Heat Balance Analysis of a C.I Engine Fuelled with Mahua Biodiesel

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Abstract
The study was extended to understand the effect of biodiesel blend magnitude on the performance of engine parameters like, brake thermal efficiency, brake power and fuel properties like flash point, cloud point, kinematic viscosity, calorific value, cetane number and density were studied. Heat balance sheet is prepared on single cylinder 4S-CI engine. The heat distributions are heat energy available from the fuel burnt, heat energy to brake power, heat energy to engine cooling water, heat energy carried by exhaust gases, unaccounted loss.
Keywords: *Mahua, diesel, biodiesel, Characterization, heat balance sheet.*

I. Introduction

DIESEL is one of the main liquid fuels used in India. The consumption of diesel is many times higher than that of petrol, as the prime use of diesel is in agriculture and transport. Efforts are being made to develop a sustainable alternative fuels which can be a replacement of diesel. Much research activity has been carried out in this area and researchers are going for renewable energy source for an alternative fuel which will reduce the gap between the demand and import of hydrocarbons. Escalating imports of crude oil with the commonly fluctuating prices affects the socio-financial structure of countries. Also, worldwide warming due to burning up of fossil fuel is a major threat to the environment. Such as scenario, demands the use of renewable energy sources. The increasing industrialization and motorization of the world has led to a steep rise in the demand of petroleum products. There are limited resources and the petroleum fuels are irreplaceable. India is endowed with a number of vegetable oils like groundnut, cotton seed, sunflower, coconut etc. and many non-edible vegetable oil producing trees like Mahua, Neem, Jatropha, Mahua which are renewable sources of energy can be used as an alternative fuels. These trees can thrive in heat, low water, sandy and rocky areas. As there is a high demand of edible oils for food, so it is justified to concern on non-food-based feedstock.

It has been found that non-edible vegetable oils have properties similar to that of diesel which can be easily extracted from their seeds. In the present investigation fuel was prepared from Mahua seeds.

The main objective of this paper is to convert crude mahua vegetable oil to biodiesel and to prepare the blends of biodiesel MB20 (20% Mahua biodiesel by volume + 80% diesel by volume). To evaluate the performance of diesel engine fuelled with MB20 biodiesel blends and diesel and to prepare heat balance sheet on single cylinder 4S C-I engine.

II. Methodology

For experiment purpose mahua oil was purchased from adivasi mela. The above mahua oil contains free fatty acids, phospholipids, sterols, water odorants and other impurities.

Above all the crude mahua oil was having high viscosity value. In order to use straight vegetable oil (SVO) in the engine, viscosity was to be reduced which can be done by heating the above oil. Other problems associated with using it directly in engine include carbon deposits, oil ring sticking, lubricating problem and also formation of deposits in the engine due to incomplete combustion.

Degumming process was carried out to mahua crude oil to nullify the gum effect. Then the oils were analysed for determination of their acid values by titrating against a known strength of KOH solution.

A. Degumming of mahua Oil

The methods adopted for degumming were treating the crude mahua oil first with immobilized phospholipase and then extracting the phospholipase-treated crude oil with pure water. 1% phosphoric acid was added to 1200 ml of crude neem/polanga oil. The mixture was heated and stirred at 90^0

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C. Then the mixture underwent settling for 24 hours resulting in gum free mahua oil.

Determination of Acid Value of Crude mahua Oils

The acid value of oil is defined as the number of milligrams of potassium hydroxide required to neutralize the free acid present in 1 gram of oil. It is the measure of amount of FFA present in the oil. Higher acid value leads to corrosion besides gum and sludge formation. The acid value or FFA is determined by a standard Titration method. The reagents used are N/10 KOH, Neutral ethyl alcohol and Phenolphthalein indicator. A solution was prepared by adding 1.4 gm KOH to 250 ml of water. 1gm sample oil was added to 20 ml ethyl alcohol, stirring it for 2 minutes without heating. Then 4 drops of phenolphthalein indicator was added into the solution. The solution underwent titration with the KOH solution.

