e -Exhaust Gas Pressure

T_1 - Exhaust Temperature

M_{eg} - Mass flow rate of exhaust gases.

(5) Destructed availability (A_d),

$$\boldsymbol{A_d = \left\{A_{in} - \left(A_{cw} + A_{ex} + A_{de}\right)\right\}} \text{ kW} \tag{13}$$

(6) Second law efficiency or exergy efficiency,

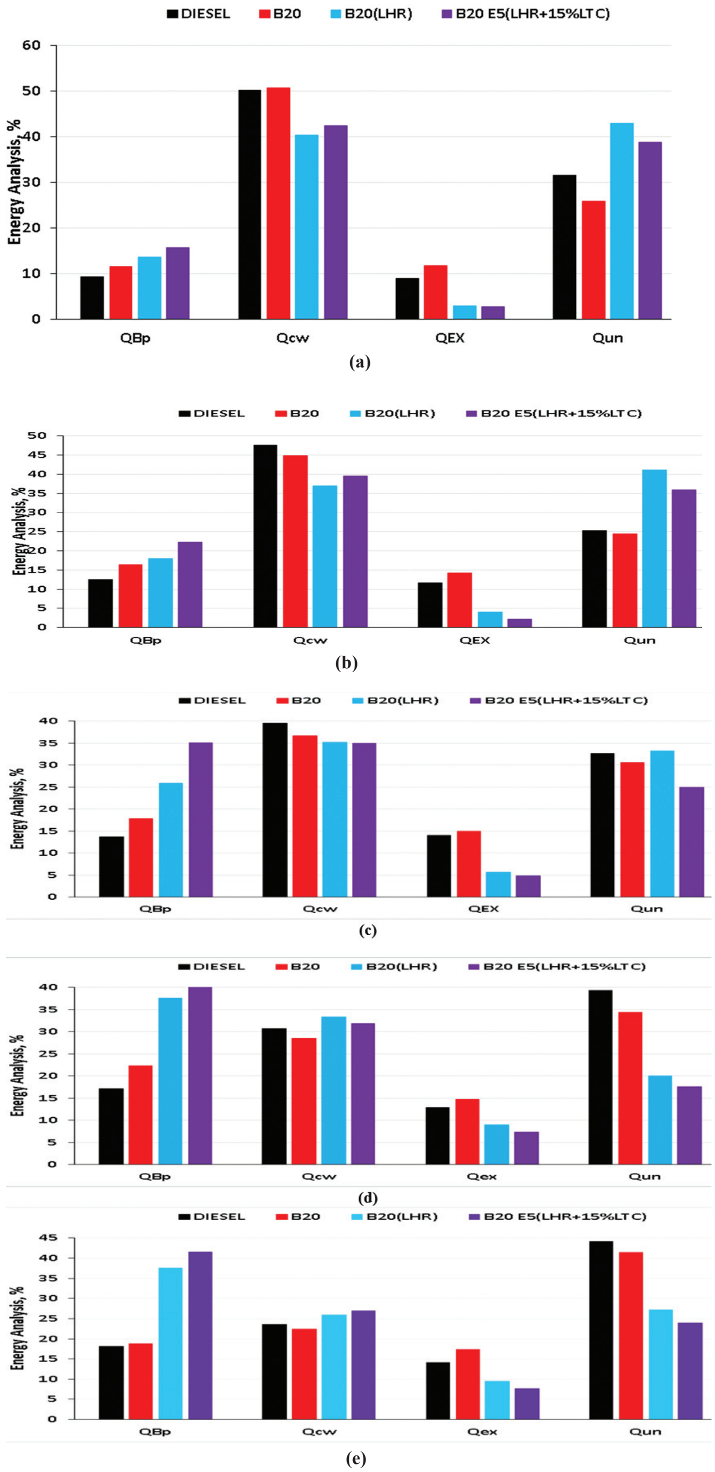


Figure 2. Energy distribution at different load condition: (a) 0%, (b) 25%, (c) 50%, (d) 75%, (e) 100%.

$$\eta_{II} = \left[\left(\frac{A_{bp}}{A_{in}}\right)\right]\% \quad (14)$$

6. RESULTS AND DISCUSSION

In this study, work was theoretically calculated which was obtained in experimental values. This analysis was made using different load conditions of the engine like 0 per cent, 25 per cent, 50 per cent, 75 per cent, and 100 per cent. And fuelled with diesel, B20, B20 (LHR) andB20E5 (LHR+15%LTC). In analysis discussed engine performance by the way of energy analysis and exergy analysis.

