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Using Blends of Jatropha Methyl Easter as Alternative Fuel: An Experimental Investigation for a Diesel Engine

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Abstract:
Energy is a basic requirement for every sector of economic development in a country. As a result, energy demands have been steadily increasing along with the growth of human population and industrialization. Common sources of energy are petroleum, natural gas and coal from fossil fuels. This growing consumption of energy has rapidly depleted non-renewable sources of energy. Biodiesel is one of the most promising alternative fuels for diesel engines. The demand of biodiesel has significantly increased from 2005 in all over the world. Biodiesel is defined as a fuel comprising of mono-alkyl esters of long chain fatty acids derived from vegetable oil or animal fat. Direct use of vegetable oils and animal fats as combustible fuel is not suitable due to their high kinematic viscosity and low volatility. Furthermore, its long term use posed serious problems such as deposition, ring sticking and injector chocking in engine. Therefore, vegetable oils and animal fats must be subjected to chemical reaction such as transesterifacation to reduce the viscosity of oils. In that reaction, triglycerides are converted into fatty acid methyl ester (FAME), in the presence of short chain alcohol, such as methanol or ethanol, and a catalyst, such as alkali or acid, with glycerol as a by- product.

Keywords: *alternative fuel, Biodiesel, Jatropha plant, transesterifacation*

1. Introduction

The rising prices of fossil-based fuels and potential shortage in the future have led to a major concern about the energy security in every country. Moreover, there are many disadvantages of using fossil-based fuels, such as atmospheric pollution and environmental issues. Fossil fuels emissions are major contributors of greenhouse gases which may lead to global warming. Combustion from fossil fuels is major source of air pollutants, which consist of CO, NOx, hydrocarbons and particulates. The disadvantages and shortages of fossil fuels have motivated many researchers to find an alternative source of renewable energy. The concept dates back to 1885 when Dr. Rudolf Diesel built the first diesel engine with the full intention of running it on vegetative source. He first displayed his engine at the Paris show of 1900 and astounded everyone when he ran the patented engine on any hydrocarbon fuel available - which included gasoline and peanut oil. In 1912 he stated "the use of vegetable oils for engine fuels may seem insignificant today. But such oils may in the course of time become as important as petroleum and the coal tar products of present time. Scientists discovered that the viscosity of vegetable oils could be reduced in a simple chemical process. In 1970 and that it could work well as diesel fuel in modern engine. This fuel is called Bio- Diesel.

2. Advantages of Biodiesel as Compared to Conventional Diesel

- It helps to reduce carbon dioxide and other pollutants emission from engines.
- Engine modification is not needed as it has similar properties to diesel fuel.
- It comes from renewable sources whereby people can grow their own fuel.
- Diesel engine performs better on biodiesel due to a high cetane number.
- High purity of biodiesel would eliminate the use of lubricant.
- Biodiesel production is more efficient as compared to fossil fuels as there will be no underwater plantation, drilling and refinery.
- Biodiesel would make an area become independent of its need for energy as it can be produced locally.

3. Heterogeneous Base Catalyzed Transesterifacation Process

In conventional industrial biodiesel processes, the methanol transesterifacation of vegetable oils (edible and non edible oil) is achieved using a homogeneous catalyst system operated in either batch or continuous mode. In most cases the catalyst is sodium hydroxide or potassium hydroxide. It is recovered after the transesterifacation reaction as sodium or potassium methyl ate and sodium soaps in the glycerol phase. An acidic neutralization step with, for example, aqueous hydrochloric acid is required to neutralize these salts or sometimes water. In that case glycerol is obtained as an aqueous solution containing sodium chloride.

Depending on the process, the final glycerol purity will be about 80% to 95%. When sodium hydroxide is used as catalyst, side reactions forming sodium soaps generally occur. This type of reaction is also observed when sodium methylate is employed and traces of water are present. The sodium soaps are soluble in the glycerol phase and must be isolated after neutralization by decantation as fatty acids. The loss of esters converted to fatty acids can reach as high as 1% of the biodiesel production.

3.1. Homogenously Catalyzed Transesterifacation

The heterogeneously catalyzed process, especially using solid base catalysts, has been studied continuously for the last decade. These operations are illustrated in Figure 1.

