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OPTIMIZATION OF THE PERFORMANCE OF DIESEL ENGINE RUNNING ON JATROPHA BIODIESEL THROUGH ETHANOL FUMIGATION

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Abstract

Performance and emissions characteristics of a Diesel engine are taken away from optimum values when biodiesel is used as a fuel. In this research Ethanol fumigation at engine inlet was used to mitigate the negative effect of biodiesel properties. Five percent increase in engine efficiency relative to biodiesel was achieved with 23 percent of ethanol fumigation. Smoke opacity and carbon monoxide emission were decreased by 50% and 30% respectively. Nitrogen oxide and unburned hydrocarbon emission were increased. Five percent reduction of carbon dioxide was observed with ethanol fumigation. That was attributed to lower carbon/hydrogen ratio in ethanol as compared to biodiesel.

Key words: *Diesel engine, efficiency, emissions, biodiesel, alcohol*

1. INTRODUCTION

Use of alternative fuels of different origin in internal combustion engines is the subject of extensive research especially in countries with limited resources of crude oil. Fatty Acid Methyl Esters (FAME, biodiesel) made from vegetable oil and animal fat become popular as a fuel for diesel engines. FAME have physical and chemical properties different from those of petroleum fuel oil (D, diesel oil), therefore diesel engine designed to operate on diesel oil shows non-optimal performance and emissions parameters when runs on biodiesel (Lapuerta et al. 2008).

Jartopha (Bannikov and Chattha 2013), Pongamia (Bannikov et al. 2010) and Mastard (Bannikov and Vasilev 2012) biodiesels were tested in single cylinder direct injection diesel engine. The common for all the fuels tested was the increased specific fuel consumption, reduced carbon monoxide (CO), unburned hydrocarbons (HC) and smoke emission as compared to diesel oil. Nitrogen oxides (NO_x) emissions proved to be very sensitive for test and engine conditions, but in most tests were reduced. Close inspection revealed that increase in specific fuel consumption of biodiesels was partly due to their lesser heating values and partly due to decreased fuel conversion efficiency. Heating value of the fuel is its inherent property and cannot be changed, but efficiency can be improved. Investigation of test results showed that the reason for reduced efficiency was higher bulk modulus and better self-ignition properties of biodiesels than that of diesel oil. Advanced fuel injection and shorter delay period resulted in earlier start of combustion of biodiesels, reduced maximum rate of heat release and eventually increase in negative compression work and reduced efficiency. It was concluded, that efficiency of the engine running on Jatropha, Pongamia and Mastard biodiesels can be improved by decreasing their cetane number. That may be done by adding alcohols to biodiesel and/or biodiesel/diesel oil blends (Bannikov and Khan 2012). Alcohols have low cetane number and high oxygen content, with the latter being additional improver of combustion efficiency, hence fuel conversion efficiency.

Goal of this research was the optimization of engine performance characteristics running on biodiesel by using alcohol additives.

Alcohol may be either blended with diesel fuel (Rakopoulos et al. 2007) or added to engine inlet air, we call the latter "fumigation". Further, fumigation may be done by carburetion (Bhupendra et al. 2011) or injection (Dhandapani Kannan et al. 2012, Noboru Noguchi et al. 1996, Hayes et al. 1988, Cheung et al. 2008). Blending of alcohol has some limitations. First, methanol-diesel fuel blends are not stable (Eugene et al. 1984). Second, in some small diesels (like engine, tested in this research) high pressure fuel pump is mounted in crank-case and heated by splashing lubricating oil to temperatures above boiling point of methanol- and ethanol-diesel oil-biodiesel blends. As a consequence, vapor plugs block the pump and engine stops (Bannikov and Vasilev 2013). Fumigation by carburetion has disadvantage of an increased flow resistance in the inlet manifold (Bhupendra et al. 2011).

In this research optimization of engine characteristics running on biodiesel was implemented by injecting alcohol into the inlet air.

While selecting alcohol two candidates were considered, namely methanol and ethanol. Both have low cetane number, are comparatively cheap and can be produced from renewable sources. Methanol was rejected because of its toxicity and corrosion activity.

