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RESEARCH ARTICLE OPEN ACCESS

Performance Analysis of a C.I. Engine Fuelled With Simarouba Biodiesel

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ABSTRACT-- In this study the energy and exergy analysis of a C.I. engine fuelled with diesel and SB20 (20% blend of simarouba oil Methyl Ester and 80% diesel) have been investigated. The study was carried out by 1st law and 2nd law of thermodynamics. It was found that fuel exergy inputs are higher than the fuel energy input and the fuel exergy of diesel is more that the biodiesel blend. The heat loss exergy of biodiesel is higher than diesel and exhaust gas exergy of biodiesel is more than diesel. The exergy destruction of diesel is more than the biodiesel blend.

Index Terms—Biodiesel, Diesel, Energy, Exergy

I. INTRODUCTION

WORLDWIDE warming due to burning up of fossil fuel is a major threat to the environment. Currently in many countries, the emissions of diesel engines running on petro-diesel are strictly regulated. The upper limits for the emission of CO, CO_2, NO_x, THC (Total unburned hydrocarbons) and PM (Particulate matters) have been defined. Also in India 75% of all crude oil was imported resulting in a large import bill. Escalating imports of crude oil which is limited, with the commonly fluctuating prices affects the socio-financial structure of countries. This economic and geopolitical factor have put added impassion to renewable energy sources. These limits and scarcity of petroleum resources has promoted researchers to go for an alternative fuel used in C.I. engines. Biodiesel is an alternative fuel to eliminate many of these problems. $CO_2$is recycled in a photo-synthesis process so greenhouse effect is noteworthy [1].

Biodiesel is a diesel equivalent to bio fuel made from renewable biological materials like vegetable oils, animal fats and bio mass, via a catalytic reaction known as transesterification. Biodiesel is an alternative fuel that can be used in diesel engines and provides power similar to conventional diesel and the characteristics of biodiesel are very close to diesel fuel [2]-[3]. Biodiesel also helps in the reduction of greenhouse emissions, biodegradation and pollution.

Among the edible and non-edible oils used for biodiesel, the use of edible vegetable oils and animal fats for production of biodiesel is a great concern as they compete with food material. Non edible vegetable oil producing trees thrives in inhospitable condition of heat, low water, rocky and sandy soils. Hence the contribution of non-edible oils such as neem, jatropha, karanja, kusum, mahua will be significant as a non-edible plant oil source for biodiesel production.

It has been recommended by different authors that twenty percent biodiesel is the optimum concentration for biodiesel blend with improved performance [4]-[5]. In recent years, energy and exergy analysis have been widely used in the design, simulation and performance assessment for many engineering devices, power plants and in many process industries for performance improvement. Kopac and Kokturk (2005) carried out energy and exergy analysis of an internal combustion engine operating on the conventional Otto cycle to determine the optimum speed [6]. Results indicate that the rpm speed of the engine is maximum at exergy efficiency than that of energy efficiency. Canakci and Hosoz (2006) performed energy and exergy analysis of a four-cylinder turbocharged diesel engine fuelled with soybean methyl ester, yellow grease methyl ester, petroleum diesel fuel, and 20% blend of each biodiesel with petroleum diesel. They found that the tested biodiesels have similar energy and exergy performance as petroleum diesel fuel and most of the energy and exergy destruction occur during combustion [7]. Caliskan et al., (2010) conducted energy exergy analysis on a diesel engine fuelled with soybean biodiesel [8].

In this study the energy and exergy analysis of a C.I. engine fuelled with diesel and SB20 (20% blend of simarouba oil Methyl Ester and 80% diesel) have been investigated in the present study [9]-[10]. The author have carried out the investigation and carried out the energy exergy analysis and has compared the above with the energy exergy analysis with diesel fuel.

