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Numerical Investigation of Performance and Emission Characteristics of Biodiesels as Compression Ignition Engine Fuels

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Abstract: In this paper, the effects on the performance and emission characteristics of a conventional compression ignition engine has been simulated using pure diesel (B0), pure methyl soyate (SB100) and methyl ester of rapeseed oil (RB100) as fuels by a commercially available software Diesel-RK. The performance characteristics like brake specific fuel consumption (BSFC), brake torque and brake thermal efficiency (BTE) and emission characteristics like NOx, CO2, particulate matter (PM) and smoke emissions were evaluated for all the three fuels so that a valid comparison can be made between the three. The performance charac-teristics show that BSFC increases and brake thermal efficiency decrease with the use of biodiesel, the difference being more for methyl soyate. It was observed that pure diesel has maximum efficiency of 28.9% whereas pure methyl soyate and rapeseed oil methyl ester have the maximum efficiency of 27.2% and 28.7% respectively. In respect of emission characteristics, NOx emission is found to increase with load as well as use of biodiesel in this study. The maximum value of NOx emission with diesel is 1991 ppm, whereas with both the biofuels it is much higher than diesel, 2922 ppm and 2616 ppm for SB100 and RB100 ester respectively. For smoke and PM, emissions decreased with the use of bio-diesels, the decrease being more for RB100. However for CO2, emissions for B0 was found to be intermediate between SB100 and RB100, highest being for SB100. Thus, it could be concluded that use of biodiesel decreases performance to some extent and im-proves emis-sions. However, when compared between methyl soyate and rapeseed bio-diesel, it could be said that rapeseed is superior to methyl soyate due to the better perform-ance and lower emissions of RB100 compared to SB100. The reason may be the higher heating value and cetane number of RB100 compared to SB100.

Keywords: Simulation, Performance, Emission, Methyl Soyate, Rapeseed Biodiesel.

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I. Introduction

With the depletion of oil resources as well as the negative environmental impact, associ-ated with the use of fossil fuels, there is a renewed interest in alternate energy sources leading to active research throughout the world in nonpetroleum, renewable, and nonpol-luting fuels. In the last decade, there has been considerable research work being carried out to promote vegetable oil as possible substitute for diesel fuel in context of Internal Com-bustion engine. India has huge potential for biodiesel production from non-edible type oil seeds, like Karanja (Pongamia Pinnata), Ratanjyot (Jatropha Curcus), Rapeseed (Brassica Rapa Var) [1-4]. As such, researchers are making sincere attempts to test the compatibility of biofuels in conventional diesel engines. However, experimental study is much expen-sive and time consuming when compared to numerical simulations. Thus, numerical simu-lation, using proper mathematical models, to evaluate the effect of biofuels on diesel en-gines can prove to be an economic approach in engine design.

The process of diesel combustion being a complex and heterogeneous one, the numerical models used can be divided into two major groups, viz. thermodynamic model and fluid dynamic model. Thermodynamic models are based on first law of thermodynamics and can be further classified as single zone heat release model, phenomenological jet based model and quasi-dimensional multi-zone model. Single zone models assume that the cyl-inder content is uniform in composition and temperature and are suitable for prediction of engine performance. Phenomenological combustion models are based on each individual processes occurring in engine cycle such as fuel injection, mixture formation, heat release, heat transfer and emission formation. Fluid dynamic based models, often called multi-dimensional or computational fluid dynamics (CFD) models are based on solving the gov-erning equations for conservation of mass, momentum and energy and species concentra-tion through a definite discretization procedure [5]. In addition to that, several softwares, based on the above models, are commercially available that can be used for the simulation of compression engines, namely; ProRacing engine simulation, Virtual engine DYNO, ECFM-3Z (three zone extended coherent flame model), ADvanced VehIcle SimulatOR (Advisor) and DIESEL-RK software etc.
In this work, the performance and emission characteristics of a conventional diesel engine using three different fuels namely, pure diesel (B0), Methyl soyate (SB100) and rapeseed biodiesel (RB100) have been numerically simulated using a commercially available soft-ware DIESEL-RK.