2. EXPERIMENTAL SETUP AND FUELS

AC1 Lister-Petter four-stroke single-cylinder diesel engine was used for testing fuels. Engine specification is given in Table 1. Swinging field dc machine was used to start and load the diesel. Engine test bench was equipped with all necessary instrumentation for measuring engine speed, load, fuel and air flow rates, temperatures of lubricating oil, inlet air and exhaust gas etc. Data of cylinder pressure, fuel line pressure, and injector needle lift were acquired by AVL Indimodul 621 indicating system and processed by Indicom software. AVL DITEST diagnostic system was used for exhaust gas analysis and measurement of exhaust opacity. More details of experimental setup can be found elsewhere (Bannikov and Khan 2012).

Ethanol was injected into inlet port of an engine. Fuel injection setup included the fuel pump, fuel injector, electronic control unit, pressure regulator and fuel tank. The pressure drop across injector was maintained constant of 0.85 bar (gauge). Fuel flow rate was controlled by changing injection pulse frequency.

Table 1. Engine specification

Rated power, kW	5.0
Rated speed, rpm	3600
Maximum torque, Nm	15.6 at 2650 rpm
Combustion system	Direct injection
Bore/stroke, mm	76.2/66/67
Engine displacement, l	0.304
Compression ratio	18.5
Injection timing (static), °BTDC	26°

Properties of fuels tested are provided in Table 2.

Table 2. Properties of fuels

Property	D	J	Ethanol
Density @ 15°C kg/m^3	831.9	881.8	792
Kinematic viscosity @40°C, cSt	3.348	4.62	1.5@20°C
Lower heating value, MJ/kg	42.41	38.30	26.95
Cetane number	50	47	8

3. TEST RESULTS AND DISCUSSION

Engine was tested at the brake mean effective pressure (bmep) of 5.0 bar and speed of 3600 rpm being fuelled with diesel oil, and neat J biodiesel with and without ethanol fumigation.

First, effects of properties of biodiesel on engine performance are discussed. As seen from Fig. 1a, higher bulk modulus of biodiesel resulted in advanced by 1.3 crank angle degree (c.a.d.) injection of J relative to D.