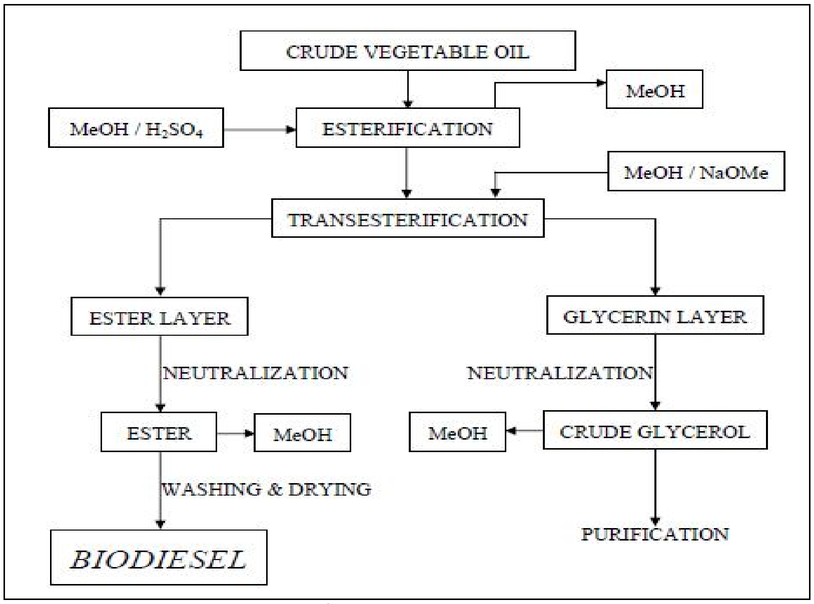

Figure 1:Flow Chart 1 Global scheme for a typical continuous homogeneous catalyzed process

To avoid catalyst removal operations and soap formation, much effort has been expended on the search for solid acid or basic catalysts that could be used in a heterogeneous catalyzed process. So a new continuous process is described, where the transesterifacation reaction is promoted by a completely heterogeneous catalyst.

4. Advantages & Disadvantages of Heterogeneous Base Catalyst

4.1. Advantages

- Relatively faster reaction rate than acid-catalyzed transesterifacation.
- Reaction can occur at mild reaction condition and less energy intensive.
- Easy separation of catalyst from product.
- High possibility to reuse and regenerate the catalyst.

4.2. Disadvantages

- Poisoning of the catalyst when exposed to ambient air.
- Sensitive to free fatty acid (FFA) content in the oil due to its basicity property.
- Soap will be formed if the FFA content in the oil is more than 2 wt.%
- Too much soap formation will decrease the biodiesel yield and cause problem during product purification.
- Leaching of catalyst active sites may result to product contamination.

Sl.No.	Homogeneous base-catalyzed Transesterifacation Process	Heterogeneous base-catalyzed Transesterifacation Process
1	Reaction is very fast.	Relatively slow process.
2	Reaction is 100% complete.	Conversion is relatively poor.
3	It requires more amount of catalyst.	It requires less amount of catalyst.
4	Catalyst dissolved in the reaction mixture.	Catalyst does not dissolve in the reaction mixture. Catalyst can be separated easily from the biodiesel.
5	Homogeneous catalysts exhibit relatively more corrosive character.	Heterogeneous catalysts exhibit less corrosive character.
6	Purification is difficult.	Purification is much easier.

7	Biodiesel purification by water wash.	Biodiesel purification by decalcification process.
8	Glycerin is crude need further purification.	Biodiesel and glycerin received is pure.
9	Catalyst cannot be recycled.	Catalyst can be recycled.
10	Process is cheaper.	Complicated catalyst synthesis procedures lead to higher cost.

Table 1: Comparison between Homogeneous & Heterogeneous base-catalyzed transesterifacation process:

5. Jatropha Plant as Potential Source for Biodiesel Production

Jatropha Curcas belongs to the Euphorbiaceous family. The name Jatropha derives from Latin words Jatros (doctor) and trope (food) as it has many medicinal values. The Jatropha plant is native to American tropics but naturally grows in tropical and subtropical countries, like sub-Sahara Africa, India, South East Asia, and China. The seeds usually mature 3–4 months after flowering and once this plant becomes an adult, it will continue producing seeds for 30 years. Jatropha the wonder plant produces seeds with an oil content of around 37-40%.

