Energy Research Journal

Original Research Paper

An Experimental Investigation on Performance of CI Engine Using Diesel, Esterified Cotton Seed Oil and Diethyl Carbonate as Additive

[1,2]Vikram G. Kamble and [1]Samson Paul Pinto

[1]St Joseph Engineering College, Mangalore, Karnataka, India-575028, India
[2]Proof and Experimental Establishment (DRDO), Balasore, Odisha, India-756025, India
[1]Manipal Institute of Technology, Manipal, Karnataka, India-576104, India

Article history
Received: 13-09-2015
Revised: 14-11-2015
Accepted: 14-12-2015

Corresponding Author:
Vikram G. Kamble
St Joseph Engineering College, Mangalore, Karnataka, India-575028, India
Email: iknowvikramkamble@gmail.com

Abstract: In this study, Cotton seed oil ethyl ester was produced by transesterification process. The performance of diesel engine was experimentally investigated by using cotton seed oil ethyl ester as fuel. For the study cotton seed oil ethyl ester was mixed with diesel fuel and B20 blend was prepared. Also Diethyl Carbonate was added as an additive in 4, 8 and 10% proportion. Fuels were tested on a single cylinder, four-stroke, direct injection, water cooled diesel engine. The effects of cotton seed oil ethyl ester diesel blend on engine performance were examined at constant speed and varying loading conditions. The effect of B20 and its blends with diethyl carbonate on engine power, brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature were clarified by the performance tests. The experimental results showed that the use of B20 with 10% diethyl carbonate increases the brake thermal efficiency, decreases fuel consumption; decreases brake specific fuel consumption and also the exhaust gas temperature. However, there were no significant differences in performance values of diesel, B20 and B20 with diethyl carbonate. The experimental results showed that the lower contents of cotton seed oil ethyl ester in the blends can partially be substituted for the diesel fuel without any modifications in diesel engines.

Keywords: Transesterification, B20 (20% Esterified Cottonseed Oil+80% Diesel), Diethyl Carbonate

Introduction

The petroleum fuels play a very important role in the development of industrial sector, transportation, agricultural sector, power generation and to meet many other basic human needs. But due high demand there has been a scarcity of fossil fuels (Fernandes *et al*., 2012). This has brought the need for finding alternative fuels to fulfill the energy crisis. Biodiesel is one of the best available alternate fuel. Biodiesel is defined as the mono-alkyl ester of vegetable oil and animal fat (Shahbazi *et al*., 2012).

The major component of vegetable oil and animal fat are triglycerides. Chemically triglycerides are esters of fatty acids with glycerol. To obtain biodiesel, the vegetable oil or animal fat is subjected to a chemical reaction termed Transesterification (Nabi *et al*., 2009; Anand *et al*., 2009). In the reaction triglyceride is reacted in the presence of a catalyst with an alcohol to give the corresponding alkyl ester of the fatty acid mixture that is found in the parent vegetable oil or animal fat (Chung, 2010; Muralidharan *et al*., 2011).

Characteristics of Oils or Fats Affecting their Suitability for Use of Fuel

Calorific value-It is the amount of heat energy released by combustion of unit value of fuel. Calorific value of diesel oil is 42500 kJ kg^{-1} while that of cotton seed oil is 40600 kJ kg^{-1}.

Flash Point-The flash point temperature of diesel fuel is the minimum temperature at which the fuel will ignite on application of ignition source. According to American standards for biodiesel (ASTM D6751) the minimum flash point of biodiesel should be 130°C and according to European (EN 14214) standards it must be 120°C.

Iodine Value-Iodine value is a value of the amount of iodine measured in grams, absorbed by 100 g of given oil. According to European standards (EN 14214) for biodiesel the maximum iodine value should be 120 g iodine/100 g (Miao *et al*., 2009; Barnwal and Sharma, 2005).

Viscosity-Viscosity refers to the thickness of the oil and is determined by measuring the amount of time taken for the give measure of oil to pass through an orifice of a specified size. Viscosity affects injector lubrication and fuel atomization. According to American standards for biodiesel (ASTM D6751) viscosity can range from 1.9 mm^2/s to 6 mm^2/s and according to European standards (EN 14214) it should range from 3.5 mm^2/s to 5 mm^2/s (Diya'uddeen *et al*., 2012; Mathur and Sharma, 2012).

Cetane Number-It is a relative measure of the interval between the beginning of injection and auto ignition of the fuel. Diesel engines operate better on fuels with cetane number above 50. According to American standards for biodiesel (ASTM D6751) the minimum cetane number has to be 47 and according to the European standards (EN 14214) the minimum cetane number has to be 51 (Misra and Murthy, 2011; Gürü *et al*., 2009).