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II. MATERIAL AND METHODS

Simarouba belongs to the family Simaroubaceae Quasia. The tree grows up to a height of about 20 m with the trunk being about 50-80cm in diameter. The seed oil extracted from the expeller was used for biodiesel production. The SB20 blend was prepared for the test. The investigations were performed on Compression Ignition Engine. The instruments fitted to the test bed were properly calibrated to minimize the possible errors during experimentation. The compression ignition research engine details are given in Table I. A Schematic diagram of the test engine is shown in Fig. 1.

TABLE I Engine Specifications

Engine Parameters	Specifications
Make	Kirloskar
No of cylinders	01
Diameter of the cylinder	87.5 mm
Length of the stroke	110 mm
Compression ratio	18:1
Brake Power	3.5 kW
Speed	1500 rpm
Injection pressure	240 bars
Fuel injection timing	25^0 BTDC
Lubricating oil	SAE 40
Length of the Connecting rod	234 mm
Diameter of the Orifice for air flow measurement	20 mm
Length of the Dynamometer arm	185 mm

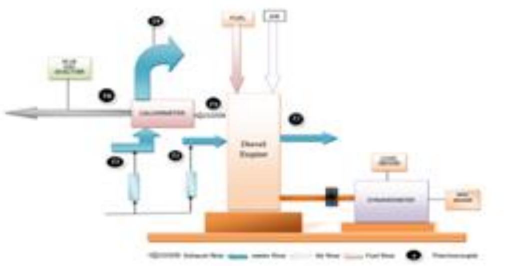

Fig. 1. Schematic layout of the test engine

A. Energy Analysis

The following assumptions made for energy analysis are as: The engine operates under steady flow system; the engine and dynamometer is selected as a control volume; the composition of air and exhaust gas is an ideal gas mixture; the potential and kinetic energy at entry and exists of the fluids are ignored. The analysis was carried out with stoichiometric or theoretical combustion of the fuel. Thus, the fuel is completely burned with theoretical air and also due to complete combustion there was no C, H_2, CO, OH or free O_2 in the product. Experiments were performed with 100% load at the engine speed of 1400 rpm where the engine has a compression ratio of 18 (CR) and fuel injection timing (IT) of 25^0 before top dead centre (BTDC) at steady state condition. The ambient temperature (25^0 C) and atmospheric pressure (1 atm.) were constant during the test. The fuel and air enters at 25^0C and 1 atm. The product of combustion leaves the engine at T (250^0C). Neglecting the formation enthalpy of O_2 and N_2, considering the known lower heating value (LHV) and taking the formation enthalpy of CO_2 and H_2O, the formation enthalpy of the sample fuel was calculated.The fuel and air enters at 25^0C and 1 atm. The product of combustion leaves the engine at T (250^0C).

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

$$\Rightarrow \dot{Q} - \dot{W} = \sum_{out} \dot{m}\left(h + \frac{V^2}{2} + gz\right) - \sum_{in} \dot{m}\left(h + \frac{V^2}{2} + gz\right) \quad (1)$$

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

By Neglecting the potential energy and kinetic energy, the Equation (2) can be written on unit mass basis as:

$$q - w = h_2 - h_1 \quad (3)$$

The energy analysis was carried out with stoichiometric basis. Therefore the product was free from C, H_2, CO, OH and O_2. The input to the system is fuel and air while output is CO_2, N_2 and H_2O. The pressure and temperature condition of input and output remain identical. The Chemical reaction of the tested fuel is given below

$$C_xH_yO_z + a(O_2 + 3.76N_2) \longrightarrow bCO_2 + cH_2O + N_2 \quad (4)$$

The steady flow energy rate balance on per mole of fuel basis resulting from Equation (3) can be written as:

$$\frac{\dot{Q}_{cv}}{\dot{n}_F} - \frac{\dot{W}_{cv}}{\dot{n}_F} = \bar{h}_p - \bar{h}_r = \sum_{product} n_{out}\left(\bar{h}_f^0 + \Delta\bar{h}\right)_{out} - \sum_{reactants} n_{in}\left(\bar{h}_f^0 + \Delta\bar{h}\right)_{in} \quad (5)$$

Where,

$$\Delta\bar{h} = \bar{h}(T) - \bar{h}(T_{ref}) \quad (6)$$

$\Delta\bar{h}$ = Entalpychangeduetoachangeofstateataconstant composition ; n_{out} and n_{in} = correspond to the relevant coefficients in the reaction equation; $\bar{h}_f^0$ = Enthalpy of formation.

