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Performance and Emission Characteristics of CRDI Engine Fuelled with Cotton Seed Oil Blended Biodiesel

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Abstract

The biofuel produced from cottonseed oil can provide a potential solution to the rapid rate of depletion and hazardous emissions of the fossil fuels for the fast-growing world. The present work investigates the suitability of cotton seed oil as a blending agent for production of biodiesel. The biodiesel blend has been tested as an alternate fuel in a common rail direct injection diesel engine from performance and emission point of view. The performance and emission parameters of biodiesel containing 10, 20 and 30 % of cotton seed oil have been compared with those of pure diesel. The experimental results indicated that the biodiesel containing 20% of cottonseed oil exhibited the most optimal performance and emission characteristics. The brake thermal efficiency of the engine decreased by 2.3% while the brake specific fuel consumption increased by 0.047kg/kWh for optimally concentrated biodiesel. Corresponding to same combustion parameters, the hydrocarbon and carbon monoxide emissions reduced by 16.5 and 58 % respectively while the nitrogen oxide emissions increased by approximately 4.8%. Thus, the cotton seed oil can be considered as a potential alternate to pure diesel considering performance and emission characteristics.

Keywords: *Biodiesel, Brake Thermal Efficiency, Cottonseed Oil Methyl Ester, Exhaust Emission, Transesterification*

1.0 Introduction

The energy consumption across the world is increasing enormously day by day due to large scale growth in industry, transportation, power production and agricultural sectors. Presently the fossil fuel-based energy sources are the prime resources for catering the energy demand which are non-renewable in nature. Keeping in view the consumption of fossil fuels and the extremely slow rate of development of the fossil sources, the fuel scarcity can be considered as a serious threat to the world in near future[1]. Besides, the hazardous emissions of fossil fuels such as unburnt hydrocarbon, carbon monoxide, carbon dioxide and oxides of nitrogen lead to unwanted environmental pollution, global warming and climatic changes[2]. Therefore, the time has reached to develop different alternate renewable energy sources to meet the challenges due to depletion of fossil fuels and simultaneously economic, social and environmental threats due to consumption of fossil fuels. In this regard, the biodiesels have been utilized as a potential candidate during the past few decades. Biodiesel being a biodegradable, nontoxic, non-flammable, non-explosive and environment friendly renewable alternate fuel with comparatively better combustion attributes than pure diesel[3]. The biodiesel is a mixture of saturated and unsaturated esters primarily produced from edible and non-edible oils, animal fats, waste cooking oils through transesterification process in presence of short chain alcohols and catalysts[4].

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The biodiesel feedstocks extracted from the different kinds of edible and non-edible oils have been the primary focus of the researchers in the recent past. The biodiesels produced from such feedstocks have offered an improved performance and emission characteristics in case of compression ignition engines. Biodiesel proportion of 20% by volume is a safely suggestible liquid fuel for the existing vehicles with minor modifications. In such a manner, Air-Fuel mixing will be improved by advanced injection timing whereas the atomization of fuel will be increased by injection pressure[5]. The emission standards and guidelines are turned out to be extreme for diesel engine emissions with the most part NOx and ash content. Hence higher Exhaust Gas Recirculation (EGR) with biodiesel may decrease the NOx and ash content. The exhaust emissions including NOx, HC, CO, smoke, and BSFC can be effectively monitored with the help of altered nozzle configuration by lowering the probability of wall impingement[6]. Thus, different biodiesel feedstocks have been utilized in the recent past for generation of an alternate fuel. Colombo *et al*., utilized soybean oil with methanol and calcium oxide as catalyst in recycle reactor for production of biodiesel[7]. The experimental investigations of Haldar *et al*., provided improved performance parameters and lower exhaust gas emissions from a diesel engine using biodiesel produced from *Karanja*, *Putranjiva* and *Jatropha* oil blended with diesel. exhibited better performance and reduced exhaust gas emissions[8]. As reported by Ong *et al*., the brake thermal efficiency can be increased by 2.3% with decrease in brake specific fuel consumption by 3.06% in a diesel engine by blending 10% of *Calophyllum inophyllum* with diesel over entire range of engine speed[9]. The investigations of Sathiamoorthy *et al*., revealed that blending of palmarosa oil with diesel at different compositions have lower emissions of CO, HC emissions and exhaust smoke compared to pure diesel[10]. The biodiesel extracted from castor oil resulted in approximately 10% lower CO and HC emissions with significantly reduced NOx emissions. However, a slight increase in BSFC was observed with all blends of castor oil in comparison to neat diesel[11]. The HC and CO emissions on a single cylinder direct injection CI engine at various engine speeds using soybean blended biodiesel lowered by 10 to 50 % composition of soybean oil in a biodiesel blend[12]. Similarly, the mahua oil blended biodiesel with 25% composition by volume exhibited lowest HC and NOx emissions corresponding to full load operating conditions[13]. By using additives with the papaya seed oil blended biodiesel, Anwar *et al.,* achieved quite improved emission and combustion characteristics with significantly reduced smoke and NOx emission[14]. Krishania *et al*., studied the third-generation biodiesels produced from fish oil, animal fats and spirulina on a compression ignition engine at different compression ratio and loads from performance, emission and ignition point of view[15].