6.1 Energy Analysis

The first thermodynamic law is used in this work to analyse the transfer of energy in diesel engines. It was based on the First Law of Thermodynamics to decide the supply of the engine than those supply outcomes and how it was transmitted to different factors such as heat input (Qin), shaft power (Q_{BP}), energy in cooling water (Q_{CW}), energy taken by exhaust gas (Q_{EX}) and unaccounted energy loss (Q_{UN}). The energy analysis tests for optimum fuels used in this study at 0 per cent, 25 per cent, 50 per cent, 75 per cent and 100 per cent engine load conditions from Fig. 2(a) - Fig. 2(e). Overall, the highest pleasing results were obtained in B20E5 (LHR+15 % LTC) as per estimates**.** Since this combination includes two modifications in engines such as LHR, LTC methods are used on time and also in diesel fuel blended with biodiesel (B20) and ethanol (E5). At 100 per cent load condition, 41.54 per cent of Heatinput (Qin) has converted into shaft power (Q_{BP}), 26.92 per cent energy in cooling water (Q_{CW}), 7.62%energy taken by exhaust gas (Q_{EX}), and 23.93 per centunaccounted energy loss (Q_{UN}) forB20E5 (LHR+15 %LTC). Heat input (Q_{in}) is the fuel energy of engine converted as the shaft power(Q_{BP}) at 0 per cent load, 9.26 per cent, 11.62 per cent, 13.69 per cent and 15.75 per cent for Diesel, B20, B20(LHR) and B20E5 (LHR+15 %LTC)correspondingly. Likewise, at 25 per cent load conditions 12.47 per cent, 16.4 per cent, 17.91 per cent, 22.34 per cent and at 50 per cent load conditions 13.68 per cent, 17.79 per cent, 25.84 per cent, 35.10 per cent and at 75 per cent load condition 17.14 per cent, 22.36 per cent, 37.57 per cent, 43.20 per cent and at 100 per cent load conditions 18.08 per cent, 18.72 per cent, 37.55 per cent, 41.54 per cent of heat input converted into shaft power(Q_{BP})[11].These results exposed the energy distribution with different combinations of modification in engine and fuels[32]. Particularly shows that instead of diesel fuel, biodiesel is the substitute but it requires modifications. Because biodiesel has a low calorific value compared to diesel[26].

Heat input is one of the most important parameters is related to fuel energy rate[36]. It depends upon the fuel Density, Viscosity the Calorific Value of the particular petroleum. As shown in Fig. 2(a) maximum heat input belongs to diesel allied to other conditions of the engine. When studied in terms of different load conditions, heat input is raised as long as engine load increases for all conditions of engine[15]. At the full load condition, heat inputs are 11.93 kW, 12.13 kW, 8.4 kW, and 8kW for Diesel, B 20, B20 (LHR) then B20E5(LHR+15 %LTC), respectively. Compared to diesel, 1.67 per cent more in B20 and 29.25 per cent, 32.94 per cent less in B20 (LHR) and B20E5 (LHR+15 %LTC) on full loads condition.

Maximum shaft power (Q_{BP}) has been obtained when operating withB20E5 (LHR+15 %LTC) at all conditions of the engine as shown in Fig. 3(b). This is explained by the engine torque high in B20E5 (LHR+15 %LTC) compared to other[18]. Because at a time implemented LHR, 15%LTC methods in the engine and B20 blend with E5. At the 100 per cent load