Density-It is the weight per unit volume. Oils that are denser have more energy. According to the European standards for biodiesel the density has to range from 860 kg/m^3 to 900 kg/m^3.

An Overview of Cotton Seed Oil

Cotton seed oil is edible oil extracted from the seeds of cotton plant of various species, mainly Gossypium hirsutum and Gossypium herbaceum. Cotton seed oil contains 70% unsaturated fatty acids (18% monounsaturated and 52% polyunsaturated) and 26% saturated fat. When it is fully hydrogenated, its profile is 94% saturated fat and 2% unsaturated fatty acids (de Angelis *et al*., 2009).

Production of Cotton Seed Oil

Cotton seed oil is obtained as a by product of cotton production. The oil is very rich in unsaturated fatty acids, linoleic acids constituting about two-thirds of these. Cotton seed oil is produced by a process called 3-stageneutralization process. The three main steps are refining, bleaching and deodorization. The3-stage neutralization is explained below.

In the first stage of chemical refining, a separator separates the soap stock with the fatty acids neutralized by acid and caustic. The second stage of refining the oil then follows; this is a second treatment of the oil with caustic to remove as much as possible of the gossypol. Gossypol is a pigment which gives raw cottonseed oil an almost black color.

Table 1. Various properties of pure cottonseed oil and pure diesel

Properties	Pure cotton seed oil	Pure diesel
Density at room temperature (kg/m^3)	892.0	809.00
Calorific value (kJ/kg)	40670.0	42322.50
Flash point (°C)	218.0	530.00
Kinematic viscosity at 40°C (cSt)	49.8	6.19

In the third stage, another separator performs the task of removing the wash water from the oil which has been washed with hot water. The pure cottonseed oil can now be dried, bleached and deodorized.

The Table 1 shows the various properties of pure cottonseed oil and pure diesel. The high viscosity, low volatility and polyunsaturated character of the oil cause problems when used in a CI engine for a very long time. The problems related to low volatility and high viscosities are offset by subjecting the oil into the process of transesterification and the high viscosity can be reduced. Blending can further improve the combustion characteristics.

Preparation of Ethyl Ester of Cotton Seed Oil

This section deals with steps involved in the preparation of biodiesel from refined cotton seed oil.

Transesterification

In the Transesterification of vegetable oils, a triglyceride reacts with an alcohol in the presence of a strong acid or base, producing a mixture of fatty acids alkyl esters and glycerol.

Raw Materials

- Refined cotton seed oils ample
- Anhydrous Ethyl Alcohol
- Potassium Hydroxide (KOH) as Catalyst
- Diethyl carbonate as a fuel additive

Procedure for Preparation of Cotton Seed Oil Biodiesel

About 3.2 g of KOH was dissolved in 200 mL ethanol to prepare alkaline, which is required to activate the alcohol. Then stirring was done vigorously in a covered container until the alkali is dissolved completely for 20 min. Care was taken to see that the mixture was protected from atmosphere carbon dioxide and moisture as both destroy the catalyst. The Ethanol-KOH mixture was then transferred to the reactor containing 800 mL moisture free cotton seed oil. Stirring of the mixture was continued for 90 min at a temperature between 80 and 85°C.

Table 2. Physiochemical properties of diesel, cotton seed oil biodiesel, B20 (20% Esterified cottonseed oil + 80% Diesel) and B20 with diethyl carbonate

Characteristics	Diesel	Cotton seed oil ethyl ester	B20	B20+4% diethyl carbonate	B20+8% diethyl carbonate	B20+10% diethyl carbonate
Density at 28°C (kg/m^3)	8106.0000	8722.0000	8254.0000	8210.000	8282.0000	8376.0000
Specific gravity	0.8106	0.8722	0.8254	0.821	0.8282	0.8376
Kinematic viscosity at 40°C (cSt)	4.5000	18.5500	3.8770	3.163	2.4190	2.0340
Flash point (°C)	54.0000	76.0000	56.0000	40.000	38.0000	36.0000
Fire point (°C)	56.0000	78.0000	58.0000	42.000	40.0000	38.0000
Calorific Value (kJ/kg)	42322.5000	39534.1000	40946.0000	38844.6.00	37667.8000	34937.3000

Table 3. Engine specifications

Parameter	Value
No. ofcylinder	One
Bore	80mm
Stroke	110mm
Rated speed	1500 RPM
Lubrication oil	SAE30/40HDtype-3asper IS: 496:1982
Rated power	3.7 kW@ 1500 RPM
Capacity	2 liters
Nominal compression ratio	16.5:1
Weight of the engine	150kg
Governortype	Mechanical centrifugal
Lubrication oil sump capacity	3.75 liters
Rate of coolingwater	3.15 liters/min

Reactor was provided with a condenser to condense the evaporating ethanol by fixing the condenser on the top of the reactor. Then the condenser was removed and stirred for 60 min. to remove the excess ethyl alcohol. The mixture was left for at least 5-6 h for the settlement of glycerol. Two distinct layers are observed. Biodiesel forms the upper layer while glycerol forms the lower layer. These two layers were separated and water washing was done. Finally obtained Esterified cotton seed oil was mixed with diesel and diethyl carbonate to obtain biodiesel.