The cotton belonging to the Malvaceae family is the one of the best probable resource for plant proteins next to soybean. Across the globe, India is the second highest cotton producing country amounting approximately 25% of the total cotton production. The cottonseed contains 17 to 24 % oil and the physical and chemical properties of cotton seed oil are similar to most of the vegetable oils comprising of heterogeneous triglycerides. The cotton seed oil contains saturated fatty acids such as palmitic acid (22-26 %) and stearic acid (2-5 %), the monosaturated fatty acid like oleic acid (15-20 %) and polysaturated fatty acid like linoleic acid (49-58 %)[16]. On the other hand, the cottonseed involves toxic gossypol and pesticide residues which restricts its consumption as a food. Hence it can be used as a raw material for biodiesel production without any adverse effect on the human food chain. besides, the price of the cottonseed oil is remarkably lower compared to other vegetable oils. Thus, keeping in view, the necessity of an alternate to the fossil fuels and suitability of cottonseed oil as a fuel, the present work presents an experimental investigation on suitability of cottonseed oil biodiesel as an alternate fuel for compression ignition engines.

2.0 Materials and Methods

The cottonseed oil has been considered to be the feedstock for the production of biodiesel in the present work. The required amount of cottonseed oil has been procured from the local market. The most conventional transesterification process has been adopted for production of the biodiesel. In order to carry out the transesterification process, the Sodium Hydroxide (NaOH) with 99% purity has been used as the alkali catalyst and methanol with 99.8% purity has been used as the alcohol.

2.1 Production of Biodiesel

The single step transesterification process being the most effective and simple method for extraction of biodiesel has been used in the present work. The single step alkaline transesterification is not suitable from yielding point of view for the feedstock containing Free Fatty Acid (FFA) content more than 2%. The FFA content of cottonseed oil is estimated by base titration technique was found to be lower than 1% for which the alkaline transesterification was considered to be suitable enough for production of biodiesel. The cottonseed oil was initially heated in a glass bottle to a temperature of about 60°C. The catalyst sodium hydroxide and methanol were mixed in a bottle for about 15 minutes to form the hot and fumed sodium methoxide. Further the sodium methoxide mixture was added to the hot cottonseed oil so that the cottonseed oil reacted with NaOH in order to mitigate the unsaturated fatty acid content in the biodiesel. The methanol to oil molar ratio was maintained 6:1 while the 1% (w/w) of NaOH was used for an optimal reaction time of 60 minutes for higher yielding of methyl ester[16]. To ensure proper mixing, the mixture was subjected to stirring at a constant speed of 600 rpm. After the transesterification reaction, the mixture was poured into a separating funnel where it was allowed to cool down for about 10 hours. The mixture was observed to settle down in two distinct layers with the upper layer being methyl ester and lower one being the glycerol. The lower layer containing glycerol was separated out and the upper layer was further heated to about 80° C to remove any existing traces of methanol. The obtained methyl ester was washed with warm water to completely eliminate any traces of catalyst or glycerides. The required methyl ester for further process was obtained by drying followed by filtration of the washed methyl ester. The experiments were conducted with pure diesel and different variants of cottonseed oil biodiesel. The biodiesel blends were prepared by mixing the cottonseed oil methyl ester and pure diesel on volume basis. The blends CSO10D90, CSO20D80 and CSO30D70 ware prepared by mixing 10, 20 and 30 % of cottonseed oil methyl ester respectively with diesel. The thermo-physical properties of the fuel blends and the corresponding ASTM standards adopted for measurement of the different properties are mentioned in Table 1.

2.2 Experimental Set-up

The experimental investigations are carried on a of Maruti Swift Dzire make four-stroke, four-cylinder diesel engine coupled with an electronic control unit. The engine is loaded with an eddy current dynamometer and Enginesoft_9.0 software for recording the engine performance parameters. The engine speed in rpm measured by a proximity sensor. The K-Type and PT100 sensors are used for measurement of high and low temperatures of the engine respectively. The detailed technical specifications of the engine are given in Table 2.