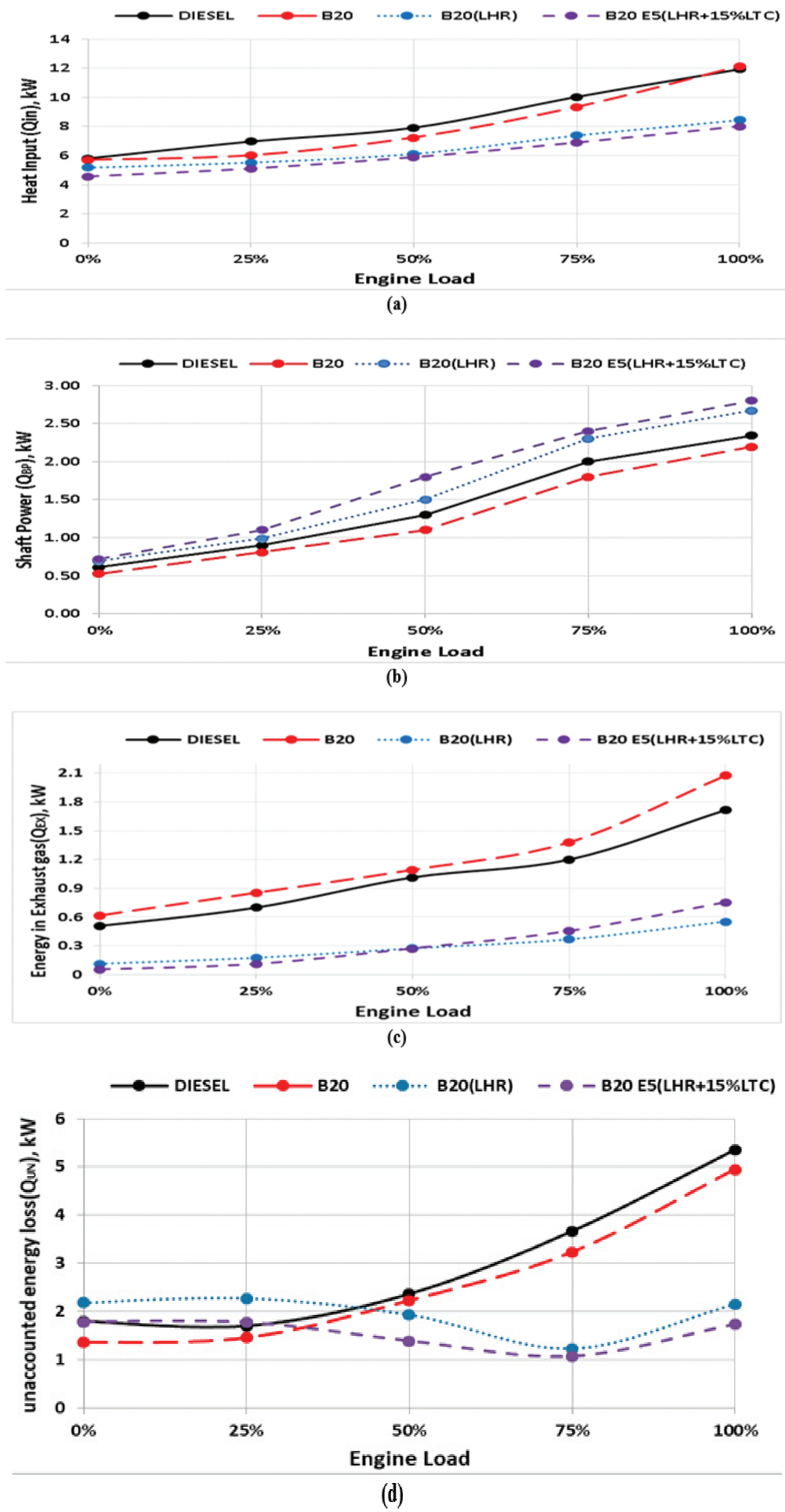
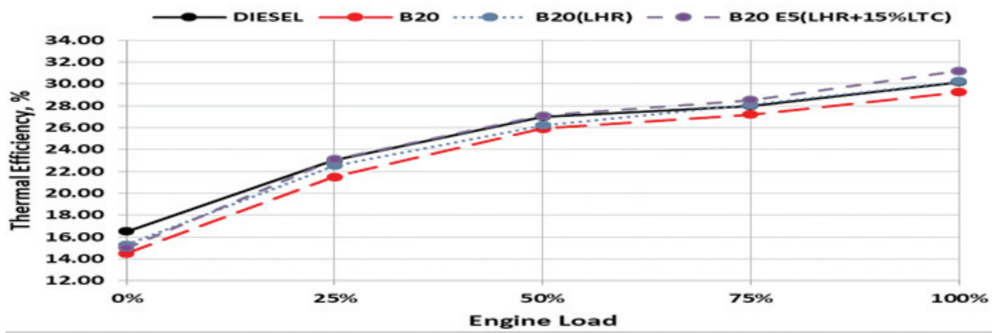


Figure 3. Different engine load conditions at the variation of (a) heat input (Q_{in}), (b) Shaft Power (Q_{BP}), (c) Energy in the Exhaust gas (Q_{EX}), (d) unaccounted energy loss (Q_{UN}), (e) thermal efficiency.



(e)

Figure 3. Different engine load conditions at the variation of (a) heat input (Q_{in}), (b) Shaft Power (Q_{BP}), (c) Energy in the Exhaust gas (Q_{EX}), (d) unaccounted energy loss (Q_{UN}), (e) thermal efficiency.

condition, Brake power are 2.34 kW, 2.19 kW, 2.67 kW, and 2.8 kW expected at Diesel, B20, B 20(LHR) then B20E5 (LHR+15 %LTC), correspondingly. Compared to diesel, 6.4 per cent less in B20 and 14.1 per cent, 19.61 per cent more in LHR Biofuel blends and B20E5 (LHR+15 %LTC) on full load conditions. In B20, there are no modifications in the engine and it has a low calorific value, cetane number, and high viscosity compared to diesel[31].

