Indian Journal of Science and Technology Vol. 5 No. 7 (July 2012) ISSN: 0974- 6846

Simulation and environmental assessment of compression ignition engine powered by neat biodiesels of different origin

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Abstract

Performance parameters and exhaust emissions of a diesel engine powered by diesel fuel and a biodiesels, namely jatropha oil methylester (JME), Cottonseed oil methylester (COME), Rapeseed oil methylester (RME), Soybean oil methylester (SME) and Castor oil methylester (CAME) at full load have been investigated using Diesel-RK engine simulation software. The performance of an engine whose basic design parameters are known can be predicted with the assistance of simulation programs into the less time, cost and near value of actual. However, inadequate areas of the current model can guide future research because the effects of design variables on engine performance can be determined before. In this study, thermodynamic cycle and performance analyses were simulated for various engine speeds ranging from 1000 rpm to 3000 rpm with an increment of 100 rpm at full load, 17.5:1 constant compression ratio (CR) of a CI engine with four stroke, single cylinder and natural aspirated. Several parameters and emission were calculated namely; engine torque, brake mean effective pressure, brake power, specific fuel consumption, thermal efficiency, NOx, and CO_2, this was carried out using DIESEL-RK Software.It was found that the engine offer lower thermal efficiency when it is powered by neat biodiesel compared to diesel, while it offer higher for JME and minimum for SME among biodiesels. Further, it was found that both the thermal efficiency of the engine and the specific fuel consumption increases with the increase in speed of engine. The NOx emission was found higher for all fuels compared with diesel fuel, whereas it was seen that CO_2 emissions were higher for SME, RME, and COME and lower for JME and CAME.

Keywords: Compression Ignition (CI) engine, Diesel-RK Simulation, Biodiesel, Exhaust emission.

Introduction

Studies on internal combustion engines have been recently concentrated on alternative fuels. The increase in alternative fuel investigations is caused by two main factors; a rapid decrease in world petroleum reserves and important environmental concerns originating from exhaust emissions. [Murat et al., 2008].The term biodiesel commonly refers to fatty acid methyl or ethyl esters made from vegetable oils or animal fats, whose properties are good enough to be used in diesel engines. Biodiesel is a promising nontoxic and biodegradable renewable fuel comprised of mono-alkyl esters of long chain fatty acids, which is produced by a catalytic transesterification reaction of vegetable oils with short-chain alcohols. Biodiesel has become an interesting alternative to diesel engines, because it has similar properties to the traditional fossil diesel fuel and may thus substitute diesel fuel with none or very minor engine modifications (Fangrui & Milford, 1999).

There are four issues related to biodiesel where public knowledge is still low:

1. Biodiesel has around 9% less heating value in volume than conventional diesel fuel. Thus, if engine efficiency is the same, engine fuel consumption should be proportionally higher, and consequently vehicle autonomy proportionally lower, when using biodiesel.
2. Biodiesel fuels have higher lubricity than conventional fuels, but they can contribute to the formation of deposits, the degradation of materials or the plugging of filters, depending mainly on their degradability, their glycerol (and other impurities) content, their cold flow properties, and on other quality specifications.
3. Biodiesel is 100% renewable only when the alcohol used in the transesterification process is also renewable.
4. Biodiesel fuels also have an interesting potential to reduce chemical emissions (Lapuerta *et al*., 2008).

Other studies have clearly indicated that the use of biodiesel may potentially reduce the dependence on petroleum diesel fuel and improve environmental aspects with satisfactory performance [Albuquerque et al., 2009].

The rapid development of computer technology has encouraged the use of complex simulation techniques to quantify the effect of the fundamental processes in the engine systems. The advances achieved by current automotive engines would have been impossible without the simulation models providing these insights (Heywood, 1989; Ganesan, 2000; Ramadhas *et al.,* 2006). In response, several codes emerged as a companion to experimental work in engine design; these codes are capable of modeling transient, three dimensional, compressible, multiphase flows with chemical reactions by solving the mass, momentum, and energy equations. These codes are used for the simulation of compressed engines that use pure diesel fuel. A brief review of such codes is presented by Ramadhas *et al*. (2006). In this paper, an appropriate code was selected and modified, by introducing different parameters, in order to allow for the simulation process when the engine run on JME, COME, RME, SME and CAME, which to the best of the author knowledge has not been carried out before.