B. Esterification of Crude Sample Oils

The reaction was carried out in the reactor. For the pre-treatment, 5 litre of each oil was heated up to 60^0C, and then methanol (6:1 molar ratio of methanol: oil) and acid catalyst (0.5% v/v) were added. The reactants were stirred at a speed of 1600 revolution per minute at a temperature of 60^0C for 2 hours. This decreased the acid value significantly. The top layer methanol was separated out by decantation process and the oil layer was taken for transesterification. Once the reaction was completed, it was dewatered by passing over a hydrous Na_2SO_4 and then fed to the transesterification process. Now, the pre-treated oil became suitable for alkali-catalysed transesterification.

Transesterification Reaction of Sample Oils

The above obtained oil feed stocks were filtered and pre-processed to remove water and contaminants if any and then fed directly to the transesterification process along with any product of the acid esterification process. The oil was pre-heated to 65^0 C and a mixture of methanol and the catalyst KOH was added to the oil. The molar ratio of MeOH / oil was 6:1 and catalyst concentration was 1% w/w of oil. A part of the alkali catalyst was used to neutralise the residual amount of acid and the remaining as catalyst for transesterification. Once the reaction was completed the major co-products, biodiesel and glycerine, were separated into two layers. The product was allowed to stand overnight to separate the layers. The upper biodiesel layer was washed with hot distilled water to remove the excess methanol, catalyst and traces of glycerol. The washed ester layer was dried under the vacuum to remove the moisture and methanol, and again it was passed over a hydrous Na_2SO_4. The biodiesel so obtained were designated as Mahua oil methyl ester (MOME).

Chemicals, including methanol, acid catalyst (H_2SO_4), alkali catalyst (KOH) etc used for the production of biodiesel were available in the Biodiesel Testing Lab and were of analytical grade.

The fuel properties of the purified biodiesels were characterized based on kinematic viscosity, flash point, acid value, calorific value.

Engine Specification

The engine specification is shown in Table I.

TABLE I.

Engine Specification

Make	SUGANA
Type	Constant speed diesel engine
Rated Output	5.9 kW/8 bhp
Rated Speed	1600 rpm
No. of Cylinder	01
Bore X Stroke	87.5mmX110 mm
Orifice Diameter	20 mm
Type of Ignition	Compression Ignition
Compression ratio	14.22:1
Air-fuel ratio	15-100:1
Exhaust gas temperature	482 ^{0}C

Heat balance sheet on Single cylinder 4S C.I engine

The thermal energy produced by the combustion of fuel in an engine is not completely utilized for the production of the mechanical power. The thermal efficiency of I.C engines is about 33% . Of the available heat energy in the fuel, about 1/3 is lost through the exhaust system, and 1/3 is absorbed and dissipated by the cooling system.

It is the purpose of heat balance sheet to know the heat energy distribution, that is, how and where the input energy from the fuel is distributed.

The heat balance sheet of an I.C engine includes the following heat distribution

a. Heat energy available from the fuel burnt
b. Heat energy equivalent to output brake power
c. Heat energy lost to engine cooling water
d. Heat energy carried away by the exhaust gases
e. Unaccounted heat energy loss

Formula used:-

a. Heat energy available from the fuel burnt, (Q_s)	m_f xCV
b. Heat energy equivalent to output brake power, (Q_{BP})	$\sqrt{3}VI\cos\emptyset$
c. Heat energy lost to engine cooling water, (Q_{CW})	m_w x C_w x (t_{wo} – t_{wi})
d. Heat energy carried away by the exhaust gases, (Q_{EG})	m_{fg} x C_{fg} x (t_{fg} – t_{air})

Where
m_f = mass of fuel in kg / sec
CV = Calorific value of fuel in Kj/kg
V= Voltage
I = Current
m_w= mass of water in kg/sec
Cw= Specific heat of water in Kj/kg K
t_{wo} = outlet temperature of water from the jacket in K
t_{wi} = inlet temp of water to the engine in K
m_{fg} = mass of flue gas in kg/sec = m_r + m_{air}
C_{fg} = Calorific value of flue gas in Kj/kg
t_{fg} = outlet temperature of flue gas from the engine in K
t_{air} = ambient temp in K

Calculation

Mass of flue gas

Use an orifice Meter at inlet manifold for measuring the air velocity across orifice. Then mass flow rate can be estimated by product of Air velocity, Air density and Cross sectional area of orifice. Pressure differential across Orifice will be used for getting velocity of Air flowing through orifice.