II. Effects of biodiesels on engine performance and emissions

In its composition biodiesel is a fatty acid methyl ester produced from vegetable oils or animal fats [6]. Thus, this difference in the composition and properties of biodiesel from pure diesel will result in difference in the engine performance and emissions. Engine power will decrease with the increase of content of biodiesel [7]. The use of biodiesel will lead to loss in engine power mainly due to the reduction in heating value of biodiesel com-pared to diesel [8]. The same reason can be accounted for the increase in the brake specific fuel consumption. Biodiesel gets injected earlier in comparison to the fossil diesel fuel [9] and hence is also combusted earlier which improves thermal efficiency. Also, higher biodiesel cetane number causes shorter delay time of fuel com-

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bustion and provides more time for complete combustion [10-11]. However, the low calorific value and high viscosity of bio-fuels again tend to decrease the thermal efficiency [7]. Use of biodiesel reduces the emission of CO2 due to the lower carbon to hydrogen ratio and also a decrease in CO due to the extra oxygen content of the biodiesel promoting complete combustion [8]. However, the use of biodiesel increases the content of NOx in the combustion products [12-13]. Higher NOx content in the combustion products can be explained by high oxygen content in biodiesel [14].

III. Properties of fuels used and methodology

Crude vegetable oil can be converted to its methyl esters via transesterification process in the presence of catalyst. The purpose of the transesterification process is to lower the viscosity of the oil. Ideally, transesterification is potentially a less expensive way of trans-forming the large, branched molecular structure of the bio-oils into smaller, straight chain molecules of the type required in regular diesel combustion engines. Biodiesel from soya-bean and rapeseed oil are free from sulphur and still exhibits excellent lubricity, which is an indication of the amount of wear that occurs between two metal parts covered with the fuel as they come in contact with each other. It contains very small amount of phosphorus and sulphur and therefore emission of oxides of sulphur (SOx) is almost negligible. In comparison with commercial petro-diesel and soyabean, rapeseed biodiesel has higher cetane number. In addition, the higher flash point (more than 100ºC) of soyabean biodiesel makes the storage and transportation issues less important. It is a much safer fuel than diesel because of its higher flash point. The amount of carbon residue from the hot decompo-sition of vegetable compounds with higher molecular weight is greater than that of com-mercial diesel oil. On the other hand, oxidation products originated with biodiesel affect storage life and contribute to deposit formation in tanks, fuel systems and filters. Some of the important fuel properties of soyabean and rapeseed biodiesel and conventional petro-diesel are presented in the tabular form for ready reference in table 1 for comparison.

An alternative fuel is always evaluated on the basis of both engine performance and its environmental impacts. The performance and environmental parameters, which we have evaluated to find the suitability of methyl soyate and rapeseed biodiesel, are: brake specific fuel consumption, thermal efficiency, exhaust gas temperature, NOx, specific CO2 and PM and smoke emissions. These parameters were calculated for diesel, methyl soyate and rapeseed biodiesel at constant engine speed of 1500 rpm and injection timing of 23°bTDC. The test engine used in this work has the specification shown in Table II. The test engine specification is collected from our departmental laboratory. A brief of transesterification reaction is given below:

Table 1: Demand of Gasoline and Diesel in India [3]

Property	Methyl Soyate	Diesel	Rape-
Cetane No.	51.3	48	54.4
Calorific Value (MJkg^{-1})	36.22	42.5	39.45
Molecular Mass of Fuel	292.2	190	296
Compositions (Mass Fractions)			
C	0.773	0.87	0.77
H	0.1188	0.126	0.120
O	0.108	0.004	0.109
Density (kgm)	885	830	874
Dynamic viscosity coefficient at 323K (Pa.s)	0.00463	0.003	0.00692
Manufacturer		Kirloskar Oil Engines Ltd.	
Model		TV	
Type		Fou Stroke. Water Cooled	
No. of cylinder		On	
Rated Power		3.5 kW @ 1500 RPM	
Compression Ratio			
Bore		87.5 mm	
Stroke		110 mm	
Connecting rod length		234 mm	
Method of Cooling		Water Cooled	

IV. Results and discussions

Performance and emission characteristics like brake thermal efficiency, brake specific fuel consumption, NOx, CO2, smoke and PM emissions have been simulated and their varia-tion with brake power have been shown and discussed in this section.