Figure 3(c) demonstrates the difference of energy in the exhaust gas at the dissimilar stage of engine load conditions when using optimum blended fuel with modified engines. As per, obtained results at 100 per cent load conditions, minimum and maximum energy loss due to exhaust is revealed is 0.55kW in B20 (LHR) and is 2.07kWin B20. Because in B20 (LHR) engine has used low heat rejection by ceramic coating and in B20 engine having mahua oil biodiesel blended with diesel then it has having calorific value is less[6]. It creates more loss of energy in exhaust gases. But this figure displays the reasonable result illustrated is 0.75kW in the B20E5 (LHR+15%LTC) due to modifications in engine and fuel[7]. Compared to diesel, 20.93 per cent more in B20 and 56.26 per cent, 67.93 per cent less in B20 (LHR) then B20E5 (LHR+15 %LTC) at full load conditions.

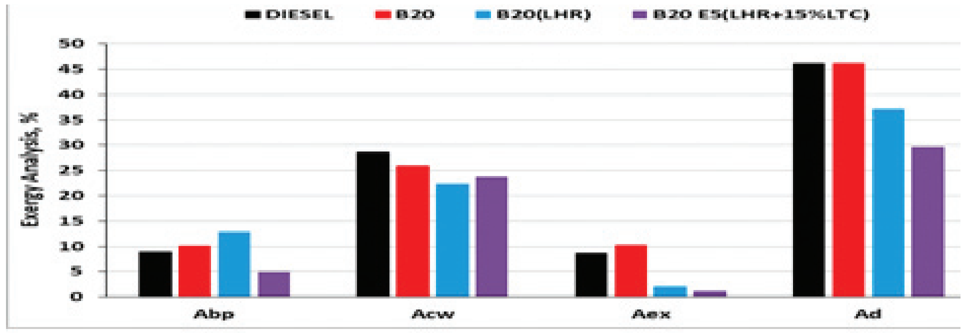
Figure 3(d) shows the variation of unaccounted energy loss (Q_{UN}) at different stages of engine load conditions when using diesel, B20, B20 (LHR), and B20E5 (LHR+15 %LTC). As per obtained results at 100 per cent load conditions, minimum unaccounted energy loss (Q_{UN}) is 1.72 kW in B20E5 (LHR+15 %LTC) due to employed optimum modification in engine and fuel[36]. Maximum unaccounted energy loss (Q_{UN}) is 5.35kW in diesel fuel. Because it is a normal conventional diesel engine without modification. Compared to diesel, 7.73 per cent, 59.87 per cent and 67.89 per cent less in B20, B20 (LHR) then B20E5 (LHR+15 % LTC).

Figure 3(e)displays the dissimilarity of thermal efficiency at different stages of engine load conditions when using Diesel, B 20, B20-(LHR) then B20E5-(LHR+15%LTC). As per obtained experiments results, maximum thermal efficiency is 31.2 per cent in B20E5 (LHR+15%LTC) due to applied modifications in the diesel engine. Minimum thermal efficiency is 29.13 per cent in B20 owing to low CV in biofuel compared to diesel[19]. Compared to diesel, 3.05 per cent less in B20 and 0.29 per cent, 3.48 per cent more in B20-(LHR) and B20E5-(LHR+15%LTC) at full load.