B. Exergy Analysis

The exergy of the system is the maximum work output possible as the system is reduced to the dead state. The maximum work is produced when all the processes involved are reversible. The difference between the maximum amount of useful work or reversible work and the useful work due to irreversibility (lost work). The assumption made for exergy analysis is given as: Exergy change of potential, kinetic, electromagnetic and electrostatic are insignificant; Steady flow engine system; Available energy is from finite energy source.

The exergy balance relation can be expressed for a control volume as

$$\frac{dX_{cv}}{dt} = \sum\left(1-\frac{T_0}{T_j}\right)Q_j - \left[\dot{W} - p_o\frac{dv_{cv}}{dt}\right] + \sum_{in}\dot{m}\psi - \sum_{out}\dot{m}\psi - \dot{X}_{destroyed} \quad (7)$$

The rate form of Equation (13) reduces for a steady – flow process as:

$$\sum\left(1-\frac{T_0}{T_j}\right)Q_j - \dot{W}_{cv} + \dot{m}(\psi_1-\psi_2) - \dot{X}_{destroyed} = 0 \quad (8)$$

Where $\psi_1 - \psi_2 = (h_1 - h_2) - T_0(S_1 - S_2) + \frac{V_1^2 - V_2^2}{2} + g(Z_1 - Z_2)$

Breakdown of Fuel Energy and Exergy for the Tested Fuelsis given in Table II

TABLE II Breakdown of fuel energy and exergy for the tested fuels

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	$\dot{n}_F\bar{X}_{in} = \dot{W}_{CV} + \dot{n}_F(\bar{X}_{heat\ loss} + \bar{X}_{exhaust}) + \dot{X}_{destroyed}$

Fuel Exergy($\dot{X}_{in}$), kW

$$\bar{X}_{in} = \left(\bar{X}_{fuel}^{chem}\right)_{in} = \left[\left\{1.0401 + 0.1728\left(\frac{H}{C}\right) + 0.0432\left(\frac{O}{C}\right) + 0.2169\left(\frac{S}{C}\right) \times \left(1 - 2.0268\left(\frac{H}{C}\right)\right)\right\}\right] \times \lvert LHV_{fuel}\rvert \quad (9)$$

Where, C, H, S and O are the mass fraction of carbon, hydrogen, sulphur and oxygen respectively.

Exhaust gas exergy($\bar{X}_{exhaust}$), kW

The exhaust gas exergy is expressed as:

$$\bar{X}_{exhaust} = \bar{X}_{exhaust}^{th} + \bar{X}_{exhaust}^{chem} \quad (10)$$

$$\bar{X}_{exhaust}^{th} = \bar{h} - \bar{h}_0 - T_0(\bar{s} - \bar{s}_0) \quad (11)$$

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 above said values can be obtained from thermo chemical table (http://kinetics.nist.gov/janaf). The exergy of the component existing in the environment is given by Equation (18) as:

$$\bar{X}_{exhaust}^{chem} = \bar{R}T_0\sum_{i=1}^{n} a_i \ln\frac{y_i}{y_i^e} \quad (12)$$

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 with the following composition 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.