Jatropha Curcas is a drought-resistant perennial, growing well in marginal/poor soil. The oil can be combusted as fuel without being refined. It burns with clear smoke-free flame, tested successfully as fuel for simple diesel engine.

Medically it is used for diseases like cancer, piles, snakebite, paralysis, dropsy etc. Depending on soil quality and rainfall, oil can be extracted from the Jatropha nuts after two to five years. Jatropha Curcas grows almost anywhere, even on gravelly, sandy and saline soils. It can thrive on the poorest stony soil. . Its water requirement is extremely low and it can stand long periods of drought by shedding most of its leaves to reduce transpiration loss. Jatropha is also suitable for preventing soil erosion and shifting of sand dunes.

1	Flowering season	March-May
2	Harvesting season	May-august
3	Yield starts from	3 years
4	Plant Life	25-30 years
5	Seed yield(Kg)	1-2
6	Oil percent	37-40
7	Rate (per Kg seed)	Rs.8.00 to Rs.10.00

Table 2: Details of the Jatropha Curcas plant

5.1. Advantages & Disadvantages of Jatropha Curcas Plant

5.1.1. Advantages

1) Good agronomic traits
   - Hardy shrub which grows in semi-arid conditions and poor soils
   - Can be intercropped with high value crops such as sugar, coconut palm, various fruits and vegetables, providing protection from grazing livestock and photo-protection action against pests and pathogens
   - It is easy to establish and grows relatively quickly.
   - Yields around 4 tons of seed per hectare in unwept hedges are achievable
   - low nutrient requirements
   - Requires low labor inputs
2) Multi-purpose plant
   - Seeds and leaves are toxic to human beings and animals
   - Toxicity is based on several components (phorbol esters, curcains, and trypsin) which make complete detoxification a complicated and difficult process.
   - Competes with food production for land use Protective hedges around fields.
   - Reclaims marginal soils
   - Non-edible and therefore does not compete with food supply when used for biodiesel production
   - Energy crop that produce seeds with high oil yields.

6. Locations for Jatropha Plantation in India

200 districts in 19 potential states have been identified on the basis of availability of wasteland, rural poverty ratio, below poverty line (BPL) census and agro-climatic conditions suitable for Jatropha cultivation. Each district will be treated as a block and under each block 15000 ha Jatropha plantation will be undertaken through farmers (BPL). Proposed to provide green coverage to about 3 Million ha of wasteland through plantation of Jatropha in 200 identified districts over a period of 3 years.

7. Biodiesel Production from Jatropha Oil

Biodiesel production is the process of producing biodiesel, through chemical reaction, transesterifacation and esterification. This involves vegetable or animal fat and oils being reacted with short-chain alcohol (typically methanol or ethanol). Base-catalyzed transesterifacation reacts lipids (fats and oils) with alcohol (typically methanol or ethanol) to produce biodiesel and an impure co-product, glycerol. The Jatropha oil required for this project was collected from Biofuel Tech Park, Agricultural university campus, Madenur, Hassan, Karnataka, India.

There are processes for the manufacturing of the biodiesel. The criterion for the selection of the process is based on the presence of the Free Fatty Acid (FFA) content in the Jatropha oil.

- If the Free Fatty Acid (FFA) content of the raw oil is less than 4%, single stage (Alkali base catalyzed Transesterifacation) process has to be undertaken.
- If the Free Fatty Acid (FFA) content of the raw oil is more than 4%, double stage (Acid catalyzed esterification & Alkali base catalyzed Transesterifacation) process has to be undertaken.

7.1. Determination of Free Fatty Acid Content in Raw Oil:
Step1: Preparation of 0.1N (N/10) NaOH solution
Step2: Titration & calculation of Free Fatty Acid content in raw oil
Step3: Free Fatty Acid (FFA) content calculation

FFA Content $\frac{28.2 \times \text{Normality of NaOH} \times \text{Titration value}}{\text{weight of the oil}}$ For Titration value = 22

FFA = (28.2 * 0.1 * 22) / 10
FFA = 6.204%
Since the FFA of raw Jatropha oil is 6.204 >4, we can choose acid catalyzed esterification process to reduce FFA of the Jatropha oil.