An orifice plate is a thin plate with a hole in it, which is usually placed in a pipe. When a fluid (whether liquid or gaseous) passes through the orifice, its pressure builds up slightly upstream of the orifice but as the fluid is forced to converge to pass through the hole, the velocity increases and the fluid pressure decreases. A little downstream of the orifice the flow reaches its point of maximum convergence, the vena contracta where the velocity reaches its maximum and the pressure reaches its minimum. Beyond that, the flow expands, the velocity falls and the pressure increases. By measuring the difference in fluid pressure across tappings upstream and downstream of the plate, the flow rate can be obtained from Bernoulli's equation using coefficients established from extensive research.

In general the mass flow rate is measured in kg/s across an orifice can be described as

$$m_{air} = \frac{C_d}{\sqrt{1-\beta^2}}\,\epsilon\,\frac{\pi}{4}d^2\sqrt{2\,\rho_1\Delta p} \quad (1)$$

Where

C_d = Coefficient of discharge, dimensionless between 0.6 to 0.85

$$\beta = diameter_{\,Orifice}/Diameter_{pipe}$$

ϵ = Expansibility factor , 1 for in compressible gases and most liquids, and decreasing with pressure ratio across the orifice, dimensionless

d= internal orifice diameter under operating condition in m

ρ_1 = Air density in kg/m^2

Δp = differential pressure measured across the orifice, in Pascal

Brake power (BP):

$$B.P = \sqrt{3}VI\cos\emptyset \quad (2)$$

Brake thermal efficiency (BTE):

$$BTE = \frac{BP}{(m_f x C_v)} \quad (3)$$

Brake Specific fuel consumption (BSFC)

$$BSFC = \frac{Fuel\ Consumption}{Break\ Power} = \frac{m_f}{BP} \quad (4)$$

Where
BSFC = Brake Specific Fuel Consumption
m_f = Mass of the fuel
BP = Break Power
Cv= Calorific value
BP=Brake power

Alternator Specification

The alternator specification is given in Table II

TABLE II.

Specification of Alternator

Make	SUGANA
Current	A.C.
KVA	6.25
Phase	3
Volts	415
Frequency	50
Speed	1500 rpm

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III. RESULTS AND DISCUSSIONS

The result is based on production of mahua biodiesel from mahua oil by degumming, esterification and transesterification method.

The acid value of oil at different stages are given in Table III.

TABLE III

Acid value of Mahua oil

Mahua oil	Acid value
Crude oil	55
After degumming	25.76
Before esterification	25.76
After 1st esterification	8.42
After 2nd esterification	6.16
After transesterification	1.12

Fuel properties of mahua oil, MOME and diesel is shown in Table IV.

TABLE IV

Fuel properties of mahua oil, MOME and diesel

Fuel	Diesel	Mahua oil	MOME	MB20
Specific gravity	0.84	1.91	0.88	0.866
Calorific value (Mj/kg)	43.00	34	36.12	42.67
Cloud point(^{0}C)	-12	7	6	-4
Fire Point(^{0}C)	68	250	225	126
Flash point (^{0}C)	63	240	218	105
Kinematic viscosity (at 40^{0}C)	2.44	32.1	4	3.8

MB20 fuel properties resembles with diesel

The engine is tested by diesel and MB20, the observation data at various loads of the engine is given in Table V.