Heat Loss exergy $(\bar{X}_{heat\ loss})$, kW

$$\bar{X}_{heat\ loss} = \left(1 - \frac{T_0}{T_j}\right)\dot{Q}_{cv}$$

(13)

Where, $\dot{Q}_{cv}$ = heat supplied from a reservoir; T_0 = environmental temperature; T_j = absolute temperature at the location on the boundary

Destroyed Exergy $(\dot{X}_{destroyed})$, kW:

$$\dot{n}_F\bar{X}_{in} = \dot{W}_{CV} + \dot{n}_F(\bar{X}_{heat\ loss} + \bar{X}_{exhaust}) + \dot{X}_{destroyed} \quad (14)$$

Exergy efficiency, (η_{exergy})

$$\eta_{exergy} = \frac{\dot{W}_{CV}}{\dot{n}_f\bar{X}_{in}}$$

(15)

III. Results and Discussions

Energy and exergy values of the tested fuels are shown in Fig.2.and Fig. 3 respectively.

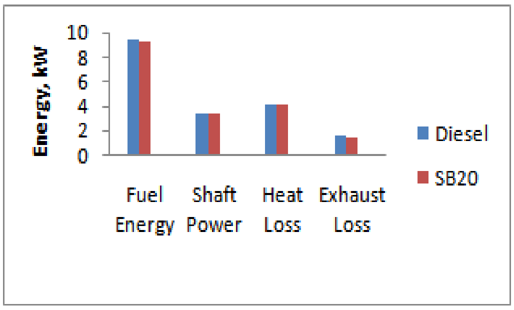

Fig. 2. Energy of the tested fuels

It was observed from Fig. 2. that, the fuel energy of diesel was 1.5% more than that of SB20. Same work done for control volume was observed. The rate of heat transfer of SB20 is 2% more than that of diesel. It was observed that exhaust loss of SB20 was 13.33% less than that of diesel fuel.

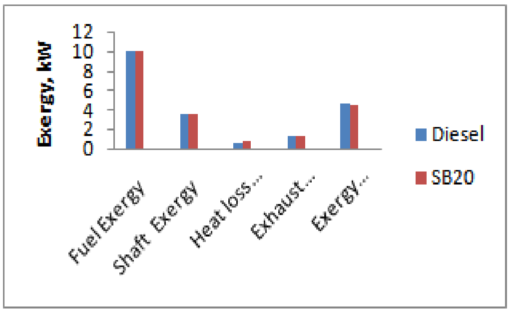

Fig. 3. Exergy of the tested fuels

It was observed from fig. 3 that, the fuel exergy input of diesel is 1.3 % more than that of SB20. Shaft exergy remain same for the tested fuels. Results show that 6.37-6.8 % of the fuel exergy input was lost due to heat transfer from the engine. Fig.3. indicates that the SB20 fuel exergy input lost is 4.7% higher than diesel in the form of heat. It also indicates that the exhaust exergy loss of SB20 was 1.48 % more than that of diesel. The exergy destruction of diesel is 3.9 % more than that of SB20.

The exergetic efficiencies of the tested fuels were 6.5–7 % lower than brake thermal efficiency.

The above results resembles with other researchers result, which is quoted in the reference [6]-[8].

IV. CONCLUSIONS

- Fuel energy of diesel was 1.5% more than that of SB20.
- Rate of heat transfer for SB20 was nearly about 2% more than that of diesel fuel.
- Exhaust loss for SB20 was 13.33% less than that of diesel fuel.
- Fuel exergy inputs are 6-7% higher than the corresponding fuel energy inputs. Fuel exergy of diesel was 1.3 % more than that of SB20.
- Heat loss exergy of SB20 was 4.7% higher than that of diesel.
- Exhaust gas exergy of SB20 was 1.48% more than that of diesel.
- Exergy destruction of diesel is 3.9% more than that of SB20.

From the above conclusion it can be concluded that SB20 fuel shows almost similar energetic and exergetic performance value with diesel. Thus SB20 can be a substitute for diesel as per energy and exergy are concerned. Hence, further investigation can be carried out as an alternative fuel for the engines used for transportation.

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