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Simulation model

Table 1. Engine specification

Sr. No	Item	Technical Data
1	Model	VRC 1
2	Make	COMET
3	Rated BHP / kW	5.0 / 3.7
4	Bore x Stroke (mm)	80.0 x 110.0
5	Swept Volume (CC)	553
6	Compression Ratio	17.5:1
7	Rated RPM	1500
8	No. of Cylinder	1
9	Method of Cooling	Air
10	Bearing Type	Bush
11	Sp. Fuel Consumption gms / Kwhr	251
12	Lubrication System	Plunger Pump
13	Crank Shaft Height (mm)	203

The theoretical models used in the case of internal combustion engines can be classified into two main groups viz., thermodynamic models and fluid dynamic models. Thermodynamic models are mainly based on the first law of thermodynamics and are used to analyze the performance characteristics of engines. Pressure, temperature and other required properties are evaluated with respect to crank angle or in other words with respect to time. The engine friction and heat transfer are taken into account using empirical equations obtained from experiments. These models are further classified into two groups namely single-zone models and multi-zone models. On the other hand, multi-zone models are also called computational fluid dynamics models. These are also applied for the simulation of combustion process in the internal combustion engines. They are based on the numerical calculation of mass, momentum, energy and species conservation equations in either one, two or three dimensions to follow the propagation of flame or combustion front within the engine combustion chamber. Several software, which are based on the above models, were commercialized in order to be used for the simulation of compression ignition engines, namely; ProRacing engine simulation,

Virtual engine DYNO, ECFM-3Z (three zone extended coherent flame model), Advisor (ADvancedVehIcleSimulatOR) and DIESEL-RK Software etc., In this work the Diesel-RK software was used since its agreement with experimental data was very good as indicated in references [13]. It is a multi-zone model of diesel sprays evolution and combustion, it takes into account: the shape of injection profile, including split injection; drop sizes; direction of each spray in the combustion chamber; the swirl intensity; the piston bowl shape. Evolution of wall surface flows generated by each spray depends on the spray and wall impingement angle and the swirl intensity. Interaction between near-wall flows (further named wall surface flows) generated by the adjacent sprays is taken into account. The method considers hitting of fuel on the cylinder head and liner surfaces.

The evaporation rate in each zone is determined by Nusselt number for the diffusion process, the pressure and the temperature, including temperatures of different walls where a fuel spray gets. A parametric study of the swirl intensity effect has been performed and a good agreement with experimental data was obtained. The calculations results allow describing the phenomenon of increased fuel consumption with increase of swirl ratio over the optimum value. The model has been used for simulation of different engines performances. The model does not require recalibration for different operating modes of a diesel engine (Hamdan, 2009).

Methodology

In this work, thermodynamic software DIESEL-RK software was used for the calculation the performance of a compression ignition engine when it is powered by different alternative fuels of different origin. The parameters, which were calculated in order to find the performance and emission characteristics of the engine, are brake torque, brake power, specific fuel consumption and the thermal efficiency. These parameters were calculated for each biodiesel and at different engine speeds. The engine used in this work has the specification shown in Table 1.While properties of the different fuel are shown in Table 2. These values shown in both tables are used as input data to the software. Also, it is used to get a more calculation about the emissions from the engine such as to determine the temperature of exhaust, CO_2, NOx for different biofuels at different operating speeds.

Results and discussion

The obtained results under full engine load conditions are presented in figures from 1to6. The variation of engine torque with speed for various biodiesel is indicated in Fig.1. It may be seen that, and as expected from theory, the engine torque increases with speed to a maximum value, beyond which it starts to decrease with speed.