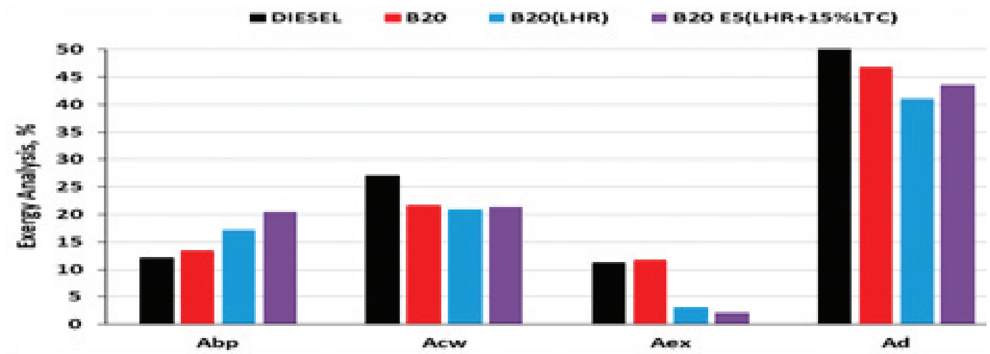
6.2 Analysis of Exergy Distribution

Figure 4(a) - Fig. 4(e) shows the results of exergy analysis of DIESEL, B20, B20(LHR) and B20 E5(LHR+15%LTC) at different load conditions such as 0 per cent, 25 per cent , 50 per cent, 75 per cent and 100 per cent respectively. It is based on the second law of thermodynamics. Availability of brake power (A_{bp}), Cooling water (A_{cw}), Exhaust gases (A_{ex}), and destruction (A_d) are shown in the figure for different fuels and modifications of the engine. Overall, the highest pleasing results were obtained in B20E5 (LHR+15 % LTC) as per estimates. Since this combination includes two modifications in engines such as LHR, LTC methods are used on time and also in diesel fuel blended with biodiesel (B20) and ethanol (E5). At 100 per cent load condition, 38.70 per cent of input availability (A_{in}) has converted into Availability in brake power(A_{bp}), 13.57 per cent Availability in cooling water (A_{cw}), 8.91 per cent Availability in the exhaust gas(A_{ex}), and 61.18 per cent. Availability in destruction (Ad) for B20E5(LHR+15%LTC). Input availability (A_{in}) is the fuel exergy of engine converted as the Availability in brake power(A_{bp}) at 0 per cent load, 8.95 per cent, 10.09 per cent, 12.80 per cent and 4.85 per cent for Diesel, B20, B20(LHR) and B20E5(LHR+15% LTC). Similarly, at 25 per cent load conditions 12.05 per cent, 13.44 per cent, 17.11 per cent, 20.34 per cent and at 50 per cent load conditions 14.71 per cent, 12.69 per cent, 23.41 per cent, 31.35 per cent and at 75 per cent load condition 18.13 per cent, 19.05 per cent, 29.74 per cent, 36.28 per cent and at 100 per cent load conditions 20.72 per cent, 21.22 per cent, 33.63 per cent, 38.70 per cent of input availability (A_{in}) converted into Availability in brake power(A_{bp})[32]. These results revealed the exergy distribution with different combinations of modifications in engines and fuels. Particularly illustrations the in its place of diesel fuel, biodiesel is the alternative but it requires modifications[25]. Because biodiesel has a low calorific value compared to diesel[12].

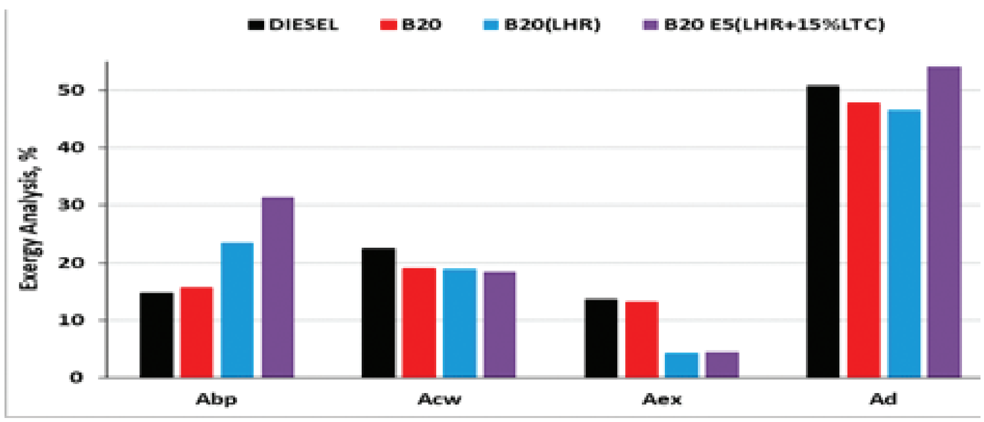
Input availability (A_{in}) is an important term is displayed in the engine fuel exergy rate which is similar to fuel energy



(a)



(b)



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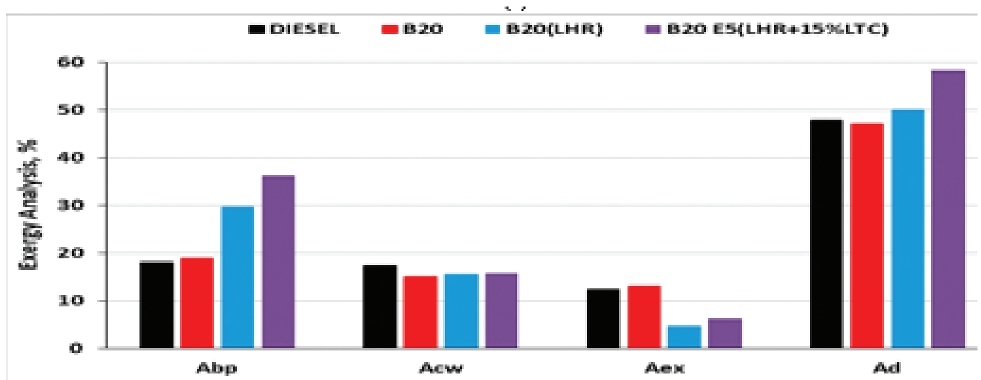


(d)

Figure 4. Distribution of Exergy at different engine load conditions: (a) 0%, (b) 25%, (c) 50%, (d) 75% (e) 100%.