8. Acid Catalyzed Esterification Process

In the Esterification process the excess of the free acid gets reacted. The remaining acid content in the oil undergoes trans-Esterification. So this method is effective for oils that contain high free fatty acid (FFA) content. So the selection of acid catalyst is very important. Generally concentrated sulphuric acid is used for this process. The aim of Esterification reaction is to remove water and to reduce FFA of oil during processing otherwise seriously hurt the reaction conversions.
The Esterification reaction equation was described as below:
RCOOH + CH_3OH = $RCOOCH_3$ + H_2O ………………… (Fatty Acid) (Methanol) (Alkyl Ester) (Water)

FFA Content $\frac{28.2 \times \text{Normality of NaOH} \times \text{Titration value}}{\text{weight of the oil}}$ For Titration value = 5.7

FFA = (28.2 x 0.1 x 5.7) / 10
FFA = 1.607 %
Since, it is less than 4. We can go for transesterifacation process.

FFA value	H_2SO_4 (in ml)
1	0.25
2	0.5
3	0.75
4	1
5	1.25
6	1.5
7	1.75

Table 3: Amount of concentrated sulphuric acid (H_2SO_4) required for Esterification process

9. Heterogeneous Base Catalyzed Transesterifacation Process

Currently Fatty acid methyl esters (FAME) is commonly produced by performing a transesterifacation reaction with homogeneous base catalysts such as KOH or NaOH dissolved in methanol under mild conditions but the produced FAME is required to be purified.

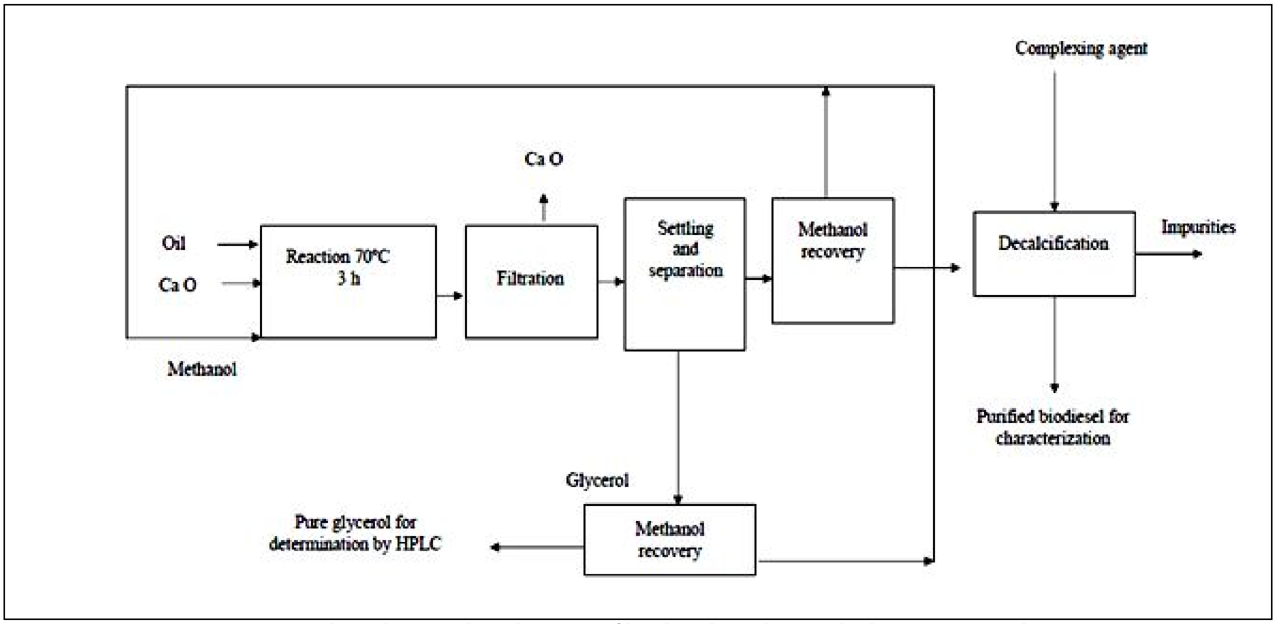

Figure 2: Flow chart 2 Flow diagram of biodiesel production by heterogeneous base

