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RESEARCH ARTICLE

EXERGY ANALYSIS OF CI ENGINE FOR KARANJA BIODIESEL

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ABSTRACT

Biodiesel is renewable energy resources that can be derive from numerous sources. In the current study, energy and exergy analysis of variable compression ratio (VCR) diesel engine for Biodiesel has been performed. The Biodiesel is prepared from karanja (Pongamia Pinnata) vegetable oil by two-step transesterification process. A comparative energy and exergy analysis of different blends (petroleum diesel with 0% karanja biodiesel (KB0), petroleum diesel with 10% karanja biodiesel (KB10), petroleum diesel with 20% karanja biodiesel (KB20), and petroleum diesel with 30% karanja biodiesel (KB30),) of biodiesel with petroleum diesel are also been studied on four stroke constant rpm CI diesel engine. Energy and exergy analysis include various calculation of net heat release rate, cumulative heat release rate, net energy destruction rate, first law efficiency, shaft input, available input, second law efficiency, cooling water and exhaust availability respectively. The energy and exergy balance sheet analysis has proof that KB30 blend of karanja biodiesel is most suitable than other karanja biodiesels for CI diesel engine. Due to greater, first law efficiency and second law efficiency KB30 was found to be the most suitable blend for utilization in CI engines.

INTRODUCTION

For the fast technological developed world, transport becomes the important part for its existence. Because of withdrawing stocks of fossil fuels and increase in number of vehicles in transport sector there is sharp rise in energy demand. To maintain the stroke of high growth rate of world economy, it is necessary to maintain these inputs of energy resources. With the fast rate of depletion of crude oil deposits, alcohol blends on conventional fuels, LPG, CNG have come to the forefront and have been extensively studied and being implemented but are non renewable. These blended fuels are not the final solution to fuel crisis, as are only a compromise for marginal increase in fuel supply. Alternate fuels are only promising hope of future, which has tremendous potential to energize fuel revolution in transport sector [1]. Likewise the petroleum diesel, the biodiesel operates the combustion ignition engines. Though the various edible and non-edible oils can be used for manufacturing biodiesel, out of which karanja (Pongamia pinnata) is one of the best oil suitable for production of biodiesel. The non-renewability of conventional fuels apart from deteriorating land, water and air quality has led to the lookout for better alternatives. Because of the demand for imported oil peaks up, the production of alternate fuels like biodiesel [2] will definitely become more competitive in the markets thus enabling the use of such cleaner fuels in mere endeavor for the environment protection for sustainable development.

Nomenclature

KB 10	Blend of Karanja Biodiesel (10% Biodiesel + 90% Diesel)
KB 20	Blend of Karanja Biodiesel (20% Biodiesel + 80% Diesel)
KB 30	Blend of Karanja Biodiesel (30% Biodiesel + 70% Diesel)
B P	Brake Power (KW)
BMEP	Brake mean effective pressure (bar)
Qin	Fuel energy supplied per unit time (KW)
Qs	Shaft Power (KW)
Qw	Energy in cooling water per unit time (KW)
Qe	Energy in exhaust gas per unit time (KW)
Qu	Unaccounted energy losses per unit time (KW)
mf	Fuel flow rate (Kg/s)
mw	Water flow rate (Kg/s)
LHVf	Lower heating value of fuel (KJ/kg)
Cpw	Specific heat of water (KJ/kg.K)
Cpg	Specific heat of gas (KJ/kg.K)
Texit	Exit temperature (0C)
Tin	Inlet temperature (0C)
Ain	Input availability (KW)
As	Shaft availability (KW)
Aw	Availability of Cooling Water (KW)
Ae	Exhaust gas availability (KW)
Ad	Destructed availability (KW)
Re	Gas constant (KJ/kg.K)
1st Law Efficiency (%)	
2nd Law Efficiency (%)	
S	Entropy generation (KW/K)

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Experimental Set up and procedure

Experimental setup for Karanja Biodiesel production [3, 4]