Diethyl Carbonate

Diethyl carbonate is a carbonate ester of carbonic acid and ethanol. At room temperature (25°C) diethyl carbonate is a clear liquid with a low flash point (Mistry *et al*., 2011). It is a colorless transparent liquid. Its chemical formula is $C_5H_{10}O_3$. It is a high quality solvent and a textile auxiliary agent.

Diethyl Carbonate as a Fuel Additive

Diethyl carbonate is potentially oxygen-containing (40.6 wt.%) additive for gasoline and diesel fuel to reduce pollutant emissions. Previous studies using a similar compound, Dimethyl Carbonate (DMC) as oxygenate have shown reduction of carbon monoxide, oxides of nitrogen, hydrocarbons and particulate matter (Kannan *et al*., 2011; Aydin and Bayindir, 2010). Research efforts indicate that 5 wt. % diethyl carbonate in diesel fuel can reduce the emission of particulate matter by as much as 50%. Apart from this it also has more favorable gasoline/water distribution coefficient when compared with ethanol or dimethyl carbonate. When in contact with soil, diethyl carbonate should slowly decompose into ethanol and carbon dioxide, two compounds with little or no environmental pollution.

The Table 2 shows the physiochemical properties of diesel, cotton seed oil biodiesel, B20 (20% Esterified cottonseed oil +80% Diesel) and B20 with various percentage of diethyl carbonate. Density, specific gravity and kinematic viscosity are the physical properties. Flash point, fire point and calorific value are chemical properties.

Experimental Setup and Procedure

The engine tests were conducted on single cylinder four-stroke, water cooled diesel engine. The flywheel of the engine is directly coupled to rope type brake dynamometer that permitted engine motoring either fully or partially. A rope is wound on the drum circumference and two spring balances are provided at slack and tension slide. A hand wheel is provided to increase or decrease the load. The brake drum is cooled inside by water flow. Various measurement systems are included in the setup. The engine and the dynamometer were interfaced to a control panel which is used for recording the test parameters such as fuel flow rate, temperatures, air flow rate, load etc. The set of experiments were conducted at the designed speed of 1500 RPM and 16.5:1 compression ratio. The engine was started by hand cranking with diesel fuel supply and it was allowed to get its steady state. Water to engine cooling jacket is maintained about 190 LPH and water flow pressure to rope type dynamometer is maintained between 1 bar to 1.5 bar throughout the experiment. Once the engine has reached a steady state, test fuel was sent into the engine using a separate fuel tank. The experiments were conducted at 0, 25, 50, 75 and 100% load condition by using diesel, B20 and blend of B20 with diethyl carbonate in 4, 8 and 10% proportions as fuel. Load was applied by rotating the loading hand wheel. Data such as manometer reading, load spring balance, exhaust temperature, fuel

DOI: 10.3844/erjsp.2016.10.18

consumption were recorded at this condition. Engine specifications are mentioned in Table 3.

Results

From the Fig. 1and Table 4, we can see that the brake thermal efficiency of diesel is 22.72% at full load and brake thermal efficiency of B20 (20% Esterified cottonseed oil+80% Diesel) is 23.08% at full load. The brake thermal efficiency of B20 grade Biodiesel blend with 4, 8 and 10% diethyl carbonate is 26.52, 26.64 and 30.15% respectively at full load. At no load condition brake thermal efficiency of all the blends is very close to each other and as the load is increased brake thermal efficiency increases. We can say that the addition of diethyl carbonate increases the brake thermal efficiency when load is increased. The increase in brake thermal efficiency is due to the reduction in viscosity, density and improved fuel atomization. Fuel atomization leads to improved fuel air mixing.

The Fig. 2 Table 5 shows that exhaust gas temperature of diesel ranges from 158 to 228°C for various loads and the exhaust gas temperature of B20 ranges from 161 to 222°C. But the exhaust gastemperature of B20 grade biodiesel blend with 10% diethyl carbonate ranges from 145 to 205°C. It is seen that exhaust gas temperature is more in case of diesel, but the addition of diethyl carbonate decreases the exhaust gas temperature by significant amount. This is because, diesel having a higher calorific value releases more heat when compared to the B20 grade biodiesel blends.