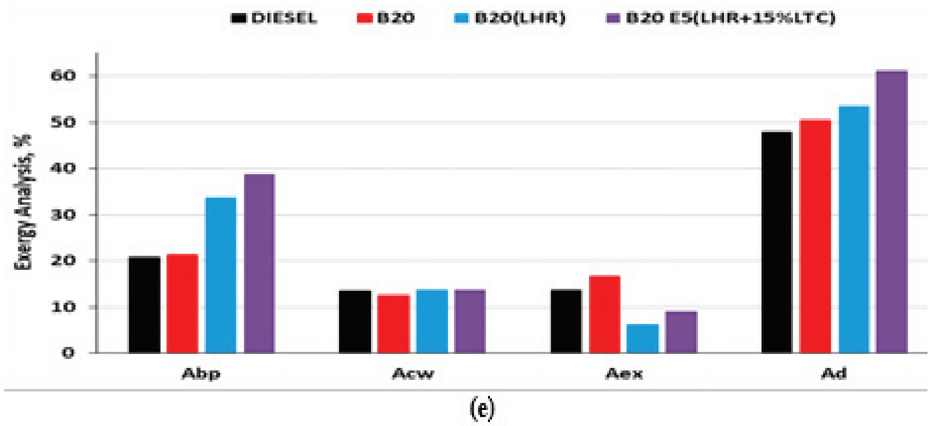


Figure 4. Distribution of Exergy at different engine load conditions: (a) 0%, (b) 25%, (c) 50%, (d) 75% (e) 100%.

rate[21]. Figure 5(a) shows the variation of Input availability (A_{in}) at different stages of engine load conditions when using diesel, B20, B20(LHR), and B20E5(LHR+15 % LTC). At 100 per cent load condition, maximum is 12.54kW in diesel and minimum is 8.45kW in B20E5 (LHR + 15 % LTC) has obtained input availability (A_{in}) as per the results revealed. When increases the engine load and also increases the fuel exergy rate for all types of engine conditions. Compared to diesel, 0.47 per cent, 29.52 per cent and 32.61 per cent is less in B20(LHR) and B20E5(LHR + 15 % LTC) at 100 per cent load. Availability in brake power (A_{bp}) is one of the important parameters and it's a useful work in the engine and it was obtained from one part of input availability (A_{in})[23]. Based on this performance and emission of the engine was dependable. Figure 5(b) shows the variation of availability in brake power (A_{bp}) at different stages of engine load conditions when using diesel, B20, B20 (LHR), and B20E5(LHR + 15% LTC). From the obtained results, maximum and minimum conversion of fuel exergy rate into availability in brake power (A_{bp}) is 3.27kW in B20E5(LHR+15% LTC) and is 2.60 kW in diesel at 100 per cent load. In 0 per cent load condition maximum and minimum conversion rate of availability in brake power (A_{bp}) is 0.61kW in B20 (LHR) and is 0.234kW in B20E5(LHR + 15 % LTC). Compared to diesel, 1.9 per cent, 14.3 per cent and 25.76 per cent more in B20, B20 (LHR) and B20E5(LHR + 15 % LTC) at 100 per cent load[28].

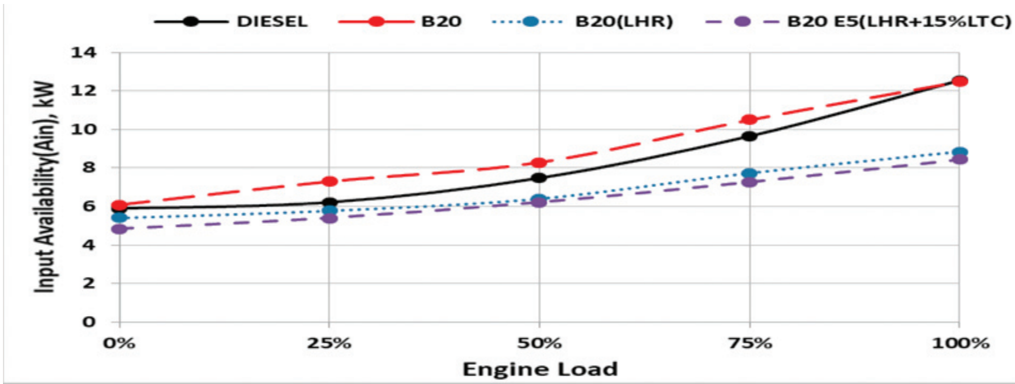
Figure 5(c) shows the variation of availability of trendy exhaust gases (A_{ex}) at different stages of engine load conditions when using diesel, B20, B20 (LHR), and B20E5 (LHR+15%LTC). Overall from the results, starting load to ending load conditions of the engine, availability in exhaust gases (A_{ex}) is minimum in B20 (LHR) and B20E5 (LHR+15 %LTC) due to both types of engine run by modifications with ceramic coating. Maximum in diesel and B20 due to both types of engine run by without modification. Compared to diesel, 21.48 per cent, high in B20 and 70 per cent to 60 per cent reduced in B20(LHR), B20E5(LHR + 15 % LTC) at full load.