Karanja Biodiesel is produce by the help of two step transestrification process in Redleys reactor. In the first step of transesterification process, 1500 ml of karanja vegetable oil, 350 ml of Sulphuric acid (H_2SO_4) and 750 ml Methyl alcohol (CH_3OH) are mixed and continuously stirrer (600 rpm) to obtain a homogenous solution at a constant temperature of 65^0C in the Redley reactor. The reactor will run until the pH of the solution reaches the range of 1 to 0.5. The esterified karanja oil and remaining Methanol of the reaction solution was separated by using separating funnel. Now in second step of transesterification process in Redleys reactor, 1000 ml of esterified karanja oil mixed with 10 gm of catalyst Sodium hydroxide (NaOH) and 350 ml of Methanol. The mixture continuously stirred at 600 rpm for 1 hour.

The transesterification reaction yield crude biodiesel with various impurities, which can damage the engine like glycerin and salts fatty acids. These impurities are separated by settling the biodiesel in hot air oven at 100°C for 24 hours and collected in the separate breaker. After resting for 24 hrs, the glycerine was taken to a beaker. Hence, the pure karanja biodiesel is ready to use in the engine testing.

Experimental setup for Engine testing

An experimental test rig which is facilitated by *Sardar Swaran Singh National Institute of Renewable Energy Kapurthala, Punjab* was used to evaluate the thermal performance and emission characteristics. The variable compression ratio CI engine is used to test the Karanja Biodiesel and its different blends with petroleum diesel (KB0, KB10, KB20 and KB30). In this test rig various experiments runs under different working conditions to evaluate the thermal performance and emission characteristics of bio diesel in comparison of diesel engine. In the experimental procedure, the engine was first set at 1500 rpm with full load (10 Kg) capacity and the compression ratio 18:1 for data acquisition system IC Engine Soft User with software version 9.0 and measure different variables and parameter (torque, engine speed, fuel consumption, exhaust gas temperature and cooling water temperatures) used in energy and exergy analysis.

Energy and Exergy analysis

Energy analysis [5]

Basic Performance Parameters Calculations

Break Power , $BP(KW) = \frac{2\pi NT}{60000}$ (1)

Break Mean Effective Pressure,
$BMEP(Bar) = \frac{BP*60}{\frac{\pi}{4}D^2L*\left(\frac{N}{n}\right)*\text{No.of cycle}*100}$ (2)

n = 2 for 4 stroke
n = 1 for 2 stroke

Air flow $(Kg/hr) = C_d * \frac{\pi}{4}d^2 * \sqrt{2gh * \left(\frac{W_{den}}{A_{den}}\right)} * 3600 * A_{den}$ (3)

Air fuel ratio $(A/F) = \frac{\text{Air flow}}{\text{Fuel flow}}$ (4)

Heat Balance Calculation

Fuel energy supplied per unit time $(Q_{in}) = m_f * LHV_f$ (5)

Shaft Power $(Q_s) = BP$ (6)

Energy in cooling water per unit time $(Q_w) = m_w * C_{pw} * (T_{exit} - T_{in})$ (7)

Energy in exhaust gas per unit time $(Q_e) = (m_f + m_a) * C_{pg} * (T_{in} - T_{exit})$ (8)

Unaccounted energy losses per unit time $(Q_u) = Q_{in} - (Q_s + Q_w + Q_e)$ (9)

Exergy analysis [5,6]

The exergy can also be termed as available energy. The availability can be described as the ability to perform useful amount of work by the supplied energy. In the CI engine the availability of fuel (A_{in}) supplied is converted into different types of exergy, like exhaust availability (A_e) and destructed availability (A_d) in the form of radiation, heat transfer to the surrounding, and operating auxiliary equipments, etc.

Calculation of various forms of exergy and 2nd law of efficiency

Input availability of fuel

$$(A_{in}) = [m_f * LHV_f * \{1.0401 + 0.1728(H/C) + 0.0432(O/C) + 0.2169(S/C)(1 - 2.0628(H/C))\}]$$ (10)

Where H, C, O and S are the mass fractions of hydrogen, carbon, oxygen and sulfur contents.

