

Research Article

Numerical Investigation of the Performance and Emission Characteristics of a CI engine using Diesel and its blends with Ethanol and Jatropha Biodiesel

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Abstract

A global concern that has arisen in the present time due to the constant depletion of the fossil fuels reservoirs and also due to the greenhouse gases emitted by use these fuels has led many researchers to find alternate sources of energy, out of which biodiesels have found a suitable place. Thus, in this effort of finding the compatibility of bio-fuels in present diesel engines, many experimental works have been carried out. However, these experimental works consume much cost and time when compared to numerical simulations. Under this context, an effort has been made in this paper to numerically simulate the performance and emission characteristics of a CI engine fueled with diesel, diesel and ethanol 20% blend (E20), diesel and jatropha 20% blend (JB20) and diese, ethanol 20% and jatropha 20% blend (JBE20) and make a comparison between the same. It was found that the use of JB20 decreased the thermal efficiency compared to pure diesel. However, ethanol blends increased the efficiency slightly, the increase being more for E20 than JBE20. On the other hand, diesel showed the lowest brake specific fuel consumption, the highest being for JB20. In case of emissions, the use of JB20 increased the NO_x emission and E20, JBE20 decreased the NO_x emissions compared to pure diesel, the decrease being more for E20. The specific CO₂ emissions followed the same trend as NO_x emission. In case of the specific particulate matter (PM) and smoke emissions, diesel showed the highest emission at full load, followed by E20, the lowest being for JB20. E20 showed the highest exhaust gas temperature followed by JB20, the lowest for pure diesel.

Keywords: Simulation, ethanol, jatropha, performance, emissions.

1. Introduction

It is a well-known fact that fuel is the backbone of modern transportation system of the world. Almost every automobile uses conventional fuels as their primary source of energy and with the recent rise in the population; development in the field of science and urbanization of the world, the demand for fuels is constantly increasing. However, these conventional fuels being a non-renewable source of energy are constantly being depleted and are in a process of extinction. In addition to that, the harmful greenhouse gases that are emitted from the burning these fossil fuels are constantly degrading the environment. Among all the countries of the world, India has taken its place in the fifth position in emitting greenhouse gas and is expected to move up to the third place in the years to come, with China topping the list. India has already started feeling the international pressure regarding the control of its green house gas emissions (Reducing Transport Greenhouse Gas Emissions: Trends & Data, 2010), (A Report of Working Group of the Intergovernmental Panel on Climate Change). A significant amount of GHG

emissions is contributed by the transportation sector. And as the growth rate of vehicle population throughout the world is increasing constantly; it is quite clear that merely controlling the emissions will not solve the problem completely (Emission Norms, Society of Indian Automobile Manufacturers). As such, the possible solution to the above mentioned problem is the use of an alternate source of energy. In this quest for an alternate source of energy, biodiesel has found itself in the center position and is attracting the mind of many researchers because of its similarity in physical composition with that of mineral diesel. It is observed India has huge potential for biodiesel production from non-edible type oil seeds, like karanja, ratanjyot (Policy on Biofuels, a Report by Government of India, Ministry of New & Renewable Energy), (Karanja-A Potential Source of Biodiesel, a Report by National Oilseeds and Vegetable Oils Development Board, Government of India, Ministry of Agriculture, 2008), (Cultivation and Use of Jatropha for Bio-Diesel Production in India), (Report of the Committee on Development of Bio-Fuel, Planning Commission, Government of India, 2003).

Thus, many research works have been carried out and are still ongoing at the present moment to test the

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performance and emission characteristics of CI engines fueled with biodiesels. However, experimental procedures are not quite feasible from the perspective of time, manpower and cost, when compared to numerical approach. Thus, numerical simulation, using proper mathematical models, to evaluate the effect of biodiesels on diesel engines 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 to simulate the various engine characteristics can be divided into two major groups, viz. thermodynamic model and fluid dynamic model. Thermodynamic models are based on first law of thermodynamics whereas fluid dynamic based models, often called multi-dimensional or computational fluid dynamics (CFD) models are based on solving the governing equations for conservation of mass, momentum and energy and species concentration through a definite discretization procedure. 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 engine parameters, viz. performance and emissions using pure diesel, diesel-ethanol 20%, diesel-jatropha 20% and diesel-jatropha 20%-ethanol 20% as fuels have been simulated using a software- Diesel-RK.