Figure 5(d) displays the variation of availability in destruction (Ad) at different stages of engine load conditions when using Diesel, B 20, B20(LHR), and B20E5(LHR+15% LTC). As per the obtained results, at full load condition availability in destruction (Ad) is maximum in diesel and minimum in B20E5 (LHR+15 %LTC). This figure displays the unaccounted loss in the engine by using exergy analysis of thermodynamic second law[14]. It occurs many reasons in the heat transfer of engine like friction in the mating parts, turbulent flow in the cylinder, during the combustion process, etc. At full load condition, values were 6.54kW, 6.18kW, 4.10 kW and 3.28kW for Diesel, B20, B20 (LHR) and B20E5 (LHR+15 %LTC)Compared to diesel, 5.5 per cent, and 37.22 per cent and 49.84 per cent less in B20, B20(LHR) and B20E5 (LHR+15 %LTC) at 100 per cent load.

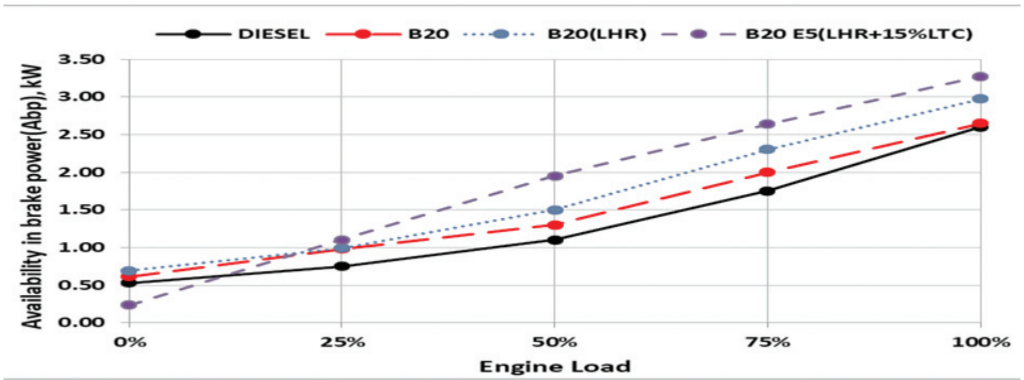
Fig. 5(e) shows the variation of second law efficiency at different stages of engine load conditions when using diesel, B20, B20 (LHR), B20E5 (LHR+15 %LTC). Second law efficiency is also an important parameter to measure the performance of the engine from the thermodynamics and it is also known as exergetic efficiency[9]. As per the obtained results, second law efficiency has maximum in B20E5 (LHR+15 %LTC) and minimum in diesel. Particularly, in B20E5 (LHR+15 %LTC)at 0 per cent load very less efficiency and continuously increased while load raising at a full load of the engine is high efficiency is revealed compared to other combinations[29]. Because of the modification of engine and fuels in starting (0 % load) is difficult to run and after increasing load, it improving the performance of the engine due to optimum modifications[31]. At full (100 %) conditions, values were 20.72 per cent, 21.22 per cent, 33.63 per cent and 38.69 per cent for Diesel, B 20, B20-(LHR) and B20E5-(LHR+15%LTC).

7. CONCLUSION

This research work investigates the energy and availability or exergy distribution of compression ignition engines using diesel, B20, B20 (LHR), and B20E5 (LHR+15%LTC). Heat input (Q_{in}), shaft power(Q_{BP}), energy in cooling water (Q_{CW}), energy taken by exhaust gas(Q_{EX}), and unaccounted energy loss(Q_{UN}) with the first law of thermodynamic, availability of brake power (A_{bp}), Cooling water (A_{cw}), Exhaust gases (A_{ex}) and destruction (A_d) with the second law of thermodynamic using by different loads (0 %, 25 %, 50 %, 75 %, and 100 %)



(a)