According to ***KOTAS formula , 1985[8]***

$A_{in}/_{CV} = \psi$, $\left[\text{when } \frac{O}{C} \text{ less than } 0.667\right]$, The value of ψ for biodiesel varies from 1.04 to 1.08 (11)

Shaft availability $(A_{in}) = BP$ (12)

Cooling water availability (A_w) = Energy in cooling water

$(Q_{inw}) - m_{we} * C_{pw} * T_{amb} * \ln\left(\frac{T_{wee}}{T_{wie}}\right)$ (13)

Exhaust gas availability (A_e) = Energy in exhaust gas (Q_e) +

$$(m_f + m_a) * T_{amb} * \left\{C_{pa} * \ln\left(\frac{T_{amb}}{T_{eiu}}\right) - R_e * \ln\left(\frac{P_{amb}}{P_e}\right)\right\}$$ (14)

Destructed availability $(A_d) = A_{in} - (A_s + A_w + A_e)$ (15)

Second law efficiency $(\eta_{II}) = [1 - (A_d / A_{in})]$ (16)

Entropy generation rate $(S) = [A_d/T_{amb}]$ (17)

RESULTS AND DISCUSSIONS

In recent years, exergy analysis method has been widely used in the design, simulation and performance assessment of various types of engines for identifying losses and efficiencies.

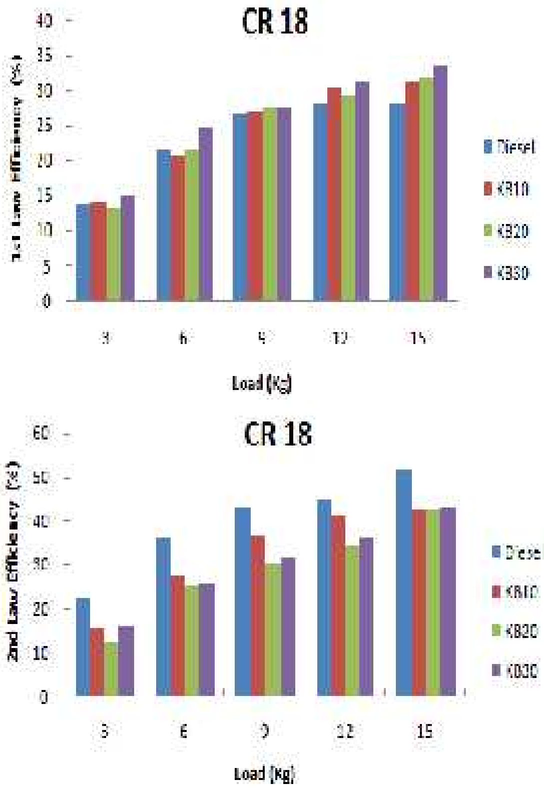

Fig. 1. (a) first law efficiency ; (b) second law efficiency.

Table 1 Energy Balance Sheet for Karanja Biodiesels

Load (Kg)	Q_{in} (KW)	Q_{Shaft} Or BP (%)	Q_W (%)	Q_e (%)	Q_{unc} (%)	Total Heat (%)	1st Law Eff. (%)
			KB 0				
3	6.42	13.70	46.26	20.40	19.62	100	13.71
6	8.17	21.54	42.59	20.07	15.78	100	21.54
9	9.92	26.41	38.81	20.06	14.71	100	26.41
12	12.3	28.04	35.61	19.59	16.74	100	28.05
15	16.7	27.96	28.08	15.74	28.20	100	27.96
			KB 10				
3	6.29	13.99	52.46	22.73	10.81	100	14.00
6	8.58	20.51	41.84	19.34	18.29	100	20.51
9	9.73	27.03	41.83	20.45	10.68	100	27.03
12	11.40	30.35	40.35	21.4	7.89	100	30.35
15	13.70	31.24	37.95	21.16	9.63	100	31.24
			KB 20				
3	6.73	13.22	47.1	21.24	18.42	100	13.22
6	8.42	21.49	42.28	20.19	16.03	100	21.50
9	9.54	27.46	41.82	21.48	9.22	100	27.46
12	11.8	29.23	37.62	20.42	12.71	100	29.23
15	13.5	31.63	36.51	21.11	10.74	100	31.63
			KB 30				
3	6.05	14.71	54.54	28.26	2.47	100	14.71
6	7.15	24.47	47.13	25.59	2.79	100	24.48
9	9.35	27.59	40.21	22.78	9.41	100	27.59
12	11	31.27	37.72	22.36	8.63	100	31.27
15	12.7	33.54	37.63	23.54	5.27	100	33.54