10. Production of Jatropha Methyl Ester (I.E. Biodiesel)

10.1. Transesterifacation Process Parameters

- Methanol to oil molar ratio : 12:1
- Amount of calcinated CaO catalyst : 1.5%(w/v)
- Reaction Temperature : 70°C
- Reaction Time : 3 hours

The general equation for transesterifacation of vegetable oils containing triglycerides is as follows,

$$\begin{array}{l} CH_2-OOC-R \\ | \\ CH-OOC-R \\ | \\ CH_2-OOC-R \end{array} \quad +3CH_3OH \xrightarrow{CATALYST} \begin{array}{l} CH_2-OH \\ | \\ CH-OH \\ | \\ CH_2-OH \end{array} + \begin{array}{l} R-COO-CH_3 \\ \\ R-COO-CH_3 \\ \\ R-COO-CH_3 \end{array}$$

(Triglyceride Oil/Fat) (Methanol) (Glycerol) (Biodiesel)... (6.2)

Where, R= Hydrocarbon Group


Figure 3: Bio-Diesel


Figure 4: Recovery of Methanol

Figure 5: Distillation set up

11. Recovery of Methanol from Jatropha Biodiesel

The obtained Jatropha biodiesel from transesterifacation process contains methanol and some amount of catalyst. The methanol from the biodiesel can be recovered from distillation setup. The steps involved in the distillation process is as follows,

- Transfer the biodiesel into a 1 liter flask with distillation setup.
- Maintain the temperature at 65°C (Since the boiling point of methanol is 64.07°C).
- Methanol starts evaporating.
- Collect the methanol condensate in a 250 ml flask. Nearly 220 ml of methanol can be recovered from a batch process.
- Switch off the system when the methanol condensation stops.

Same procedure can be followed in order to recover the methanol from glycerin.

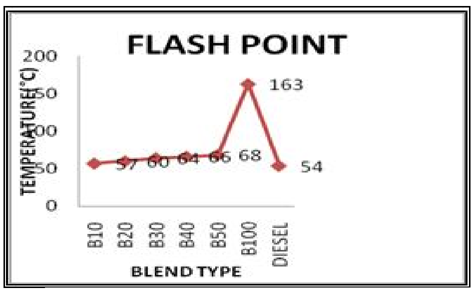

Figure 6: Flash Point of blends of Jatropha biodiesel and diesel

SL.NO.	BLEND TYPE	FLASH POINT(In °C)
1	B10	57
2	B20	60
3	B30	64
4	B40	66
5	B50	68
6	B100	163
7	DIESEL	54

Table 4: Flash point of different blends of Jatropha

12. Fuel Properties of Different Blends of Jatropha Biodiesel & Diesel

Flash Point: The flash point of a volatile liquid is the lowest temperature at which it can vaporize to form an ignitable mixture in air. The biodiesels would be considered significantly safer with temperatures between 128°C and 167°C.

Kinematic Viscosity: Kinematic viscosity is the resistance of the fluid to flow under gravity. The viscosity is important in determining optimum handling storage, and operational conditions.

SL.NO.	BLEND TYPE	TIME (In Sec)	KINEMATIC VISCOSITY (In Cst)
1	B10	128	3.04
2	B20	154	3.66
3	B30	165	3.92
4	B40	175	4.18
5	B50	186	4.42
6	B100	251	5.97
7	DIESEL	107	2.54

