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RESEARCH ARTICLE OPEN ACCESS

Energy and Exergy Analysis of a Diesel Engine Fuelled with Various Non-Edible Biodiesel

Dr Nabnit Panigrahi[1], M Ramakotaiah[2], Jyotiranjan Barik[3]

[1]*Professor, Department of Mechanical Engineering, Gandhi Institute For Technology (GIFT), Bhubaneswar*
[2] *Assistant Professor, Department of Mechanical Engineering, Gandhi Engineering College, Bhubaneswar*
[3]*Assistant Professor, Department of Mechanical Engineering, Gandhi Institute For Technology (GIFT), Bhubaneswar*

ABSTRACT-- The present work deals with two biodiesel blend i.e. mahua and neem. A comparative energy and exergy analysis of a 3.5 kW diesel engine using two different blends of biodiesels derived from non-edible oils with petroleum diesel. The blends were 20% biodiesel with 80% diesel by volume. Utilizing experimental data obtained from steady-state tests, balances of energy and exergy rates for the engine were determined. Then various performance parameters of the engine were evaluated from each fuel operation. It was found that the tested biodiesels offer almost the same energetic and exergetic performance parameters as petroleum diesel fuel. The analysis was conducted on per mole of fuel and on stoichiometric basis.

Index Terms—Diesel engine, Energy and Exergy, Mahua biodiesel, Neem biiodiesel

I. INTRODUCTION

ENERGY is inevitable for each part of the living world including human being, animals, plants, mechanical devices and vehicles. All India study report submitted to PPAC, 70% of diesel and 99.6% petrol is consumed in the transport sector alone. Transport sector is the major consumer of diesel accounting for 70% of the total Diesel sales. The agriculture sector is a major consumer of Diesel with about 13% of the total consumption accounted for by it. Diesel consumption by other segments is 17 per cent. This comprises of industry 9.02% (of which industry gen sets is 4.06 % and others for industrial purposes is 4.96%), mobile towers (1.54%) and others (6.45%) comprising of gen sets for non-industrial purposes, civil construction, etc. as per press

Information bureau. The import bill of crude oil is estimated to increase by 42 per cent from $88 billion in 2017-18 to $125 billion in 2018-19 as per oil ministry of India. With increasing use and demand of vehicles in the developing society and wide consumption of non-renewable source of energy, it becomes very much essential to think about new sources of energy and its proper utilization. One of the most essential preconditions for the overall development of a society is the efficient use of energy resources. The conventional energy sources like fossil fuels are widely used for production of energy. However, in the present day scenario, the attention has been shifted to non-conventional energy sources considering the pros and cons of conventional energy resource utilization. The sources of such non-conventional energy are renewable in nature, and hence origin cyclically, safeguarding the sustainability of the globe, driven majorly by modernized needs of human beings.

Odisha is home of a number of oil seed bearing tree species (Madhuca, Neem, Simarauba, Jatropha, etc.) which have tremendous potential for bio-diesel production. It can be noticed that 78.9 percent villages in Odisha are electrified. Thus non-edible oils can play a vital role in decentralized power generation in the state.

Many researchers have carried out research work on biodiesel, diesel and gasoline fuel for energy and exergy analysis in terms of efficiency and losses occurred in I.C. engines. Kopac and Kokturk (2005) carried out energy and exergy analysis of an IC engine operating on otto cycle to determine the optimum speed. Results indicate that the rpm speed is maximum at exergy efficiency [1]. Canakci and Hosoz (2006) performed energy and exergy analysis of a 4-S diesel engine fuelled with soybean methyl ester, yellow grease methyl ester, petroleum diesel fuel and 20% blend of each biodiesel with petroleum fuel. The results indicated that the tested biodiesel have similar energy and exergy performance as diesel and most of the energy and exergy destruction occur during combustion [2]. Caliskan et al. (2009) conducted energy and exergy analysis on a diesel engine fuelled with soybean biodiesel. It was found that the exergetic efficiency increased as dead state temp decreased [3]. Sayin et al. (2006) studied comparative energy and exergy analysis of a 4-S spark ignition using gasoline fuels of three different research octane numbers [4]. The author Panigrahi (2018) have also conducted energy and exergy analysis on non-edible polanga biodiesel and found that the result revealed with petroleum diesel [5]. Debnath et al (2013)explored the effect of compression ratio and injection timing on energy and exergy potential of a palm oil methyl ester (POME) run diesel engine. They concluded that the entropy generation is also reduced for the similar CR and IT modifications [6]. Sahoo et al. (2011)performed second law analysis of syngas with a mixture of hydrogen (H_2) and carbon monoxide (CO), in a 5.2 kW engine for various loads. The results indicate that, compared to the 100% CO dual fuel mode, increasing the H_2 content in syngas from 50% to 100%, increased second law efficiency from 8 to 51% [7].