Energy analysis of Karanja biodiesel include net heat release rate, cumulative heat release rate, net energy destructed rate, 1st Law efficiency while exergy analysis was done to study shaft input, availability input, 2nd Law efficiency and destructive exergy is recovered in the water jacket and gas exhaust. Special attention is given to identification and quantification of second-law efficiencies and the irreversibility of various processes and subsystems. From the Energy and Exergy balance sheet shown in Table 1 and Table 2, we can say that KB30 blend of karanja biodiesel is most suitable than other karanja biodiesels for CI diesel engine due to its high 1st and 2nd law efficiency. Also the oxygen content of Biodiesel helps in better combustion of the blend.

Table 2 Exergy Balance Sheet for Karanja Biodiesels

Load (Kg)	A_{in} (KW)	A_{shaft} Or BP (%)	A_w (%)	A_e (%)	A_d (%)	Net Exergy (%)	2nd Law Eff. (%)
				KB 0			
3	6.50	12.91	0.53	8.08	77.79	99.70	22.10
6	8.05	20.34	0.69	14.79	64.16	100	35.88
9	10.51	24.93	0.66	16.93	57.37	99.90	42.61
12	12.98	26.58	0.77	17.41	55.25	100	44.78
15	14.22	32.84	1.61	17.15	48.31	99.93	51.64
				KB 10			
3	6.50	12.91	0.13	2.32	84.25	100	15.39
6	9.27	18.98	0.13	8.11	72.70	100	27.27
9	10.51	25.02	0.29	11.10	63.55	100	36.42
12	12.56	27.99	0.41	12.59	58.98	100	40.98
15	14.31	28.31	0.52	12.92	57.63	100	42.29
				KB 20			
3	9.27	9.50	0.46	1.86	88.11	100	11.91
6	10.51	17.22	0.54	7.48	74.78	100	25.23
9	12.98	20.18	0.58	9.16	70.11	100	29.91
12	14.84	23.24	0.64	10.35	65.75	100	34.24
15	14.84	25.77	0.81	12.76	57.65	100	42.34
				KB 30			
3	8.05	11.08	1.21	3.48	84.20	100	15.78
6	10.51	16.65	0.97	7.71	74.68	100	25.32
9	12.56	20.37	0.99	9.78	68.12	100	31.6
12	14.22	24.19	1.01	10.94	63.85	100	36.14
15	14.84	28.70	1.23	13.19	56.85	100	43.13

CONCLUSIONS

From the thermodynamic point of view, energy and exergy analysis of CI engine is an important tool for finding better available energy management. Due to this fact, a single cylinder, constant speed diesel engine was run with different blends of karanja biodiesel fuels at constant compression ratio and variable load condition. According to the existing study; using exergy as a measure of quality, the petroleum diesel fuel is a greater quality fuel than biodiesel. Because of the net calorific value of diesel is greater than that of the biodiesel. It means that to cover the same distance, greater amount of biodiesel is needed. In addition to this, comparison of different blends of karanja biodiesel fuels shows that KB 30 is having highest energetic and as well as exergetic performance values. The most important factor of the system inefficiency is the destruction of exergy by irreversible processes. This is mainly occurred by the combustion. Exergy losses due to the exhaust gas and heat transfer are other contributors in decreasing order. In addition to these results; this study reveals that a combined energy and exergy analysis provides a much better and more realistic answer for the comparison of biodiesels.

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