Figure 3 and Table 6 explains regarding brake specific energy consumption is the energy consumed per unit power. Brake specific energy consumption is an ideal variable as it is independent of the fuel. From the Figure we can see that, the brake specific energy consumption of diesel and B20 is almost close to each other and higher at all levels than B20 blends with diethyl carbonate. This may be due to higher calorific value and higher value of kinematic viscosity of diesel and B20. Therefore we can say that the brake specific energy consumption decreases with the increase in diethyl carbonate percentage.

Brake Specific Fuel Consumption (Fig. 4 and Table 7) (BSFC) is an ideal parameter for comparing engine performance. The Figure indicates that BSFC of diesel is 0.534 kg/kW-hr at 50% load and BSFC of B20 is 0.535 kg/kW-h at 50% load. But BSFC of B20 grade biodiesel blend with 4, 8 and 10% diethyl carbonate is 0.526, 0.535 and 0.518 kg/kW-h respectively at 50% load. So this shows that as the additive percentage increases the fuel consumption goes on decreasing at various loads. As the load is increased more fuel is burnt inside combustion chamber. Complete utilization of fuel takes place inside the combustion chamber due to increased oxygen content of the fuel caused by the addition of diethyl carbonate. Hence we can see that brake specific fuel consumption decreases as the diethyl carbonate percentage is increased.

The Fig. 5 and Table 8 shows the effect on mechanical efficiency to the load on the engine. There are no significant changes over the entire range of the loading of the engine and different blends.

The Fig. 6 and Table 9 shows that the volumetric efficiency of the engine with B20 (20% Esterified cottonseed oil + 80% Diesel) is observed to be greater than that of the diesel fuel. This may due to low exhaust gas temperature. Irrespective of the load on the engine volumetric efficiency is observed to be maximum for the blends of B20 when compared to diesel.