In this study the energy and exergy analysis of a C.I. engine fuelled with diesel and B20 (20% blend of biodiesel and 80% diesel) blends of neem and mahua biodiesel separately with petroleum diesel. The author has given a comparative statement of the neem and mahua biodiesel with diesel fuel. The analysis was carried out with stoichiometric in which no extra amount of oxygen is required for combustion which results is negligence of carbon, hydrogen, carbon monoxide and oxygen in the product.

II. MATERIAL AND METHODS

Considering the number of oil seed bearing tree species having tremendous potential of biodiesel production in Odisha, Neem(Azadirachta Indica), Mahua (Madhuca Indica) tree borne oils were selected for present investigation. The oil obtained from their respected kernels by mechanical extraction method followed by esterification and transesterification method for its biodiesel is shown in Fig. 1.

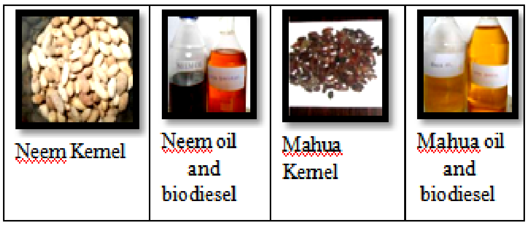

Fig.1. Tested fuels with its kernel

The samples blend was prepared from the biodiesel, obtained by esterification and transesterification process. The test samples are termed as MB20 (20% mahua biodiesel by volume + 80% diesel by volume). and NB20 (20% neem biodiesel by volume + 80% diesel by volume) respectively. The properties of sample blend are given in Table I.

TABLE I Properties of test samples

Fuels	Specific Gravity	Kinematic Viscosity at 40^0 C (cSt)
MB20	0.866	4.30
NB20	0.878	4.50
Diesel	0.820	2.5

Tests were performed in a 4-S diesel engine. The engine details are given in Table II and the test engine is shown in Figure 2. The engine exhaust emission was measured by exhaust gas analyzer.

TABLE II

Engine specification

Engine Parameters	Specifications
Cylinder diameter x Stroke Length	87.5 mm x 110 mm.
Compression ratio	18:1
Rated output	3.5 kW.
Injection pressure	240 bars
Fuel injection timing	25BTDC
Connecting rod length	234 mm
Orifice diameter	20 mm
Dynamometer arm length	185 mm

Fig. 12. Diesel engine set up

First the engine was tested with the pure diesel. Then the two samples MB20 and NB20 were tested respectively at steady state operation. The tests were conducted with 100% load at the engine speed of 1500 rpm.

A. Energy analysis

The The assumption made for energy analysis and exergy analyses are the steady state flow system, dynamometer as control volume, air and exhaust gas is ideal gas mixture. The inlet condition to the engine is 1 atm and ambient temp as 25^0C. The combustion leaves the engine at 285^0C.

By considering heat input into the system and work output the steady-state flow energy equation is as

$$\Rightarrow \dot{Q} - \dot{W} = \dot{m}\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(Z_2 - Z_1)\right] \quad (1)$$

The chemical reaction of the tested fuel is given below.

$$C_xH_yO_z + a(O_2 + 3.76N_2) \longrightarrow bCO_2 + cH_2O + N_2 \quad (2)$$

The steady flow energy rate balance on per mole of fuel basis resulting from Equation (1) can be written as:

$$\frac{\dot{Q}_{cv}}{\dot{n}_F} - \frac{\dot{W}_{cv}}{\dot{n}_F} = \bar{h}_p - \bar{h}_r = \sum_{product} n_{out}\left(\bar{h}_f^0 + \Delta\bar{h}\right)_{out} - \sum_{reactants} n_{in}\left(\bar{h}_f^0 + \Delta\bar{h}\right)_{in} \quad (3)$$

Where, $\Delta\bar{h} = \bar{h}(T) - \bar{h}(T_{ref})$ (4)

$\Delta\bar{h}$ = Entalpy change due to a change of state at a constant composition; n_{out} and n_{in} = correspond to the relevant coefficients in the reaction equation; $\bar{h}_f^0$ = Enthalpy of formation.For each tested fuel engine yields a shaft power or brake power of 3.5 kW. For more practical approach the enthalpy of combustion is replaced by enthalpy of formation.