Table 5 Kinematic viscosity of different blends

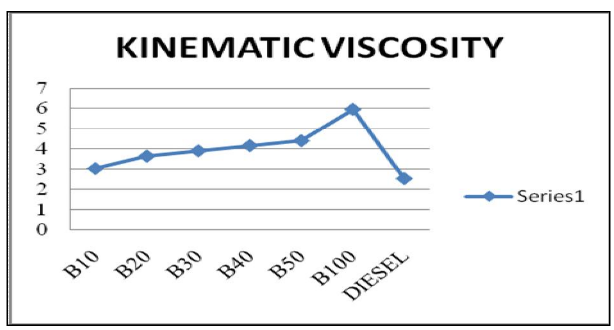

Figure 7: Graph.2 Kinetic Viscosity of different blends

12.1. Copper Strip Corrosion Test:

Acid and sulfur-containing compounds have the potential to cause corrosion in an engine system. The Copper strip corrosion test indicates the potential of biodiesel to affect the copper and brass fuel system part. Copper corrosion assesses the relative degree of corrositivity of a petroleum product due to active sulfur compounds.

12.2. Calculations to find out calorific value of a given sample of biodiesel:

Formula:

Calorific value of sample, $CV_s = \frac{T\times W-(CVt+CVw)}{M}$

Where,

W = water equivalent in Cal/°C. T = Final rising temperature in °C
M = Mass of sample in gram. H = Known Calorific value of sample.
CV_t = Calorific value of thread. CV_w = Calorific value of wire.
CV_s=Calorific value of sample.
In order to determine the calorific value of any sample, first we have to determine the water equivalent of pure biodiesel, the formula used is,

$$W = \frac{H \times M + (CV\ of\ thread + CV\ of\ wire)}{T}\ Cal/°c$$

Cal/°c

Where,
H = Known Calorific value of sample; for B100, H=39000 KJ/kg = 9321.2 cal/gm
M = Mass of sample in gram taken =3gms
CV_t =21cal & CV_w = 9.32cal

$$W = \frac{9321.2 \times 3 + (21 + 9.32)}{6.18}$$ =3987.73 Cal/°c

Example: For Jatropha B50,
Calorific value, CVs = $\frac{T \times W - (CVt + CVw)}{M}$ KJ/Kg Where,
W = Water equivalent in Cal/°C= 3987.73 Cal/°C
T = Rise in temperature for B50 sample = 7.09°C
M = Mass of fuel blend taken= 3gm
CV_t = Calorific value of thread=21cal
CV_w= Calorific value of wire=9.32cal

$$CV_s = \frac{7.09 \times 3987.73 - (21 + 9.32)}{3}$$ = 9414.228 Cal/gm = 39389.133 kJ/kg

The calorific value of Jatropha B50 sample is 39389.133 KJ/Kg.

SL.NO.	BLEND TYPE	RISE IN TEMERATURE (°C)	CALORIFIC VALUE (kJ/kg)
1	B10	7.40	41,120
2	B20	7.29	40,523
3	B30	7.23	40,212
4	B40	7.16	39,827
5	B50	7.09	39,389
6	B100	6.18	38,886
7	DIESEL	7.58	42,141

Table 6: Calorific value of different blends

From the above table, it can be observed that as blending proportion of biodiesel with diesel increases the calorific value keeps on decreasing i.e. for B10 calorific value will be more compared to B50 or B100. The calorific value of blends B10 & B20 are very nearer to diesel.

Sl.No	PROPERTIES	STANDARD	RANGE	OBTAINED
1	Flash point (°C)	ASTM D93	>130 *	163
2	Viscosity (mm^2/s) at 40°C	ASTM D445	1.9-6.0	3.04-5.97
3	Specific gravity	ASTM D4052	0.87-0.90	0.825-0.880
4	Calorific value (KJ/kg)	ASTM D240	--	38,886
4	Calorific value (KJ/kg)	ASTM D240	--	38,886

Table 7: comparison of fuel properties with ASTM standards:

13. Experimental Set Up and Procedure

The experimental work carried out for the objectives, requires an engine test set-up adequately instrumented for acquiring necessary performance and emission characteristics. Jatropha methyl ester blends (Biodiesel-B10, B20, B30, B40 and B50) and pure Diesel were used to test a TV1, Kirloskar, single cylinder, 4-stroke, water-cooled diesel engine having a rated output of 5.2 kW at 1500 rpm and a compression ratio of 24:1. The engine was coupled with an eddy current dynamometer to apply different engine loads. The emissions from the engine were studied at different engine loads. After the engine reached the stabilized working condition, emissions like carbon monoxide (CO), hydrocarbons (HC), Nitrous oxide (NO_x) and exhaust gas temperature (EGT) were measured using a smoke-meter and an exhaust gas analyzer. A single cylinder diesel engine with intercooler e483 type is chosen for experiment.