Table 1. Thermophysical properties of the fuel blends

Properties	CSO10D90	CSO20D80	CSO30D70	Diesel	ASTM Standard
Density (kg/m^3)	836	842	846	826	ASTMD4052
Viscosity@40°C (mm^2/s)	3.58	3.79	3.92	3.42	ASTMD445
Flash point (°C)	87	92.5	96.8	58	ASTMD93
Fire point (°C)	68	71	76	62	ASTM D93
Calorific value (MJ/Kg)	44.6	43.8	43.2	45.5	ASTMD5865
Cetane number	50.3	51.4	52.2	49	ASTMD613

Table 2. Detailed technical specification of experimental setup

Parameter	Specification
Make	Maruti
Model	Swift Dzire
No of Cylinder	4 cylinder
Swept Volume	1248 CC
Torque Rating Maximum Power	190Nm @ 2000RPM 50 bhp
Compression Ratio	18:1
Injection Timing	13° BTDC
Injection Type	Common Rail (CRDI)
Dynamometer	Eddy Current Dynamometer

The exhaust emissions of the engine such as hydrocarbon, carbon monoxide and oxides of nitrogen are estimated by an AVL 444-5 gas analyzer with suitable filters.

3.0 Results and Discussion

The experiments were performed at a constant speed on a Common Rail Direct Injection (CRDI) diesel engine for pure diesel and cottonseed oil blended biodiesel variants (CSO10D90, CSO20D80 and CSO30D70). The number next to CSO represents the content of cottonseed oil methyl ester in the biodiesel blend on volume basis. The tests were carried out over a span of 0 to 100 % load with an increasing step of 20% from zero to full load conditions. Different biodiesel blends were being prepared and their impact on engine performance and emission was studied and aimed at optimizing the best blend ratio. Engine performance parameters such as brake thermal efficiency, brake specific fuel consumption are reported along with hydrocarbon, carbon monoxide and NOx emissions. Registered results are compared with the diesel and the optimum composition for the biodiesel blend is determined based on the experimental outcome.

3.1 Brake Thermal Efficiency

The variation of Brake Thermal Efficiency (BTE) with brake power for diesel and various biodiesel blends is shown in Figure 1. According to the tests conducted, it is perceived that brake thermal efficiency for biodiesel blends is lesser than that corresponding to pure diesel for entire range of load. It is observed that corresponding to full load condition, brake thermal efficiency is 37.3% for diesel while it varies from 35.7% to 31.2% for CSO10D90 and CSO30D70 respectively. The experimental outcome indicates that there is a slight decrease in brake thermal efficiency with an increase in cottonseed oil methyl ester. This can be ascribed to higher density, higher viscosity, lesser adiabatic flame temperature and lower heating value of the cottonseed oil methyl ester. Besides inordinately increasing the proportion of methyl ester with diesel also

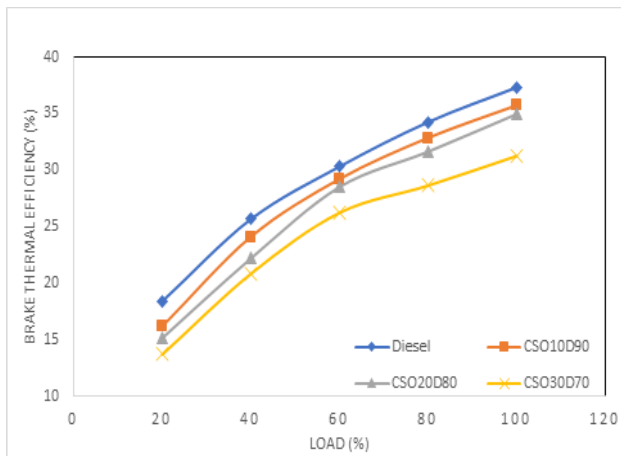

Figure 1. Variation of BTE with load.

decreases the brake thermal efficiency as the calorific value is found to decrease with the addition of the methyl ester. However, it can be observed that CSO10D90 and CSO20D80 blends have quite values of BTE and the difference is merely 0.7% which is very much negligible. It has also been observed from the experiments that the variation of BTE with respect to load follows an almost similar trend to that of full load condition.