B. Exergy Analysis

The performance of the engine is evaluated in light of second law of thermodynamics, which describe the worth of energy as well as the lost opportunities to do work by recognising the irreversible losses. Exergy destruction or lost work is known as irreversibility, which is the wasted work potential. Thus the maximum work output or exergy of the system is possible when the processes involved are reversible and the system is reduced to the dead state. Exergy analysis is a useful tool for identifying the magnitude of losses. Thus the fundamental difference between energy and exergy is that while energy is conserved, the exergy is destroyed in all real process due to irreversibility. In a steady flow system Exergy Equation can be expressed as:

$$\dot{X}_{heat} - \dot{X}_{work} + \dot{X}_{mass\ in} - \dot{X}_{mass\ out} - \dot{X}_{destroyed} = 0 \quad (5)$$

$$\Rightarrow \sum_s\left(1 - \frac{T_0}{T}\right)\dot{Q} - \dot{W} + \sum_{in}\dot{m}\cdot e - \sum_{out}\dot{m}\cdot e - \dot{X}_{destroyed} = 0 \quad (6)$$

Where, T = absolute boundary condition temperature

$$e_{in} - e_{out} = (h_1 - h_2) - T_0(s_1 - s_2) \quad (7)$$

T_o = Heat rejection temp.; $s_1 - s_2$ = Change of entropy of the system. The breakdown of energy and exergy of the tested fuel is mentioned in Table III.

TABLE III
Breakdown of fuel energy and exergy for the tested fuel

Breakdown of Fuel Energy for the Tested Fuels	
Fuel-Heat($\dot{Q}_{in}$), kW	$\dot{Q}_{in} = \dot{n}_f$ X LHV
Shaft Power ($\dot{Q}_s$), kW	$\dot{Q}_s = \dot{W}_{cv}$
Rate of heat flow from the engine ($\dot{Q}_{cv}$), kW	$\frac{\dot{Q}_{cv}}{\dot{n}_F} - \frac{\dot{W}_{cv}}{\dot{n}_F} = \bar{h}^0{}_c + \left[n_{CO_2}(\bar{h} - \bar{h}^0)_{CO_2}\right] + \left[n_{H_2O}(\bar{h} - \bar{h}^0)_{H_2O}\right]$
Heat Carried away by Exhaust gases ($\dot{Q}_{ex}$), kW	$\dot{Q}_{ex} = \dot{n}_F\lvert\overline{LHV}_{fuel}\rvert - \dot{W}_{cv} - \lvert\dot{Q}_{cv}\rvert$
Breakdown of Fuel Exergy for the Tested Fuels	
Fuel Exergy ($\dot{X}_{in}$) , kW	$\bar{X}_{in} = \left(\bar{X}_{fuel}^{chem}\right)_{in} = \left[\left\{1.0401 + 0.1728\left(\frac{H}{C}\right) + 0.0432\left(\frac{O}{C}\right) + 0.2169\left(\frac{S}{C}\right) \times \left(1 - 2.0268\left(\frac{H}{C}\right)\right)\right\}\right] \times \lvert LHV_{fuel}\rvert$
Shaft Exergy ($\bar{X}_{shaft}$)	$\bar{X}_{shaft} = \dot{W}_{cv}$
Exhaust gas exergy ($\bar{X}_{exhaust}$) , kW	$\bar{X}_{exhaust} = \bar{X}_{exhaust}^{th} + \bar{X}_{exhaust}^{chem}$
Heat Loss exergy ($\bar{X}_{heat\ loss}$), kW	$\bar{X}_{heat\ loss} = \left(1 - \frac{T_0}{T_j}\right)\dot{Q}_{cv}$
Destroyed Exergy ($\dot{X}_{destroyed}$), kW	$\dot{n}_F\bar{X}_{in} = \dot{W}_{CV} + \dot{n}_F(\bar{X}_{heat\ loss} + \bar{X}_{exhaust}) + \dot{X}_{destroyed}$

Where, C, H, S and O are the mass fraction of carbon, hydrogen, sulphur and oxygen respectively.
The exhaust gas exergy is expressed as:

$$\bar{X}^{th}_{exhaust} = \bar{h} - \bar{h}_0 - T_0(\bar{s} - \bar{s}_0) \quad (8)$$

Where $\bar{h}$ and $\bar{s}$ are specific enthalpy and specific entropy per unit mass at exhaust temperature while the subscripts '0' represents the reference state. The exergy of the component existing in the environment is given by Equation (9) as:

$$\bar{X}^{chem}_{exhaust} = \bar{R}T_0 \sum_{i=1}^{n} a_i \ln \frac{y_i}{y_i^e} \quad (9)$$

Where, y_i = molar ratio of the ith component of the exhaust gas; y_i^e = molar ratio of the ith component in the reference environment; $\bar{R}$ = Universal gas constant in kJ /mol-K. The reference environment is considered a mixture of perfect gases on a molar basis: N_2, 75.67%; O_2, 20.35%; CO_2, 0.0.3%; H_2O, 3.12%; other, 0.83%. The reference environment has a temperature (T_0) of 298.15 K and a pressure (P_0) of 1 atm. $\dot{Q}_{cv}$ = heat supplied from a reservoir; T_0 = environmental temperature; T_j = absolute temperature at the location on the boundary.