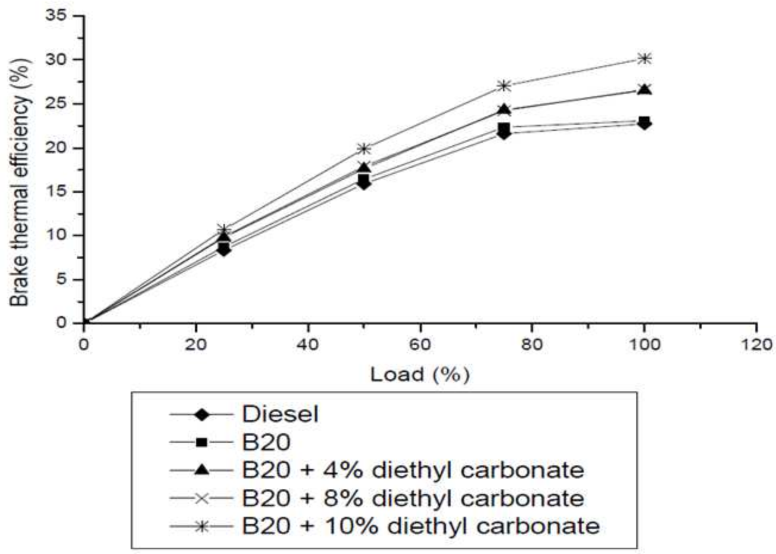

Fig. 1. Effect on brakethermal efficiencyof engine at variousloads

DOI: 10.3844/erjsp.2016.10.18

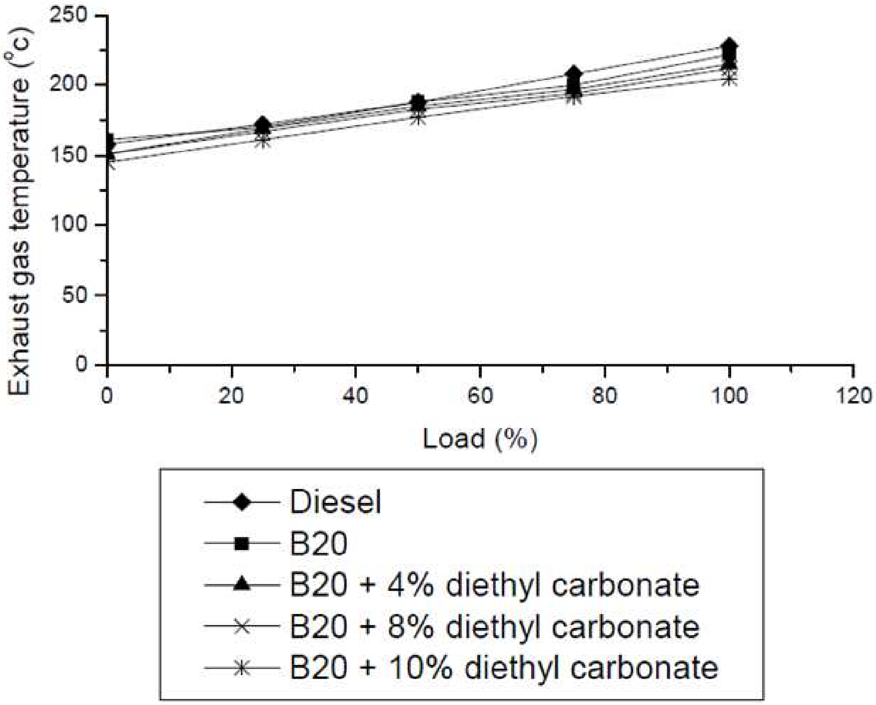

Fig. 2. Effect on exhaust gas temperature of engine at various loads

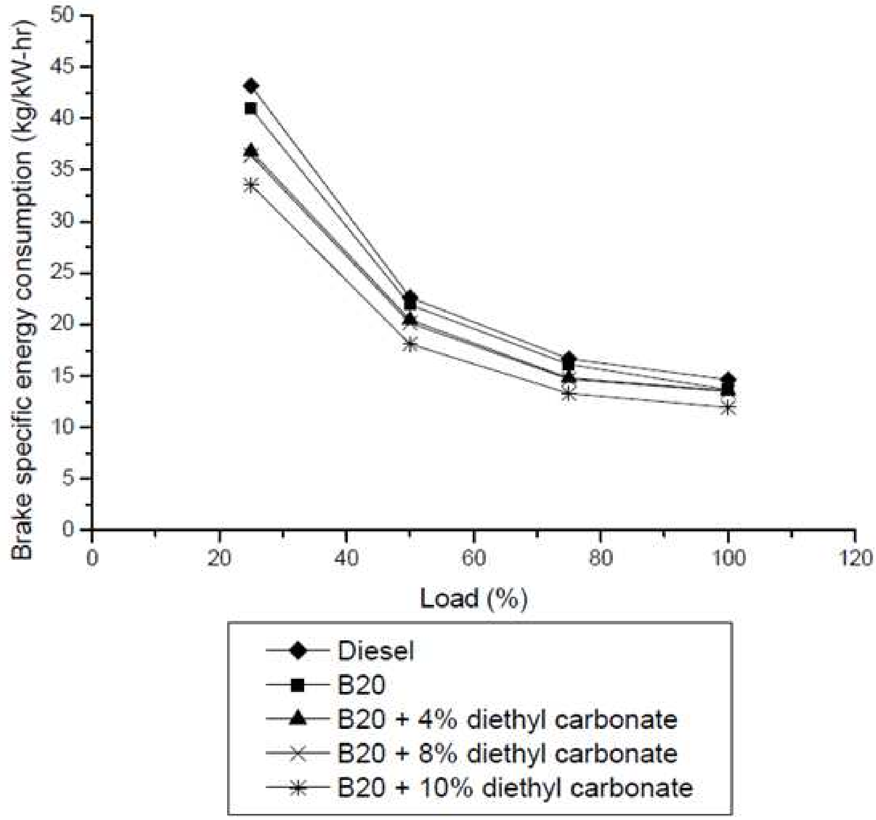

Fig. 3. Effect on brake specific energy consumption at various loads

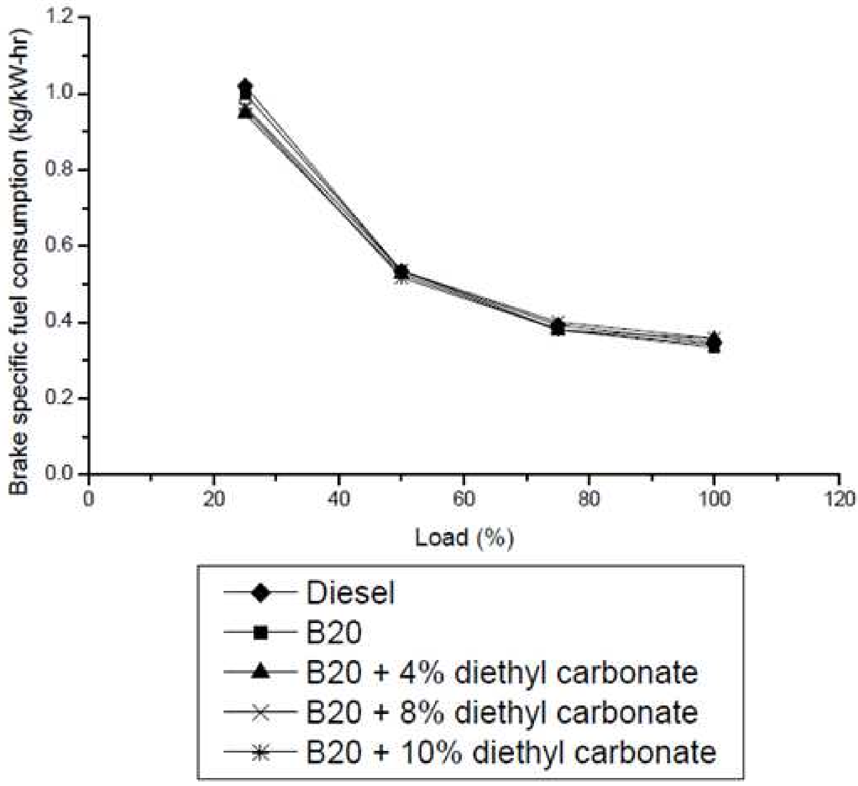

Fig. 4. Effect on brake specific fuel consumption of engine at various loads

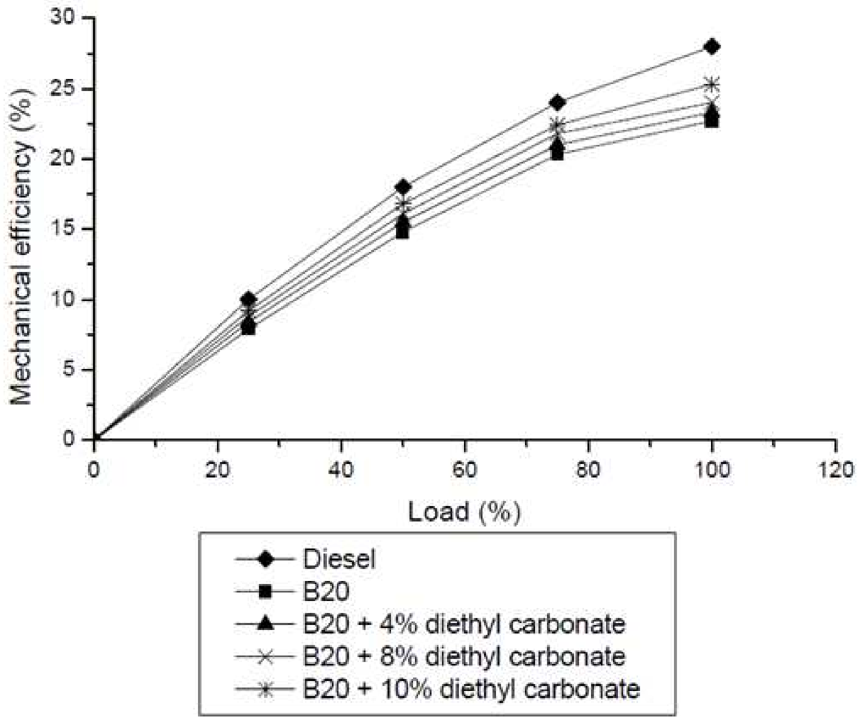