Figure 8: Schematic Diagram of the Experimental Set-up

1 = Control Panel
2 = Computer system 3 = Diesel flow line
4 = Air flow line
5 = Calorimeter 6 = Exhaust gas analyzer
7 = Smoke meter 8 = Rota meter 9, 11= Inlet water temperature
10 = Calorimeter inlet water temperature 12 = Calorimeter outlet water temperature
13 = Dynamometer 14 = CI Engine 15 = Speed measurement
16 = Burette for fuel measurement T_1= Inlet water temperature 17 = Exhaust gas outlet
T_2 = Outlet water temperature
18 = Outlet water temperature T_3 = Exhaust gas temperature

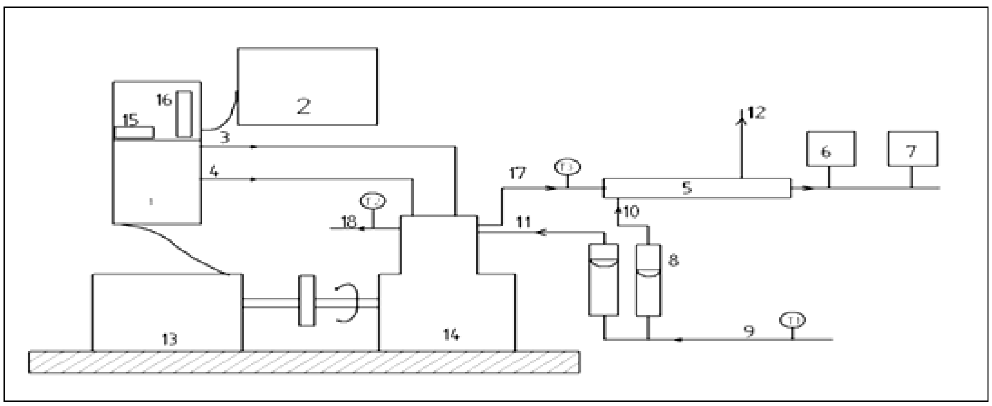

Figure 9

SL. NO.	ENGINE PARAMETERS	SPECIFICTIONS
01	Machine supplier	INLAB Equipments. Bangalore.
02	Engine Type	TV1(Kirloskar, Four Stroke)
03	Number of cylinders	Single Cylinder
04	Number of strokes	Four-Stroke
05	Rated power	5.2KW (7 HP) @1500RPM
06	Bore	87.5mm
07	Stroke	110mm
08	Cubic Capacity	661cc
09	Compression ratio	24:1
10	Rated Speed	1500 RPM
11	Dynamometer	Eddy Current dynamometer, make SAJ
12	Type of cooling	Water cooling
13	Fuel injection Pressure	200bar & 225bar
14	Fuel	Diesel
15	Load Measurement	Strain gauge load cell
16	Speed Measurement	Rotary encoder
17	Temperature Indicator	Digital, PT-100 type temperature sensor
18	Cylinder Pressure Measurement	Piezo-Sensor, range 2000 Psi, make PCB USA
19	Fuel Injection Pressure Measurement	Piezo Sensor, range 5000 Psi, make PCB USA
20	Water flow Measurement	Rota meter

Table 8: Engine specifications

14. Methodology & Experimental Procedure

- Switch on the mains of the control panel and set the supply voltage from servo stabilizer to 220volts.
- The main gate valve is opened, the pump is switched ON and the water flow to the engine cylinder jacket (300 liters/hour), calorimeter (50 liters/hour), dynamometer and sensors are set.
- Engine is started by hand cranking and allowed to run for a 20 minutes to reach steady state condition.