2. Effects of diesel blends with jatropha and ethanol on engine performance and emissions

An alternative fuels or supplementary fuels used in engines are always evaluated on the basis of both engine performances and its environmental impacts. The effects of ethanol addition, jatropha addition and both jatropha and ethanol addition on different performance parameters have been discussed first in this section. Shi et al. (Shi, et al, 2006) observed that the addition of alcohol and biodiesel in the blends showed a slight change in brake specific fuel consumption (BSFC) compared with diesel fuel. BSFC depends upon the calorific values of fuels, whereas the calorific value of blend is less than that of diesel. The ethanol-diesel blends have less density and lower calorific values, which results higher fuel consumption and as such higher brake specific fuel consumption than that of diesel as reported by Ajav et al. (Ajav, et al, 1999). Banapurmath and Tewari (Banapurmath and Tewari, 2010) observed in their experimental study that the brake thermal efficiency increased with ethanol-jatropha blended fuels with increasing ethanol content in blended fuels. It was due to lower boiling point of ethanol than that of jatropha oil methyl ester. The combustion is more complete in the fuel-rich zone due to the oxygen content of ethanol-blended fuels. This enhances the combustion efficiency and decreases heat losses in the cylinder due to lower flame temperature of ethanol-blended fuels than that of plain biodiesel of jatropha oils. It was also observed by

Xingcai et al. (Xingcai, et al, 2004) that the addition of ethanol to ethanol-diesel blended fuel enhanced the efficiency. The lower flame temperature and lower boiling point can be considered to be responsible for the increase of efficiency. The use of biodiesel will lead to loss in engine power mainly due to the reduction in heating value of biodiesel compared to diesel as reported by Xue et al. (Xue, et al 2011). The same reason can be accounted for the increase in the brake specific fuel consumption. Ashok and Saravanan (Ashok and Saravanan, 2007) found that exhaust gas temperature of emulsified fuel was higher than that of diesel, because the latent heat of vaporization is high which increases combustion temperature and results an increase in exhaust temperature. It was observed by Ajav et al. (Ajav, et al, 1999) and He et al. (He, et al, 2010) that the percentage of NO_x emission reduced with the increasing percentage of ethanol in the blends. They explained that the air-fuel ratio in the case of ethanol-diesel blends is lower than that of diesel. As latent heat of vaporization of ethanol is high and heating value of the blends is low, the higher the load, the more the fuel injected which results a reduction in cylinder charge temperature and combustion temperature, and also NO_x emission reduced. However, the use of biodiesel increases the content of NO_x in the combustion products (Imdat and Mucahit, 2009), (Hazar, 2009). Mustapic (Mustapic, 2006) explained that comparatively high temperature inside the cylinder due to the combustion of biodiesel and higher oxygen content of the fuel are responsible for higher NO_x emission. Imdat and Mucahit (Imdat and Mucahit, 2009) observed that the CO₂ emissions decreased with the increase of ethanol in the blends. The main reason of CO₂ reduction is low C/H ratio and high oxygen content of the blends. However, Barabas et al. (Barabas, et al, 2010) experimentally observed that the CO₂ emission increased with the addition of oxygenated fuel into diesel due to the higher carbon-hydrogen ratio and presence of oxygen molecule in biodiesel. Krishnaswamy and Moorthi (Krishnaswamy and Moorthi, 2012) and Li et al. (Li, et al, 2005) observed the reduction of smoke emission with the addition of alcohol and biodiesel and concluded that the reduction in smoke emission was because of the availability of fuel-bound oxygen in the ethanol and biodiesel even in locally rich zones of combustion.

3. Properties of fuels used and methodology

Properties of any fuel depend fully on its chemical compositions which determine the performance and emission characteristics of the engine. Ethanol is oxygen enriched chemical element; containing 35% oxygen by weight. It therefore can be treated as partially oxidized fuel. When ethanol is added to the blended fuel it can be provided more oxygen for the combustion process and leads to the so-called "leaning effect". Owing to the leaning effect engine combustion is improved. Lower heating value (LHV) has an average value of 26.8 MJ/kg. Ethanol does not contain phosphorous or sulphur, so there is no reason behind emission of oxides of sulphur (SO_x). Biodiesel from jatropha oil is also 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. Jatropha biodiesel has higher density and cetane number compared to commercial petro-diesel. It is a much safer fuel than diesel because of its higher flash point. In comparison with commercial diesel and jatropha biodiesel, ethanol has lower density. In addition the lower flash point of ethanol makes the storage and transportation issues a bit problematic. Some of the important fuel properties of ethanol, jatropha biodiesel and conventional petro-diesel are presented in the tabular form for ready reference in table 1 for comparison.