Fig. 5. Effect on mechanical efficiency at various loads

DOI: 10.3844/erjsp.2016.10.18

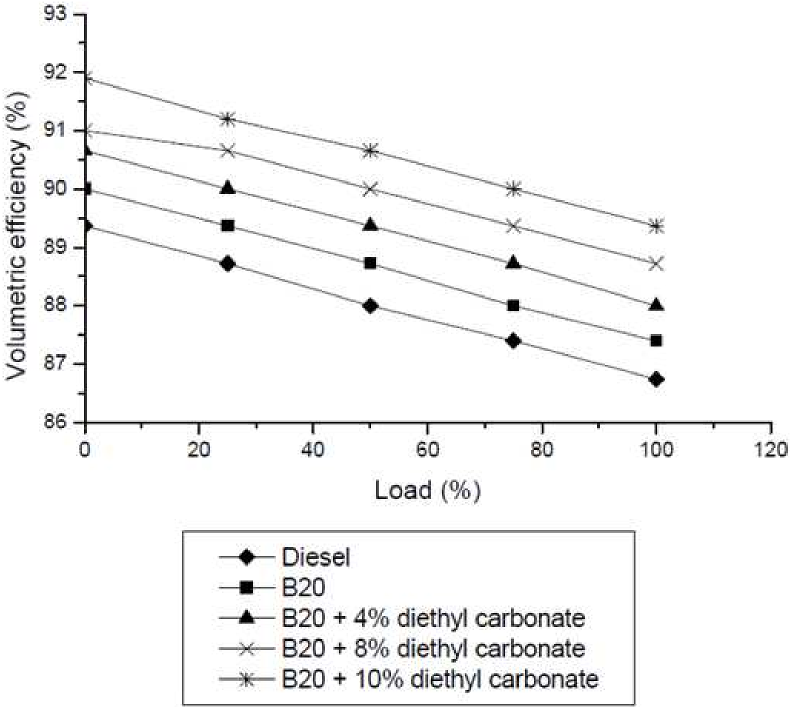

Fig. 6. Effect on volumetric efficiency at various loads

Table 4. Effect on brake thermal efficiency of engine at various loads

Load (%)	Diesel (%)	B20 (%)	B20+4% diethyl carbonate (%)	B20+8% diethyl carbonate (%)	B20+10% diethyl carbonate (%)
0	0.00	0.00	0.00	0.00	0.00
25	8.34	8.75	9.78	9.88	10.72
50	15.91	16.44	17.62	17.88	19.88
75	21.60	22.32	24.33	24.20	27.05
100	22.72	23.08	26.52	26.64	30.15