TABLE V

Voltage, current, Fuel consumption of diesel and MB20 at various load

	Diesel	MB20
At No Load condition		
Voltage (volt)	400	400
Current (Amps.)	2.1	2.3
Fuel consumption (m_f) kg/sec	0.000114	0.00011
Inlet water temp. (^{0}C)	27	27
Outlet water temp. (^{0}C)	40	42
Exhaust Temp (^{0}C)	250	260
Engine cooling water flow rate (kg/sec)	0.031	0.026
Mass of air	0.0030	0.00029

(kg/sec)		
Load at 35%		
Voltage (volt)	400	412
Current (Amps.)	2.6	2.8
Fuel consumption (m_f) kg/sec	0.00014	0.0021
Inlet water temp. (^{0}C)	27	27
Outlet water temp. (^{0}C)	50	54
Exhaust Temp (^{0}C)	275	300
Engine cooling water flow rate (kg/sec)	0.023	0.020
Mass of air (kg/sec)	0.0036	0.0025
Load at 45%		
Voltage (volt)	400	408
Current (Amps.)	3.1	3.2
Fuel consumption (m_f) kg/sec	0.00019	0.00018
Inlet water temp. (^{0}C)	27	27
Outlet water temp. (^{0}C)	61	62
Exhaust Temp (^{0}C)	280	305
Engine cooling water flow rate (kg/sec)	0.020	0.019
Mass of air (kg/sec)	0.005	0.0028
Load at 50%		
Voltage (volt)	400	404
Current (Amps.)	3.9	4.1
Fuel consumption (m_f) kg/sec	0.00025	0.00025
Inlet water temp. (^{0}C)	27	27
Outlet water temp. (^{0}C)	65	67
Exhaust Temp (^{0}C)	285	320
Engine cooling water flow rate (kg/sec)	0.026	0.024
Mass of air (kg/sec)	0.007	0.0038

Specific heat, density, gas constant is given in Table VI for the calculation purpose of heat balance sheet.

TABLE VI

Specific heat, density, gas constant

Specific heat of water (C_w)	4.187 Kj/kg.K
Specific heat of exhaust flue gas (C_{fg})	2.1 kJ/kg.K
Gas constant (R)	0.287 Kj/Kg.K
Co-efficient of discharge (C_d)	0.6
Density of water (ρ_w)	1000 kg/m^3
Density of diesel (ρ_d)	910 kg/m^3
Density of MB20 (ρ_{bd})	950 kg/m^3
Density of air at 27^0 C (ρ_a)	1.17 kg/m^3
Expansibility factor (ϵ)	1
Diameter of air pipe	50 mm

The brake power, BTE and BSFC at different loads is shown in Table VII

TABLE VII

Load calculation

LOAD	**No Load**		**35% load**		**45% load**		**50% load**	
FUEL	**MB 20**	**Diesel**	**MB 20**	**Diesel**	**MB 20**	**Diesel**	**MB 20**	**Diesel**
Brake Power (kW)	1.59	1.45	1.79	1.99	2.14	2.26	2.70	2.86
Brake Thermal Efficiency (%)	34	30	29.7	31	26.1	29.4	24.7	26.8
C. Brake specific fuel consumption (bp/kg.hr)	0.28	0.31	0.28	0.27	0.32	0.28	0.33	0.31

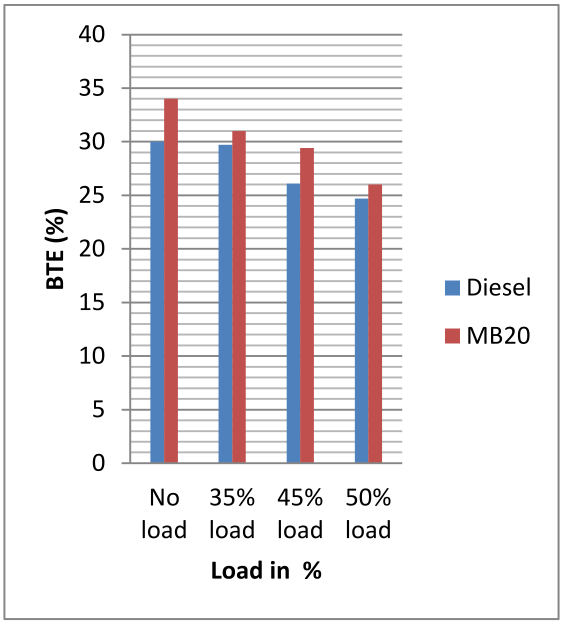

Fig.1. BTE vs Load

Fig 1 indicated that the break thermal efficiency of MB20 is more than diesel at all loads.