III. RESULTS AND DISCUSSIONS

During the production process, light gases were produced about 10%. The solid residue is black colour were about 15%. The liquid plastic fuel is 75%. Production yield percentage is shown in Table II. Molecular Formula, Molecular Weight, Lower Heating Value (LHV), Formation Enthalpy and Specific Exergy of tested sample is shown in Table IV.

TABLE IV

Molecular Formula, Molecular Weight, LHV, Formation Enthalpy and Specific Exergy of tested sample

Fuels	Molecular Formula	Average Molecular Weight (kg kmol^{-1})	LHV (kJ kg^{-1})	Formation enthalpy (kJ kmol^{-1})	Specific Exergy (kJ kg^{-1})	Fuel consumption (kg/hr)
MB20	$C_{13.326}H_{27.97}S_{0.0019}O_{0.4}$	194.56	40,450	-752,502	43,281	0.83
NB20	$C_{13.34}H_{27.98}S_{0.019}O_{0.4}$	194.74	40,500	-745,773	43,335	0.82
Diesel	$C_{12}H_{26}$	172.08	42,640	-528,523	45,624.8	0.79

Energy and exergy values of the tested fuels are shown in Figure.3.and Figure 4 respectively.

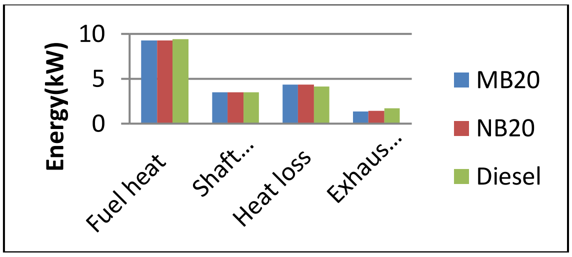

Fig. 3. Comparison of energy distribution of the tested fuels

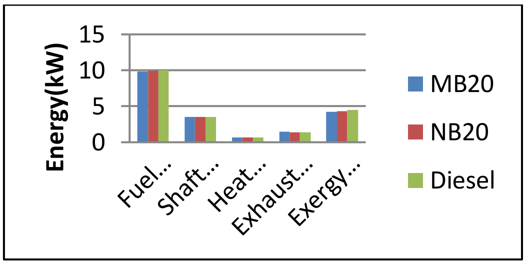

Fig. 4. Comparison of exergy distribution of the tested fuels

Figure 3 showed that the fuel energy entering the engine for the diesel was higher than that of biodiesel as fuel energy is directly proportional to the lower heating value of the fuel to the same power output of 3.5 kW. The rate of heat transfer for biodiesels is more than that of diesel fuel. This was also endorsed to the promotion of better combustion with biodiesel fuels. It was observed that the energy loss due to exhaust gas for biodiesels was less than that of diesel fuel. The exhaust loss was a function of the difference between the fuel energy input and the heat loss energy from the engine.

Figure 4 revealed that the fuel exergy input to the engine for the diesel is more than the B20 fuels as the fuel exergy values sustain similar trends to the fuel energy value. The heat loss exergy values are comparable in same ways to heat loss energy values. Results show that fuel exergy input was lost due to exhaust gas for all tested B20 fuels. The maximum exergy destruction was seen in case of diesel.

IV. CONCLUSION

- Biodiesel provides slightly less energy (1.62%-1.73%) to the engine than diesel fuel.

- The rate of heat transfer for biodiesels was nearly about (4.07% – 4.31% more than that of diesel fuel.
- The energy loss due to exhaust gas for MB20 and NB20 biodiesels were 22.30% and 21.4%, less than diesel fuel.
- The fuel exergy inputs are 6-7% higher than the corresponding fuel energy inputs.
- Results show that 6.37-6.82% of the fuel exergy input was lost due to heat transfer from the engine.
- Results show that 14.25-14.47 % of the fuel exergy input was lost due to exhaust gas for all tested B20 fuels.
- The exergy destruction in the test engine for biodiesels was found to be 43.21%-45.26% of the fuel exergy input.

Finally it can be concluded that the use of biodiesels of B20 blends results in almost the same energetic and exergetic performance with diesel. Thus the tested blends can be a substitute for diesel fuel which will help to reduce the import bill of petroleum products of India.

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