Table 5. Effect on exhaust gas temperature of engine at various loads

Load (%)	Diesel (°C)	B20 (°C)	B20+4% diethyl carbonate (°C)	B20+8% diethyl carbonate (°C)	B20+10% diethyl carbonate (°C)
0	158	161	151	151	145
25	172	170	169	167	161
50	188	188	185	183	177
75	208	200	197	194	192
100	228	222	215	212	205

Table 6. Effect on brake specific energy consumption at various loads

Load (%)	Diesel (kg/kW-hr)	B20 (kg/kW-hr)	B20+4% diethyl carbonate (kg/kW-hr)	B20+8% diethyl carbonate (kg/kW-hr)	B20+10% diethyl carbonate (kg/kW-hr)
0	-	-	-	-	-
25	43.17	40.946	36.79	36.42	33.55
50	22.62	21.910	20.43	20.15	18.10
75	16.66	16.130	14.80	14.70	13.31
100	14.64	13.670	13.56	13.49	11.94

Table 7. Effect on brake specific fuel consumption of engine at various loads

Load (%)	Diesel (kg/kW-hr)	B20 (kg/kW-hr)	B20+4% diethyl carbonate (kg/kW-hr)	B20+8% diethyl carbonate (kg/kW-hr)	B20+10% diethyl carbonate (kg/kW-hr)
0	0.000	0.000	0.000	0.000	0.000
25	1.020	1.000	0.947	0.967	0.960
50	0.534	0.535	0.526	0.535	0.518
75	0.393	0.381	0.380	0.400	0.381
100	0.346	0.334	0.357	0.358	0.341

Table 8. Effect on mechanical efficiency at various loads

Load (%)	Diesel (%)	B20 (%)	B20+4% diethyl carbonate (%)	B20+8% diethyl carbonate (%)	B20+10% diethyl carbonate (%)
0	0	0.0	0.0	0.0	0.0
25	10	7.9	8.4	8.8	9.2
50	18	14.8	15.5	16.1	16.8
75	24	20.3	21.0	21.8	22.4
100	28	22.7	23.3	24.0	25.3

Table 9. Effect on volumetric efficiency at various loads

Load (%)	Diesel (%)	B20 (%)	B20+4% diethyl carbonate (%)	B20+8% diethyl carbonate (%)	B20+10% diethyl carbonate (%)
0	89.37	90.00	90.66	91.00	91.90
25	88.72	89.37	90.00	90.66	91.20
50	88.00	88.72	89.37	90.00	90.66
75	87.40	88.00	88.72	89.37	90.00
100	86.74	87.40	88.00	88.72	89.37

Conclusion

In this investigation, it is found that cottonseed oil ethyl ester can be successfully used as an alternative fuel in four stroke CI engine without any modifications to the engine or injection system. By transesterification of cotton seed oil, a bio-degradable liquid was obtained and it was tested by blending different proportions of ethyl ester of cotton seed oil with diesel fuel and diethyl carbonate. The comparison of these blends was done. The comparison was in terms of engine performance. It was found, the engine operated smoothly with different blends. The blends burned more efficiently with better fuel economy. In this investigation various parameters such as brake specific fuel consumption, brake power, brake specific energy consumption, exhaust gas temperature, mechanical efficiency, volumetric efficiency and brake thermal efficiency were measured during combustion process under varying operating condition with diesel, pure biodiesel and biodiesel blends with diethyl carbonate.

For biodiesel fuel a considerable improvement in performance was obtained under part load and full load operation of the engine. It was observed that the brake thermal efficiency for all the loads of B20 blend with 10% diethyl carbonate is 6% higher compared to diesel. It was observed that there was no much improvement is brake specific fuel consumption and brake specific energy consumption with B20. With the addition of 10% diethyl carbonate the brake specific fuel consumption considerably reduced and it was almost equal to diesel. It was observed that there was no much change in mechanical efficiency and volumetric efficiency at various loads. It was observed that there is no much difference in exhaust gas temperature of diesel and B20. Whereas B20 blends with 10% diethyl carbonate showed the decrease in exhaust gas temperature.