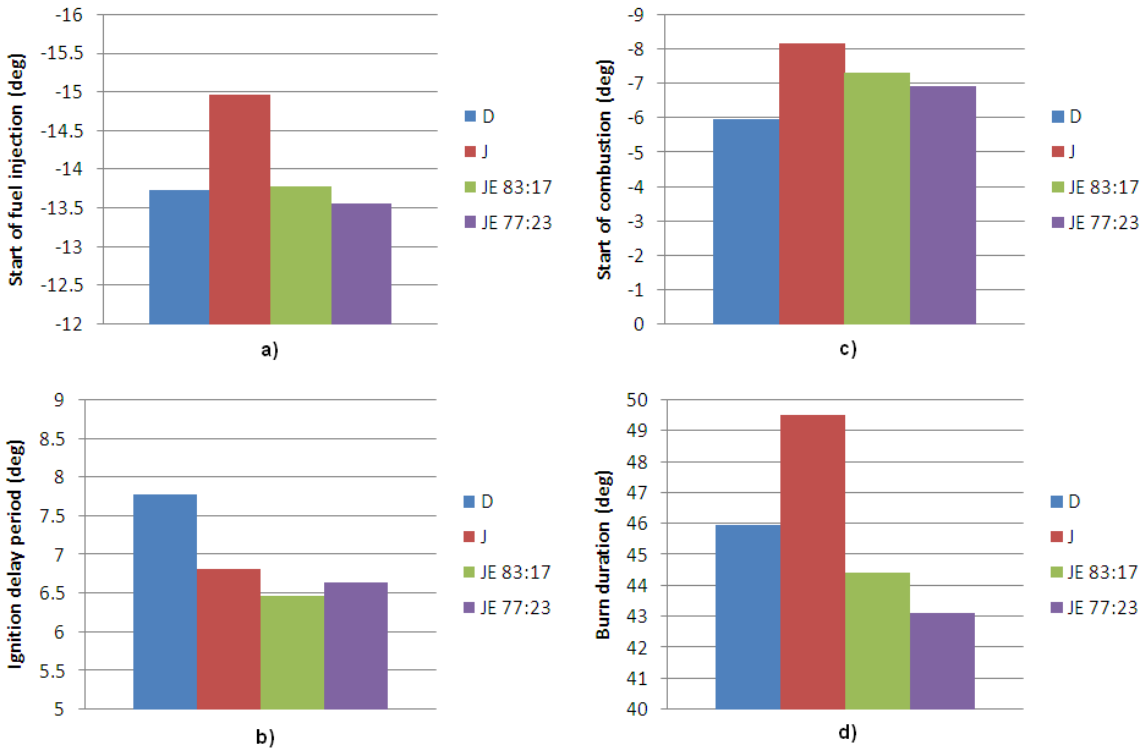


Fig. 1. Fuel injection and combustion characteristics. Bmep = 5.0 bar; N = 3600 rpm.

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Higher cetane number of biodiesel decreased ignition delay period by 0.9 c.a.d. relative to D (Fig. 2b). Advanced injection and shorter delay period resulted in earlier by 2.2 c.a.d. start of combustion of biodiesel relative to diesel oil (Fig. 2c).

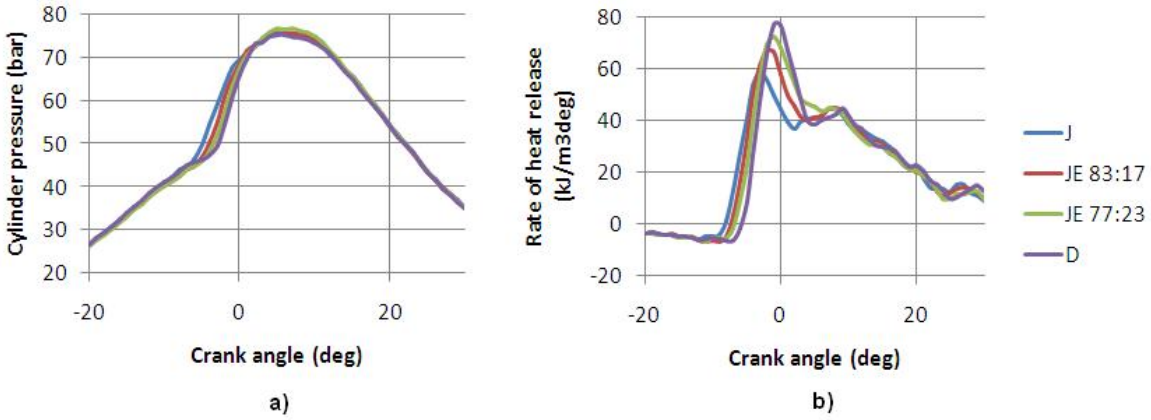


Fig. 2. Indicator diagram and rate of heat release. Bmep = 5.0 bar; N = 3600 rpm.

Increased consumption of biodiesel required to maintain the same load as for D resulted in longer by 3.6 c.a.d. combustion duration as compared to that of diesel oil (Fig. 2d). Thus, properties of biodiesel mentioned above predetermined the cylinder pressure and rate of heat release changes as illustrated in Fig. 2.

Biodiesel showed higher pressure during premixed combustion, hence higher negative compression work of the cycle (Fig. 2a), lesser maximum rate of heat release and lower premixed burn fraction, whereas fuel fraction burn in diffusion combustion phase was increased. As a consequence, brake fuel conversion efficiency (η_b) with biodiesel was decreased by 7.5% relative to diesel oil (Fig. 3). 16% increase in brake specific fuel consumption (bsfc) was attributed partly to decreased efficiency and partly to lesser heating value of biodiesel.

At the next stage of experiment biodiesel flow rate was reduced and ethanol flow rate was adjusted to keep the same bmep of 5.0 bar at the same speed of 3600 rpm. Engine was tested at Jatropha biodiesel/ethanol volume ratios of JE 83:17 and JE 77:23. As seen from Fig. 1, five percent increase in engine efficiency with JE 77:23 in comparison with J was achieved with moderate increase (1.6%) in specific fuel consumption. Such an improvement of brake efficiency was the result of low cetane number of ethanol. Decrease in cylinder charge temperature due to ethanol vaporization also contributed to longer ignition delay. Start of combustion was retarded with JE 77:23 by 1.2 c.a.d. relative to J; pressure and rate of heat release curves of JE 77:23 are now closer to that of diesel fuel rather than to J. One more reason for improved efficiency is the lesser by 6.4 c.a.d. burn duration of JE 77:23 than that of J (Fig. 1d).