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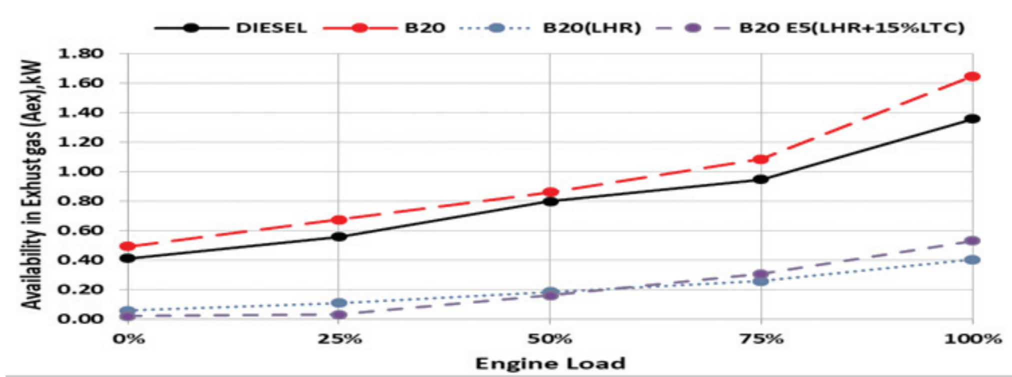

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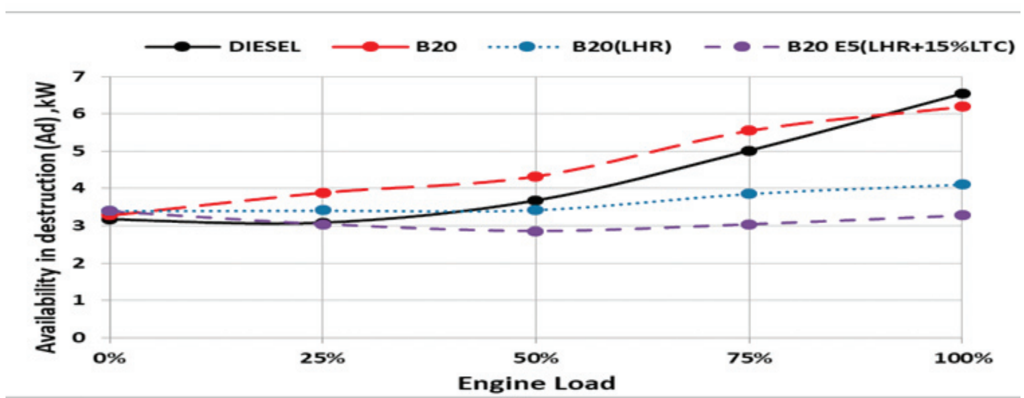
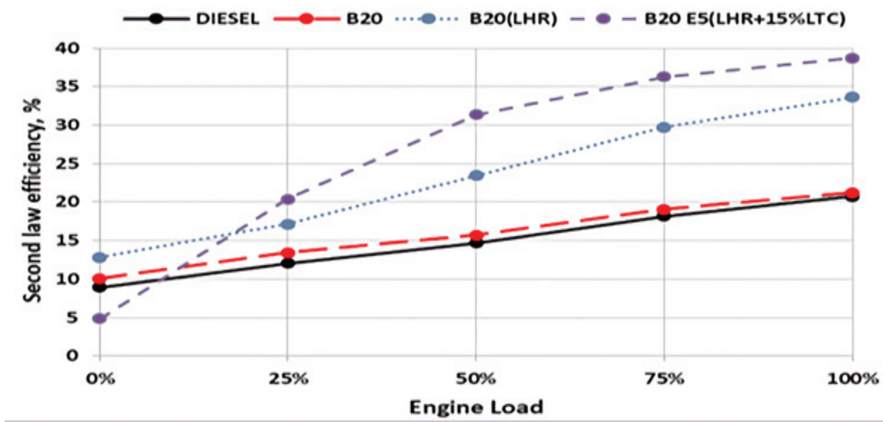


(d)

Figure 5. Different engine load conditions at variation of availability in (a) input (A_{in}), (b) brake power (A_{bp}), (c) exhaust gases (A_{ex}), (d) destruction (A_d), (e) second law efficiency.



(e)

Figure 5. Different engine load conditions at variation of availability in (a) input (A_{in}), (b) brake power (A_{bp}), (c) exhaust gases (A_{ex}), (d) destruction (A_d), (e) second law efficiency.

compared to each other. And also efficiencies of the thermal and second law are determined. Summaries of this wok are discussed as follows.

- Maximum brake power (2.8 kW), efficiencies of thermal (31.2 % kW), and second law (38.69 %) have been obtained in B20E5 (LHR+15 %LTC) compared to other type engines at full load conditions
- The greatest exergy efficiency is revealed in B20E5 (LHR+15 %LTC) compared to conventional diesel with diesel or biodiesel engines
- Exergy analysis shows realistic and accurate measures of engine loss
- LHR and LTC methods of modifications illustrated the better of diesel engines while using biodiesel
- In energy or exergy distribution in the exhaust gas (Q_{ex} or A_{ex}) and unaccounted (Q_{UN}) or destruction (A_d) is the main loss to the engine performance
- Shaft power (Q_{BP}) is the potential of the engine or it is nothing but useful work.

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His contribution to this study is continuous guidance from the start of the research to the completion of the research paper.