By studying the performance characteristics of various loads of biodiesel it has been concluded that the blend which contain 80% diesel, 20% cotton seed ethyl ester and 10% diethyl carbonate is more efficient, economical fuel which can successfully replace petroleum based standard diesel.

Acknowledgement

We respectfully thank all staff of Mechanical Engineering Department, St Joseph Engineering College, Mangalore, for their impartial guidance and support throughout our work.

Author's Contributions

Vikram G. Kamble: Analyzed the result and edited the whole work.

Samson Paul Pinto: Conducted the experiments and did all mouse work.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

References

Anand, R., G.R. Kannan, K.R. Reddy and S. Velmathi, 2009. The performance and emissions of a variable CR diesel engine fuelled with biodiesel from CSO. ARPN J. Eng. Applied Sci.

Aydin, H. and H. Bayindir, 2010. Performance and emission analysis of cottonseed oil methyl ester in a diesel engine. Renewable Energy, 35: 588-592. DOI: 10.1016/j.renene.2009.08.009

Barnwal, B.K. and M.P. Sharma, 2005. Prospects of biodiesel production from vegetable oils in India. Renewable Sustainable Energy Rev., 9: 363-378. DOI: 10.1016/j.rser.2004.05.007

Chung, K.H., 2010. Transesterification of *Camellia japonica* and *Vernicia fordii* seed oils on alkali catalysts for biodiesel production. J. Industrial Eng. Chem., 16: 506-509. DOI: 10.1016/j.jiec.2010.03.007

de Angelis, A., G. Bellussi, P. Pollesel, G. Assanelli and M.M. Eni, 2009. Diethyl carbonate a new and environmentally friendly additive to fuels. Italy.

Diya'uddeen, B.H., A.R.A. Aziz, W.M.A.W. Daud and M.H. Chakrabarti, 2012. Performance evaluation of biodiesel from used domestic waste oils: A review. Process Safety Environ. Protect., 90: 164-179. DOI: 10.1016/j.psep.2012.02.005

Fernandes, D.M., D.S. Sequeria, F.M. Portela, R.M.N. Assunção and R.A.A. Munoz *et al*., 2012. Preparation and characterization of methylic and ethylic biodiesel from cottonseed oil and effect of tert-butylhydroquinone on its oxidative stability. Fuel, 97: 658-661. DOI: 10.1016/j.fuel.2012.01.067

Gürü, M., B.D. Artukoğlu, A. Keskin and A. Koca, 2009. Biodiesel production from waste animal fat and improvement of its characteristics by synthesized nickel and magnesium additive. Energy Convers. Manage., 50: 498-502. DOI: 10.1016/j.enconman.2008.11.001

Kannan, G.R., R. Karvembu and R. Anand, 2011. Effect of metal based additive on performance emission and combustion characteristics of diesel engine fuelled with biodiesel. Applied Energy, 88: 3694-3703. DOI: 10.1016/j.apenergy.2011.04.043

Mathur, M.L. and R.P. Sharma, 2012. Internal Combustion Engine. 1st Edn., McGraw Hill Education (India) Pvt Ltd, New Delhi, ISBN-10: 1259006190, pp: 730.

Miao, X., R. Li and H. Yao, 2009. Effective acid-catalyzed transesterification for biodiesel production. Energy Convers. Manage., 50: 2680-2684. DOI: 10.1016/j.enconman.2009.06.021

Misra, R.D. and M.S. Murthy, 2011. Blending of additives with biodiesels to improve the cold flow properties, combustion and emission performance in a compression ignition engine--A review. Renewable Sustainable Energy Rev., 15: 2413-2422. DOI: 10.1016/j.rser.2011.02.023

Mistry, A.B., B.H. Mehta and H.V. Mandalia, 2011. A review on effect of oxygenated fuel additive on the performance and emission characteristics of diesel engine.

Muralidharan, K., D. Vasudevan and K.N. Sheeba, 2011. Performance, emission and combustion characteristics of biodiesel fuelled variable compression ratio engine. Energy, 36: 5385-5393. DOI: 10.1016/j.energy.2011.06.050

Nabi, M.N., S.M.N. Hoque and M.S. Akhter, 2009. Karanja (*Pongamia Pinnata*) biodiesel production in Bangladesh, characterization of Karanja biodiesel and its effect on diesel emissions. Fuel Process. Technol., 90: 1080-1086. DOI: 10.1016/j.fuproc.2009.04.014

Shahbazi, M.R., B. Khoshandam, M. Nasiri and M. Ghazvini, 2012. Biodiesel production via alkali-catalyzed transesterification of Malaysian RBD palm oil-Characterization, kinetics model. J. Taiwan Institute Chem. Eng., 43: 504-510. DOI: 10.1016/j.jtice.2012.01.009