The engine has a compression ratio of 24 and a normal speed of 1500 rpm controlled by the governor. An injection pressure of 200bar and 225bar are used for the best performance. This is because at higher injection pressures atomization, spray characteristics, mixing with air are better, which result in improved combustion, thereby improves the engine performance and reduces the emissions. The engine is first run with neat diesel at loading conditions such as 6.5, 13, 19.5 and 26 N-m. Between two load trials the engine is allowed to become stable by running it for 3 minutes before taking the readings. At each loading condition performance parameters namely speed, exhaust gas temperature, brake power, peak pressure are measured under steady state conditions.

The experiments are repeated for various combinations of diesel and Jatropha biodiesel blends. With the above experimental results, the parameters such as total fuel consumption, brake specific fuel consumption, brake mean effective pressure & brake thermal efficiency are calculated. Finally graphs are plotted for brake specific fuel consumption, brake thermal efficiency with respect to loading conditions for diesel and bio-diesel blends. From these plots, performance characteristics of the engine are determined.

15. Results and Discussions

The experiments were conducted on a TV1, Kirloskar, single cylinder, 4-stroke, water-cooled, direct injection compression ignition engine keeping compression ratio (CR) of 24:1 as constant, with two injection pressures (IP) of 200bar and 225bar for various loads and various blends of Jatropha biodiesel. Analysis of performance parameters and emission characteristics like brake power, brake specific fuel consumption, brake thermal efficiency, hydrocarbon, carbon monoxide, carbon dioxide, nitrogen dioxide and exhaust gas temperatures are evaluated.

16. Conclusions

The present investigation evaluates production of Jatropha methyl ester from calcinated calcium oxide (CaO) catalyst and conducting the performance & emission tests on a TV1 Kirloskar, single cylinder, 4-stroke, direct injection, water cooled, diesel engine for varying loads and various blends of Jatropha biodiesel & neat diesel with one compression ratio (24:1) and two injection pressure (200 & 225bar) as engine varying parameters. The following conclusions are drawn from this investigation:

- The actual study suggests that calcium oxide being treated with ammonium carbonate solution and calcinated at high temperature, it becomes a solid super base, which shows high catalytic activity in transesterifacation. CaO will probably brought about as the good productivity as homogeneous catalyst (NaOH or KOH) and by taking advantage of the easy product recovery Under the optimum conditions, the conversion of Jatropha oil reaches over 88%.
- It show that blends fuel up to 20% Jatropha have value of viscosity and density equivalent to specified range for diesel engine fuel.
- Engine performance with biodiesel does not differ greatly from that of diesel fuel. The B20 shows good brake thermal efficiency in comparison with diesel.
- Most of the major exhaust pollutants such as CO, CO_2 and HC are reduced with the use of neat biodiesel and the blend as compared to neat diesel. But NO_2 emissions increase when fuelled with biodiesel fuel blends as compared to conventional diesel fuel.
- The blend B20 shows the better performance and emission characteristics.
- In view of the petroleum fuel shortage, biodiesel can certainly be considered as a potential alternative fuel.

17. Scope of Future Work

- Need to study the biodiesel production from Jatropha oil using other heterogeneous base catalysts like MgO, SrO, ZnO & Zeolites.
- Combustion characteristics of single cylinder 4-stroke diesel engine can be analyzed.
- Performance, combustion & emission characteristics of 4-stroke multi cylinder turbocharged direct injection diesel engine with blends of Jatropha methyl ester produced using calcinated calcium oxide catalyst.
- Performance, combustion & emission characteristics of homogeneous charge compression ignition engine with blends of Jatropha methyl ester produced using calcinated calcium oxide catalyst.
- Performance, combustion & emission characteristics of low heat rejection engine with blends of Jatropha methyl ester produced using calcinated calcium oxide catalyst.
- Performance, combustion & emission characteristics of homogeneous charge compression ignition engine with blends of pyrolytic oil from Jatropha seed cake need to be studied.
- Need to study the effect of biodiesel derived from Jatropha oil and its blend with diesel when directly injected at different injection pressures & injection timings in a single cylinder water-cooled compression ignition engine.
- By following same production procedure, Biodiesel can also be produced by using karanja, Jatropha, Mahua or Hippe and Simaruba oils.
- Further analysis can be conducted on computational fluid dynamics.

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