3.2 Brake Specific Fuel Consumption

Figure 2 illustrates the variation of Brake Specific Fuel Consumption (BSFC) with load for various blends of cottonseed oil biodiesel and pure diesel. As demonstrated in Figure 2 based on the experimental results, it can be mentioned that by increasing the proportion of cottonseed oil methyl ester in the diesel, the BSFC increases. Corresponding to full load conditions, the BSFC was found to be 0.248, 0.272 and 0.341 kg/kW.hr for CSO10D90, CSO20D80 and CSO30D70 respectively while it was found to be 0.22 kg/kW.hr for pure diesel. Among all blends, the BSFC for diesel is lower due to lesser specific gravity, viscosity and higher calorific value of the diesel fuel which ultimately leads to complete combustion. Due to higher viscosity, density, and lower calorific value with an increase in cottonseed oil methyl ester, proper mixing of air and fuel cannot be achieved which in turn results in incomplete combustion. This is the main reason behind the increase in BSFC with cottonseed oil methyl ester.

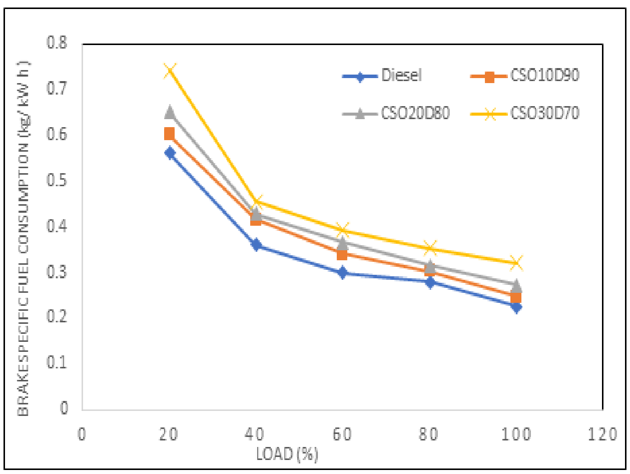

Figure 2. Variation of BSFC with Load for different fuel blends.

3.3 Hydrocarbon Emissions

The variation in hydrocarbon emissions with engine load for the pure diesel and the different biodiesel is depicted in Figure 3. The hydrocarbons emission in the diesel engine differs as speed and load differ. However, the HC emissions are lower for the operation of cottonseed oil biodiesel compared to the operation of petroleum diesel. The CSO10D90, CSO20D80 and CSO30D70 fuels exhibited reduced HC emissions of 51, 48 and 46 ppm which can be ascribed to more intrinsic oxygen presence in the greater biodiesel percentage resulting in improved combustion. It is noted that under full load conditions, the HC emission reduces by 16.5% for CSO20D80 compared to pure diesel. This is due to higher cetane number, higher gas temperature and high oxygen content in biodiesel which causes complete combustion.

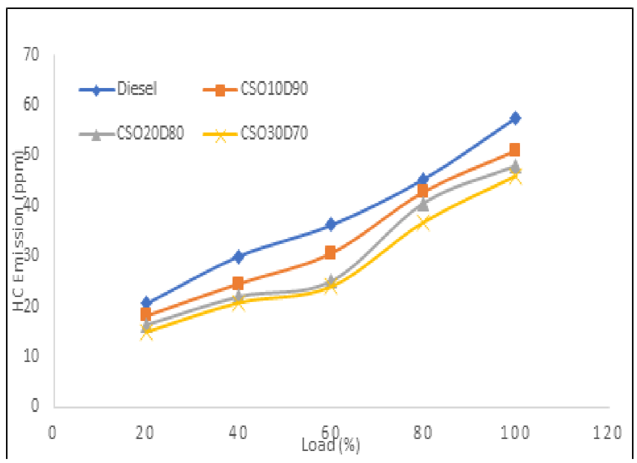

Figure 3. Variation of HC emission for different fuel blends.

3.4 Carbon Monoxide Emission

For Diesel and the different biodiesel blends, the comparison of CO emissions with load is shown in Figure 4. The CO emissions for cottonseed oil biodiesel and their corresponding blends are lesser than diesel because of higher oxygen content in the methyl ester blended biodiesels. As observed in the experiments, the CO emissions for diesel, CSO10D90, CSO20D80 and CSO30D70 at full load are found to be 0.17, 0.096, 0.065, and 0.052 % respectively. From the figure, it is also observed that the CO emission originally decreased with elevating load and subsequently risen significantly to