Further, as indicated from the figures, torque produced by JME is higher at all speed range of engine under test. Fig.2 shows the variation of the engine power with speed for various biodiesel respectively. As expected and as a general trend, initially the engine power increases with a speed to a maximum value at a speed of 3000 rpm, beyond which the power remains constant, however it is expected to decrease as

Table 2. Physical properties of biodiesels and diesel fuel

Property	Fuel					
	Miner Diesel	JME	RME	SME	COME	CAME
Density (kg/m^3)	815	879	874	885	857.3	913
Kinematic Viscosityat 40^{o}C(cSt)	4.3	4.84	4.7	4.5	5.94	11
Calorific value(MJ/kg)	42.5	38.5	37.23	33.5	36.89	39.16
Cetane Number	48	51	54.4	45	45.5	50

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Fig. 1. Variation of engine torque with speed

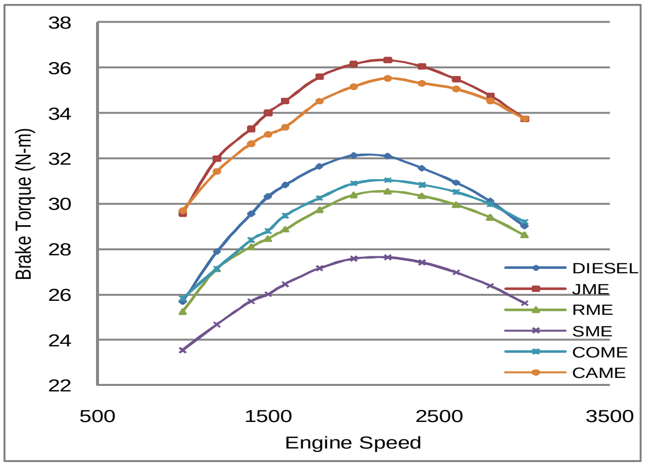


Fig. 2. Variation of engine power with speed

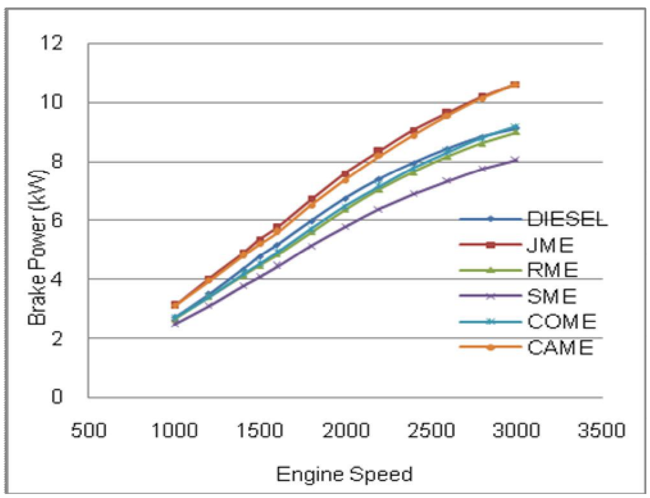


Fig. 3. Variation of BSFC with Speed

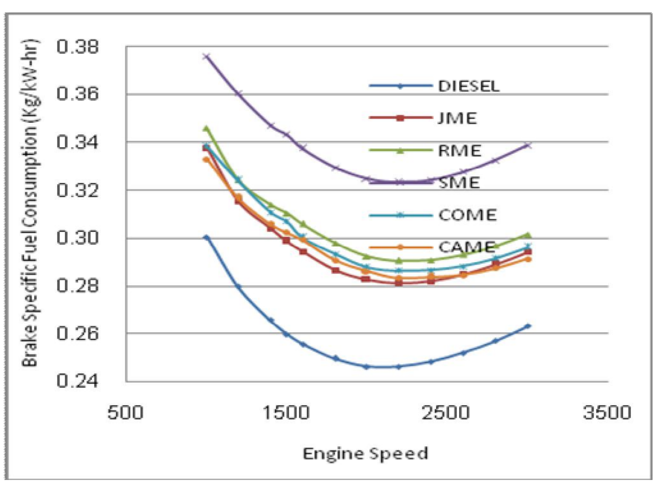


Fig. 4. Variation of thermal efficiency with speed

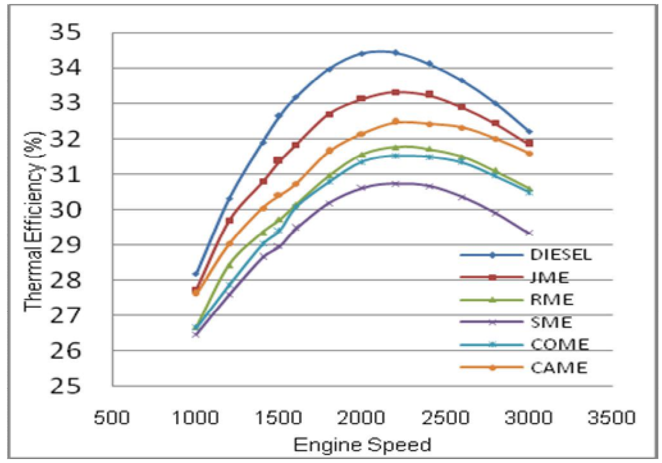


Fig. 5. Variation of NO_X Emissionswith speed

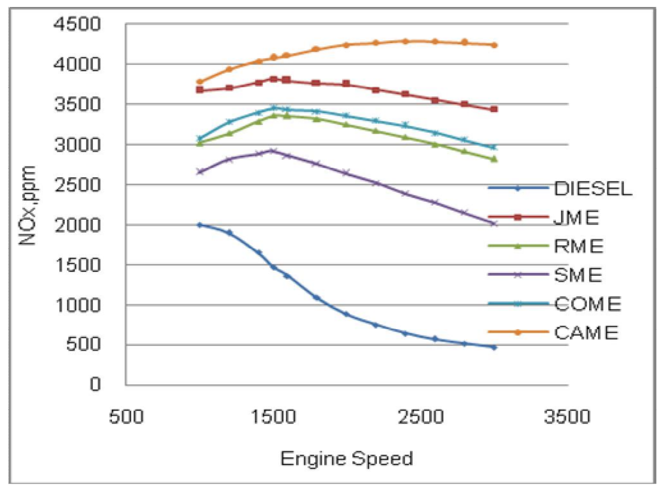
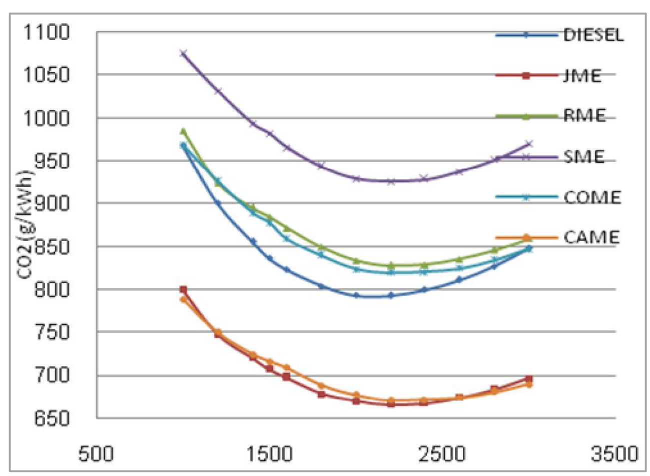


Fig. 6. Variation of CO_2 Emissionswith speed



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speed further increases. Further, it may be noticed that the power produced decreases with the increase in speed more than 3000 rpm. The decrease in engine power after reaching its maximum value is an expected phenomenon as the speed further increases. Further, it may be noticed that the power produced is slightly higher than that of ordinary diesel fuel with the increasing speed of the engine for JME and CAME whereas it is found lower for RME, SME and COME.

Brake-specific fuel consumption

Brake-specific fuel consumption (bsfc) is the ratio between mass fuel consumption and brake effective power, and for a given fuel, it is inversely proportional to thermal efficiency (Lapuerta *et al*., 2008). The results for the variation in the brake specific fuel consumption (bsfc) with increasing speed of the engine at various speed range studied are presented in Figure 3. For all fuels, the specific fuel consumption varies with increasing speed. For neat jatropha oil fuel, brake specific fuel consumption has high value at low speed but decreases as the speed increases, and then it reaches the lowest value to that of other biofuels operation. The brake specific fuel consumption (bsfc) becomes equal at the maximum speed for both neat JME and CAME oil fuel but higher then diesel fuel (within the speed range studied).