A. Brake Specific Fuel Consumption

The variation of brake specific fuel consumption (BSFC) with brake power for diesel, methyl soyate and rapeseed biodiesel has been shown in figure 1. It can be seen that the BSFC is lowest with pure diesel followed by Rapeseed biodiesel and the highest being for methyl soyate. The primary reason for this trend is due to the lower calorific value of both the biodiesel compared to diesel. When compared between the two biodiesels it is seen that the calorific value of methl soyate

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(36.22 MJkg-1) is lower than that of rapeseed biodiesel (39.45 MJkg-1). Hence, the more fuel is consumed in case of methyl soyate to give the same power output as given by rapeseed biodiesel, eventually giving the highest BSFC.

B. Brake Thermal Efficiency

Figure 2 shows the variation of brake thermal efficiency with brake power for diesel, methyl soyate and rapeseed bio-diesel. It can be seen that the use of biodiesel decrease the thermal efficiency due to their lower heating value compared to diesel. However, the ther-mal efficiency of rapeseed bio-diesel is slightly lower than that of diesel. In fact, it is slightly higher than diesel at low load. This may be due to the higher cetane number of rapeseed (54.4) causing shorter delay time of fuel combustion and providing more time for complete combustion, eventually increasing the efficiency. However, at higher loads per-haps the low calorific value and high viscos-ity of rapeseed again tend to decrease the thermal efficiency.

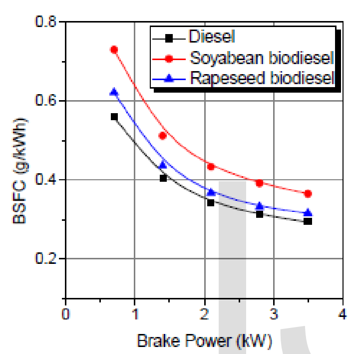

Fig. 1 Variation of BSFC with brake power for three different fuels

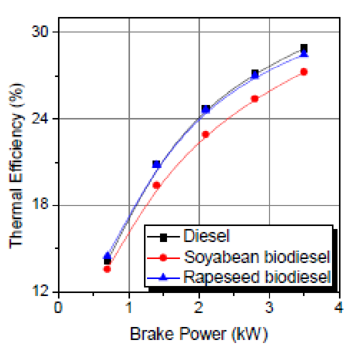

Fig. 2 Variation of brake thermal efficiency with brake power

C. Exhaust Gas Temperature

Figure 3 shows the variation of exhaust gas temperature with brake power for diesel, methyl soyate and rapeseed biodiesel. The figure shows an increase in the exhaust tem-perature for biodiesels, the highest being for methyl soyate. This is due to the higher oxy-gen content of biodiesels resulting in complete combustion and higher pressure and tem-perature rise during combustion.

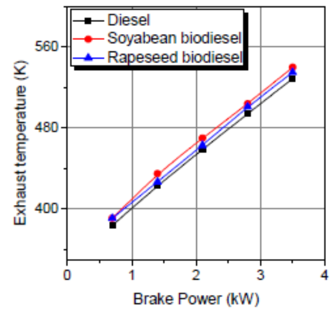

Fig. 3 Variation of exhaust gas temperature with brake power

D. NOx Emissions

Figure 4 shows the variation of the NOx emission with brake power for diesel, methyl soyate and rapeseed biodiesel. The figure shows a higher NOx emission with the use of biodiesels compared to diesel, the highest being for methyl soyate. The higher oxygen con-tent of biodiesels compared to pure diesel causes a more complete combustion in case of biodiesels and this leads to a higher pressure and temperature rise during combustion.

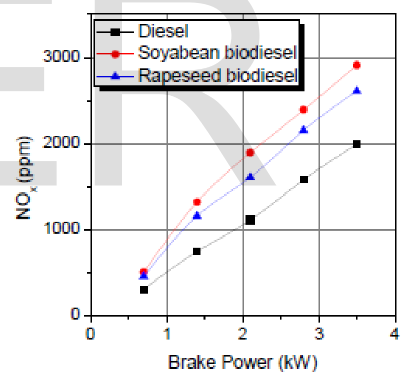

Fig. 4 Variation of NO_x emission with brake power for differ-ent fuels.