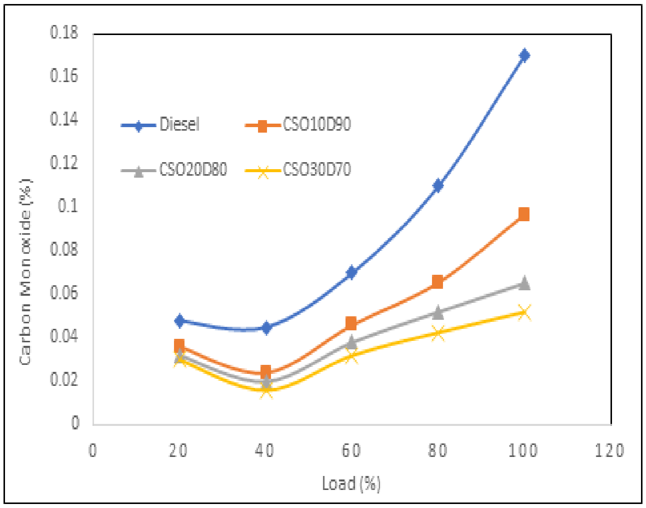

Figure 4. Variation of CO emission for different fuel blends.

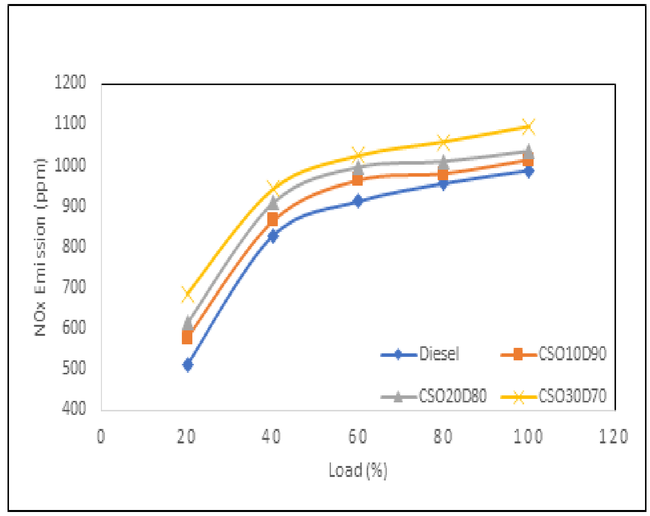

Figure 5. Variation of NOx emission for different fuel blends.

full load. This is due to the possibility that the cylinder temperature could be low at lower load which increases as the load in increased approximately beyond 50%. Secondly, the reduced CO emissions might be due to the better combustion and complete oxidation of the biodiesel blend compared to pure diesel.

3.5 Oxides of Nitrogen (NOx) Emission

Figure 5 demonstrates the comparisons in NOx emissions for conventional diesel and cottonseed oil blended biodiesel variants with load. For cottonseed oil blended biodiesel, the emission of NOx is found to be greater than the diesel at full load. NOx emissions are observed to be 988, 1014, 1036 and 1096 ppm for Diesel, CSO10D90, CSO20D80 and CSO30D70 respectively at full load condition. During the premixed combustion stage, it may be attributable to higher-level heat release rate and temperature as biodiesel blends have higher oxygen content than diesel leads to complete combustion. A desirable combustion rate might also be the reason for it. The desirable combustion rate is due to the good homogeneous air-fuel mixing which leads to a massive part of combustion just before the Top Dead Center (TDC). The Exhaust Gas Recirculation (EGR) being one of the most is an effective methodology for monitoring the NOx emissions from CI engines, it can be adopted to reduce the NOx emissions of the engine working with cottonseed oil biodiesel.

4.0 Conclusion

In this present work, the use of compression cottonseed oil blended biodiesel has been investigated as an alternate fuel for a common rail direct injection diesel engine from performance and emission point of view. The biodiesel blends containing 10, 20 and 30 % composition of cottonseed oil methyl ester have been analyzed and the respective parameters have been compared with that of pure diesel. The biodiesel CSO20D80 consisting of 20% cottonseed oil methyl ester was found to be an optimal blend with BTE lower by 2.3% and BSFC higher by 0.047kg/kWh compared to pure diesel at full load condition. From emission point of view, the HC and CO emissions were 10 ppm and 0.105% lower in comparison to pure diesel. However, the NOx emissions were observed to be higher by 4.5% in case of CSO20D80 biodiesel which can be reduced by adopting exhaust gas recirculation techniques. Thus taking into account the performance and emission characteristics and keeping in view the scarcity of fossil fuel, the biodiesel blend extracted from cottonseed oil can be considered as a potential alternate to diesel fuel in compression ignition engines.

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