Thermal efficiency

Thermal efficiency is the ratio between the power output and the energy introduced through fuel injection, the latter being the product of the injected fuel mass flow rate and the lower heating value.Thus, the inverse of thermal efficiency is often referred to as brake-specific energy consumption (Lapuerta *et al*., 2008; Hamdan & Khalil, 2009). It is observed that the brake thermal efficiency is slightly lower than that of the corresponding diesel fuel, for JME at higher speed of the engine. It can be seen from the Fig.4 that the efficiency for neat JME is quite close to that of a diesel at very high speed of the engine. This means that the increase of brake specific fuel consumption is lower than the corresponding decrease of the lower calorific value of the neat JME oil, which could have been caused by reductions in friction loss associated with higher lubricity of neat jatropha oil. For rest biodiesels it is still lower.

NO_X emissions

Although most of the literatures reviewed showed a slight increase in NOx emissions when using biodiesel fuel, some works showing different effects have been found. Some of them found increase in NOx emission only for certain operating conditions, some others did not report differences in NO_x emission between diesel and biodiesel fuels, and others reported even decrease in NO_x emissions when using biodiesel (Lapuerta *et al*., 2008). Diesel engine combustion generates large amounts of NO_x because of high flame temperatures (1800^{o}K) in the presence of abundant oxygen and nitrogen in the combustion chamber (Deepak Agarwal *et al.,* 2006). The variation of NO_x emissions for fuels with engine speed is shown in Fig.5.

The NO_x emission increases with the increase in engine speed and reaches its maximum value at a speed of 1500 rpm and further goes on decreasing and there is significant increase in $NO_x$for all biodiesels. SME is found to be least whereas CAME has maximum NOx emission among all the biodiesel under test. To reduce NO_x emission, the temperature in the cylinder should be reduced. The NO_x emission increases with the engine load at higher combustion temperature. This proves that the most important factor for the emissions of NO_x is the combustion temperature in the engine cylinder and the local stoichiometry of the mixture. From Fig.5, it can be seen that within the range of tests, the NO_x emissions from the neat biodiesels are higher than that of diesel fuel.

CO_2 emissions

With regard to most of the literature reviewed, a decrease in CO_2 emissions when substituting diesel fuel with biodiesel can be considered as the general trend (Hansen & Jensen, 1997; Pinto *et al*., 2005; Shi *et al*., 2005). Nevertheless, a few authors found no differences between diesel and biodiesel (Serdari *et al*., 1999), and even noticeable increases when using biodiesel (Hamasaki *et al*., 2001). Several reasons have been reported to explain the general CO_2 decrease when substituting conventional diesel with biodiesel:

The variation of Specific Carbon dioxide emission (CO_2) emissions for fuels with engine speed is shown in Fig.6. It can be seen from the figure, CO_2 emission is lower for CAME and JME while it is found higher for RME, SME and COME with respect to diesel fuel. CO_2 emission follows the decreasing trend for low operating speed whereas showing the increasing trend for higher operating speed of the engine. It was found least for JME and highest for SME, while COME and RME shows the slight increase in CO_2 emissions.

Conclusions

In this work a four stroke compression engine was simulated using DIESEL-RK software. The simulations were performed in order to find the performance of the engine when it is powered by neat biodiesels of different origin. The results obtained through the simulations can be summarized as follows:

1. JME and CAME developing maximum torque at all operating speed of the engine. RME, SME and COME produce less torque as compared to diesel fuel operating. Further, torque developed by COME is much closer to diesel.
2. Engine power increases with speed to a maximum value at an engine speed of 3000 rpm for all fuels. At maximum speeds around 3000 rpm the power produced is slightly higher than that of ordinary diesel fuel for JME and CAME. This clearly indicates that at higher engine speed conditions the performance of vegetable oil fuel can exceed that of diesel fuel

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operation. For RME, SME and COME the power produced is lower within the speed range studied.

3. The biodiesel fuel produced the low brake thermal efficiency at all speed range of the engine studied. Besides all fuels under test, JME is offering highest but lower than mineral diesel fuel and SME offer lowest.
4. There was significant increase in NO_X emissions when running on neat biodiesel oil fuels compared to diesel fuel operation. The overall test results showed that, it follows decreasing trend as the speed increases, except for CAME.
5. CO_2 emissions were found to be lower for JME and CAME, whereas it is found higher for RME, SME and COME.

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