Table 1 Properties of fuels

Property	Ethanol	Jatropha	Diesel
Mass fraction			
Hydrogen	0.131	0.121	0.126
Oxygen	0.347	0.113	0.004
Sulphur fraction (%)	0	0.0024	0
Lower heating value	26.8	30.5	39
Cetane number	07	53	48
Density at 323K (kg/m ³)	70	862	830
Molecular mass	46.07	282	190
Latent heat of	841	320	250
Flash point (°C)	13	240	73.88

4. Methodology

In the present work, the effect of using biodiesel blend (20% jatropha + 80% diesel), ethanol blend (20% ethanol + 80% diesel) and biodiesel-ethanol blend (20% jatropha + 20% ethanol + 60% diesel) on the performance and emission characteristics of a CI engine were simulated using Diesel-RK software. In order to carry out the simulations, a numerical model of a 4-stroke, single cylinder, TV1 engine was fed into the software along with the thermo-physical properties of the different fuels. In order to check the compatibility of the various blends of fuels with the CI engine and study their effect on the engine, different engine parameters were successfully predicted by the software and a thorough study has been made for the same.

Table 2 Engine specifications

Manufacturer	Kirloskar oil engine Ltd.
Model	TV1
Type	4 stroke, water cooled
No. of cylinders	1
Rated power	3.5 kW @ 1500 rpm
Compression ratio	18
Bore	87.5 mm
Stroke	110 mm
Connecting rod length	234 mm
Method of cooling	Water cooled

The parameters, which were calculated in order to find the performance and emission characteristics of the engine

are: brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature, NO_x, CO₂, PM and smoke emissions. These parameters were calculated for all the fuels at constant engine speed of 1500 rpm. The engine used in this work has the specification shown in table 2.

5. Results and Discussions

Performance and emission characteristics like brake thermal efficiency, brake specific fuel consumption, exhaust gas temperature, NO_x, CO₂, smoke and PM emissions have been numerically simulated and their variation with brake power have been shown and discussed in this section.

5.1 Brake specific fuel consumption

The variation of BSFC with brake power for the four different fuels is shown in figure 1. It can be seen that the BSFC is minimum for pure diesel, followed by E20, with the highest being for JB20. This trend is primarily because of the low calorific value of the ethanol and jatropha biodiesel. BSFC depends on the calorific value of the fuels and thus the lower heating value of the diesel blended with ethanol and jatropha results in higher consumption of fuel compared to pure diesel, increasing the BSFC.

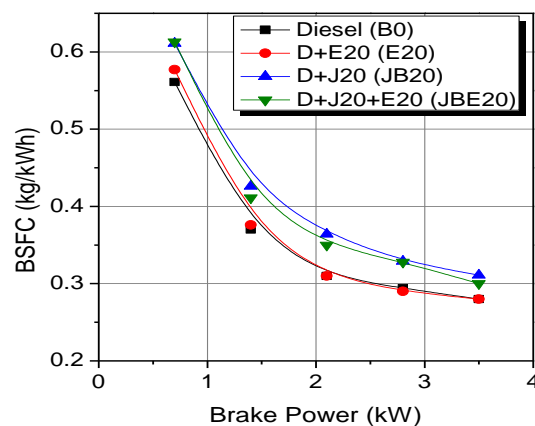


Fig.1 Variation of BSFC with brake power for the different fuels

5.2 Brake thermal efficiency

Figure 2 shows the variation of brake thermal efficiency with brake power for the four different fuels. The figure shows a decrease in the efficiency for JB20 than pure diesel. However, there is a slight increase in the efficiency for E20 and JBE20, the highest being for E20. The use of biodiesel blends reduces engine efficiency mainly due to the reduction in heating value of biodiesel compared to diesel. In case of diesel ethanol blends the lower flame temperature and lower boiling point can be considered to be responsible for the increase of efficiency with ethanol blends. When compared between ethanol and jatropha blends, the oxygen content of ethanol-blended fuels causes a more complete combustion in the fuel-rich zone, enhancing the combustion efficiency and decreasing the

heat losses in the cylinder due to lower flame temperature of ethanol-blended fuels than that of plain biodiesel of jatropha oils.