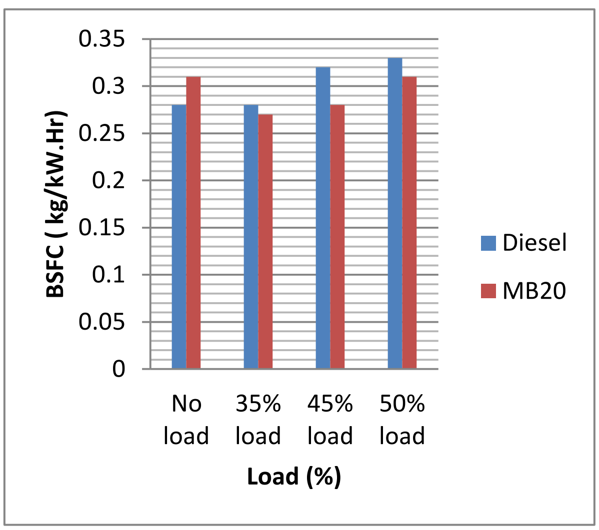

Fig.2. BSFC vs. Load

Fig 2indicated that at no load MB20 consumes more fuel than diesel but during other loads MB20 consumes less than diesel.

Heat Balance sheet

Heat Balance sheet on engine fuelled by diesel and MB20 is calculated based on the formula given under methodology is shown in Table VIII and Table IX respectively.

TABLE VIII

Heat Balance Sheet on engine fuelled by diesel

Heat Energy	No load	35% load	45% load	50% load
Heat energy supplied (Q_s), kW	4.97	6.11	8.29	10.91
Heat energy equivalent to output brake power(Q_{BP}), kW	1.45 (29.17%)	1.79 (29.29%)	2.14 (25.81%)	2.70 (24.74%)
Heat energy lost to engine cooling water(Q_{CW}), kW	1.73 (34.8%)	2.26 (36.9%)	2.98 (35.94%)	4.14 (37.94%)
Heat energy carried away by the exhaust gases, (Q_{EG}), kW	1.49 (29.97%)	1.95 (31.91%)	2.81 (33.89%)	3.81 (34.92%)
Unaccounted Heat energy loss(Q_{un}), kW	0.3 (6%)	0.11 (1.8%)	0.36 (4.34%)	0.26 (2.31%)

The heat energy supplied and the unaccounted heat energy loss was found maximum in diesel at no load and heat energy lost to engine cooling water, heat energy carried away by the exhaust gases was found maximum in diesel at 50% load.

TABLE IX

Heat Balance Sheet on engine fuelled by MB20

Heat Energy	No load	35% load	45% load	50% load
Heat energy supplied (Q_s), kW	4.69	6.40	7.68	10.66
Heat energy equivalent to output brake power(Q_{BP}), kW	1.59 (33.9%)	1.99 (31%)	2.26 (29.47%)	2.86 (26.82%)
Heat energy lost to engine	1.68 (35.8%)	2.36 (36.87%)	2.84 (36.97%)	4.05 (37.99%)

cooling water(Q_{CW}), kW				
Heat energy carried away by the exhaust gases, (Q_{EG}), kW	1.12 (23.8%)	1.53 (23.90%)	1.76 (22.91%))	2.55 (23.92%)
Unaccounted Heat energy loss(Q_{un}), kW	0.3 (6.39%)	0.52 (8.1%)	0.82 (10.67%)	1.2 (11.25%)

The heat energy supplied, heat energy lost to engine cooling water, heat energy carried away by the exhaust gases and the unaccounted heat energy loss was found maximum in MB20 at 50% load.

IV. Conclusion

- The Mahua biodiesel properties resembles with diesel.
- The engine performance fuelled by MB20 is compared with diesel and the BTE and BSFC resembles with diesel.
- The heat energy supplied and the unaccounted heat energy loss was found maximum in diesel at no load and heat energy lost to engine cooling water, heat energy carried away by the exhaust gases was found maximum in diesel at 50% load.
- The heat energy supplied, heat energy lost to engine cooling water, heat energy carried away by the exhaust gases and the unaccounted heat energy loss was found maximum in MB20 at 50% load.
- The C.I. Engine can run with MB20 without any engine modification

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