This higher temperature causes the formation of valance oxy-gen from dissociation, even-tually resulting in higher NOx emission. When compared between the two biodiesels, the higher viscosity of rapeseed biodiesel (0.00692 Pa.s) compared to methyl soyate (0.00463 Pa.s) may lead to the poor atomiza-tion of rapeseed biodiesel which in leads to poorer com-bustion, resulting in lower temperature and eventually reduc-ing the NOx emission.

E. CO2 Emissions

Figure 5 shows the variation of specific CO2 emission with brake power for diesel, methyl soyate and rapeseed biodiesel. It can be seen from the graph that the specific CO2 emis-sion increases with the use of methyl soyate. This is due to higher oxygen content of methyl soyate, resulting in complete com-bustion, thus producing more CO2 than that with diesel, for any operating condition. However, the use of rapeseed biodiesel decreases the CO2 emission.

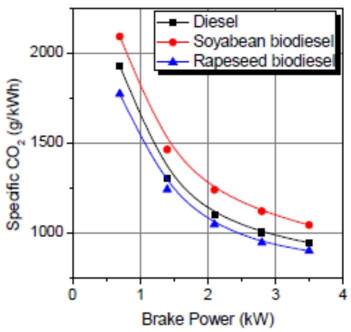

Fig. 5 Variation of CO2 emission with brake power for different fuels.

F. Particulate Matter and Smoke Emissions

Figure 6 and figure 7 show the variation of specific particulate matter (PM) and smoke emissions with brake power for diesel, methyl soyate and rapeseed biodiesel. It can be clearly seen that specific PM decreases for both the bio-fuels. The primary reason of the particulate emission (PM) from CI engine is improper combustion and combustion of heavy lubricating oil and smoke formation occurs primarily in the fuel-rich zone of the cylinder, at high temperatures and pressures [15].

Use of biodiesels reduces the PM and smoke emissions which are primarily due to the complete combustion of the biodiesel, owing to the higher oxygen content in it. The higher cetane number of biodiesel is also a reason for this.

When compared between the two biodiesels, the higher viscosity of rapeseed biodiesel causes poor atomization of fuel, leading to higher smoke and PM emissions. As such the lowest smoke and PM emission is observed in case of methyl soyate.

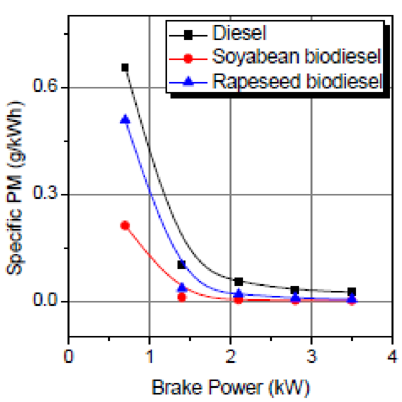

Fig. 6 Variation of PM emission with brake power for different fuels.

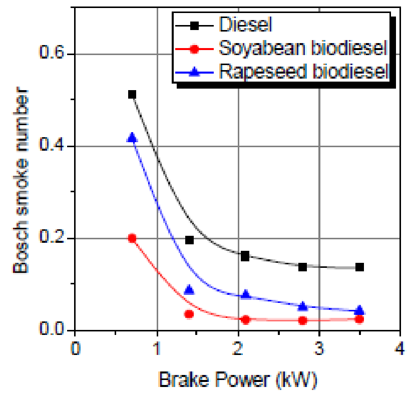

Fig. 7 Variation of smoke number with brake power for different fuels.

XII. Conclusion

From the above study it is concluded that, biodiesel can be used in Compression Ignition engine without any major engine modification which makes it very popular among the alternate fuels. Hence, biodiesels can prove to be a suitable alternative to that of diesel. However, the use of has an effect on engine performance and emissions. From the above numerical results it can be said that engine performances decrease slightly along with PM and smoke emissions, with the use of biodiesels. A little increase in the NOx and CO2 emissions can be considered when the question of replacement of diesel fuel with bio-diesels comes into the picture. Also the exhaust gas temperature increases slightly with biodiesel when compared to diesel. A comparison between the two biodiesels shows that rapeseed is superior to methyl soyate due to the better performance and lower emissions of RB100 compared to SB100. The reason may be the higher heating value and cetane number of RB100 compared to SB100.

XIII. Aknowledgement

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