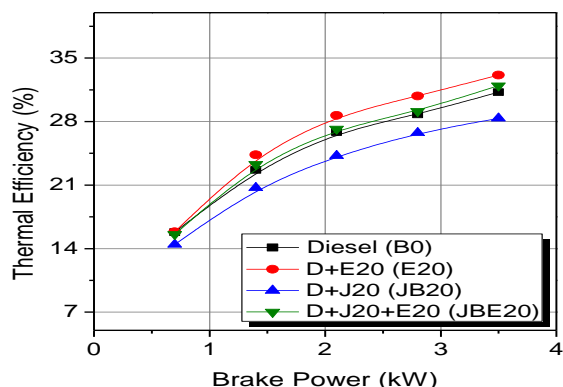


Fig.2 Variation of brake thermal efficiency with brake power for the different fuels

5.3 Exhaust gas temperature

Figure 3 shows the variation of exhaust gas temperature with brake power for the four different fuels. The figure shows the lowest temperature for pure diesel, followed by JB20, with the maximum being for E20. The main reason for this behavior is the high latent heat of vaporization of ethanol and jatropha compared to pure diesel. Again, between jatropha and ethanol, ethanol has a higher latent of vaporization than jatropha biodiesel, eventually resulting in the following trend.

5.4 NO_x emission

The variation of NO_x emission with brake power for the four different fuels is shown in figure 4. It can be seen from the figure that compared to pure diesel, jatropha blend shows an increase in the NO_x emission and the ethanol blends E20 and JBE20 show a decrease in the same, with the decrease being more for E20.

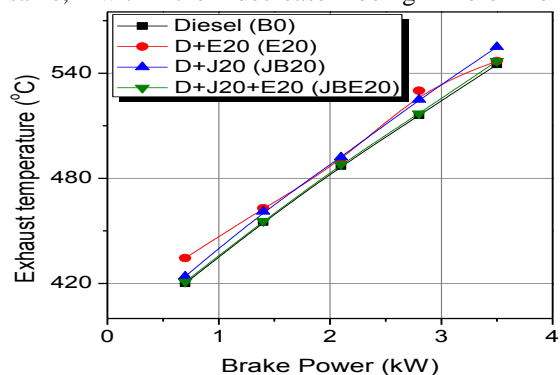


Fig.3 Variation of exhaust gas temperature with brake power for the different fuels

This is primarily because the air-fuel ratio in the case of ethanol-diesel blends is lower than that of diesel. As latent heat of vaporization of ethanol is high and heating value of the blends is low, the higher the load, the more the fuel injected which results a reduction in cylinder charge

temperature and combustion temperature, reducing the NO_x emission. However, in case of jatropha blend, the comparatively high temperature inside the cylinder due to the combustion of biodiesel and higher oxygen content of the fuel are responsible for higher NO_x emission.

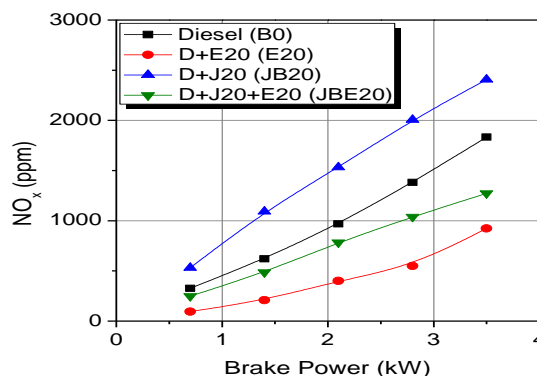


Fig.4 Variation of NO_x emission with brake power for the different fuels

5.5 Specific CO₂ emission

The variation of specific CO₂ emission with brake power for the four different fuels is shown in this figure 5. It can be clearly seen that the variations for the fuels follow exactly the same trend as that of NO_x emission. Use of jatropha blend increases the CO₂ emission compared to diesel. Whereas, the use of ethanol blends show a decrease in the CO₂ emission, the maximum decrease being for E20. The main reason of CO₂ reduction is low C/H ratio and high oxygen content of the blends. However, the increase in the CO₂ emissions in case of jatropha blend is primarily due to the higher carbon-hydrogen ratio and presence of oxygen molecule in biodiesel. Moreover, the complete combustion in case of jatropha blend results in a higher temperature causing almost complete oxidation of carbon mono-oxide to carbon dioxide resulting more CO₂ in the tailpipe exhaust for biodiesel.