Engine emissions were also affected by fuel properties. Considerable decrease in CO and smoke emissions were achieved with ethanol fumigation (Fig. 3). NO_x emissions with ethanol injection were increased relative to J and reached those of diesel oil. Undesirable effect of ethanol fumigation was the increased by 300% HC emissions. But in spite of so high relative increase in HC emissions their absolute values were low; maximum bsHC are of order of 1 g/kW·h.

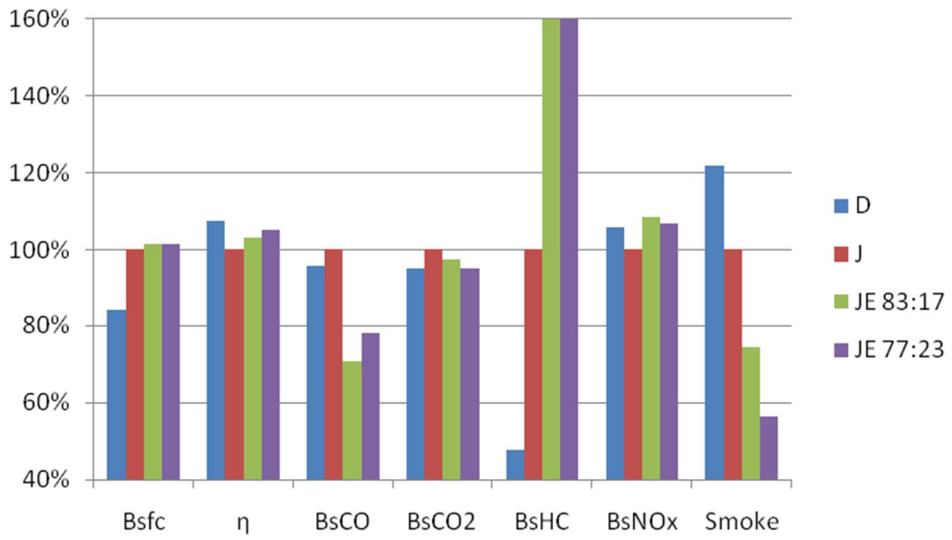


Fig. 3. Engine performance and emissions characteristics. Bmep = 5.0 bar; N = 3600 rpm.

Despite increased fuel consumption emission of carbon dioxide (CO_2) was decreased by 5% with ethanol fumigation relative to J which is undoubtedly good news. The reason for that was the lower C/H ratio of JE 77:23 (5.98 vs. 6.37 that of J). That is with the same mass of fuel burned less carbon is available in JE 77:23 for CO_2 formation.

4. CONCLUSIONS

Jatropha biodiesel with ethanol fumigation and diesel oil were tested in direct injection diesel engine. Based on results following conclusion have been made.

1. Use of biodiesels resulted in decreased engine efficiency and increased fuel consumption. Emissions of nitrogen oxides and soot have been reduced when engine ran on biodiesel. Slight increase in carbon monoxide and unburned hydrocarbon emissions were observed at high load.
2. Ethanol fumigation at the rate of JE 77:23 resulted in five percent increase in engine efficiency relative to neat Jatropha biodiesel with moderate increase (1.6%) in specific fuel consumption. Fifty percent reduction in exhaust opacity and thirty percent reduction in CO were achieved with only eight percent increase in NO_x emissions. Undesirable effect of ethanol fumigation was the three hundred percent increase in HC emissions. Regardless of high relative increase in HC emissions their absolute values were low; maximum bsHC were of order of 1 g/kW·h.
3. Five percent reduction of CO_2 was observed with ethanol fumigation. That was attributed to lower C/H ratio in ethanol as compared to biodiesel.
4. It was concluded that alcohol addition is the effective method of an optimization of combustion characteristics of biodiesel for better engine efficiency. In this research fumigation of ethanol in proportion JE 77:23 showed good results with respect to both engine efficiency

and emissions. Alcohol selection (methanol, ethanol, butanol etc.), method of addition (blending or fumigation) and biodiesel/alcohol ratio require further investigation.

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