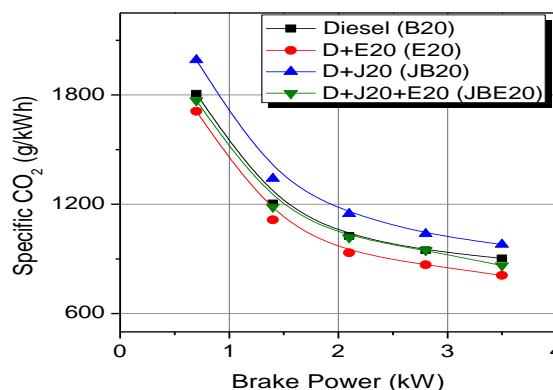


Fig.5 Variation of Specific CO₂ emission with brake power for the different fuels

5.6 Specific PM and smoke emissions

The variation of the specific PM and smoke emissions with brake power have been shown in figure 6 and 7

respectively. The figures show the similar trend for both specific PM and smoke emissions. The highest emissions are found with the use of pure diesel followed by E20, with the lowest being for jatropha blend (JB20). 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 (Nabi, et al, 2009). As such, the reason for such trend can be because of the availability of fuel-bound oxygen in the ethanol and biodiesel even in locally rich zones of combustion. Again, the complete combustion of the jatropha biodiesel, owing to the higher oxygen content in it and also its higher cetane number can be the reason for JB20 showing the lowest PM and smoke emissions.

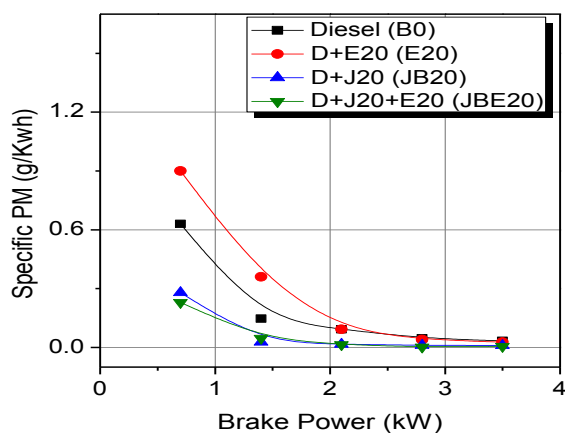


Fig.6 Variation of Specific PM emission with brake power for the different fuels

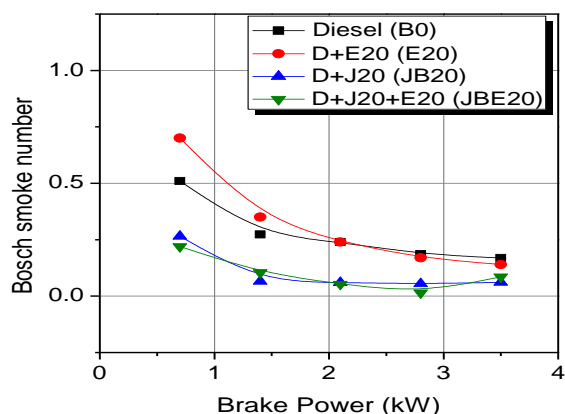


Fig.7 Variation of Bosch smoke number with brake power for the different fuels

6. Conclusion

From the above study it is concluded that, ethanol can be a suitable supplementary fuel of CI engine. It can both be used with mineral diesel and biodiesel. It doesn't require any major engine modification also. This makes it so popular among the alternative fuels. The performance gets deteriorated with the use of jatropha blend and also the complete combustion of jatropha blended fuel causes higher NO_x and CO_2 emissions at the tail pipe. However,

the PM and smoke emissions are highly reduced. On the other hand, the use of ethanol blend with both pure diesel and diesel jatropha blend reduces the performance slightly, i.e. it increases the BSFC. But a slight increase in the thermal efficiency is also observed which maybe because of the lower boiling point of ethanol, resulting in more complete combustion in the fuel-rich zone due to the oxygen content in it. This enhances the combustion efficiency and decreases heat losses in the cylinder due to lower flame temperature of ethanol-blended fuels. But in case of emissions, ethanol blended fuels give a significant reduction in the harmful emissions like NO_x and CO_2 and also emissions like PM and smoke due to their higher latent heat of vaporization.

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