Studies on performance and emission characteristics of multicylinder diesel engine using hybrid fuel blends as fuel

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This study compared performance and emission characteristics of hybrid fuel blend [diesel-ethanol (anhydrous)-biodiesel (methyl esters of pungamia oil)] with diesel in a multi cylinder, naturally aspirated, direct injection diesel engine. Brake thermal efficiency of engine operated with hybrid fuel blends is found to be slightly higher than that of diesel fuel. Smoke and oxides of nitrogen (NO\textsubscript{x}) are found to be reduced simultaneously, while using hybrid fuel blends as fuel. Hydrocarbon (HC) emission is higher than diesel fuel for 10% ethanol addition, however when percentage of pungamia methyl ester (PME) increases in blends, HC emission is reduced. Carbon monoxide emission (CO) is found to be higher and a significant reduction is observed when increasing percentage of PME in blends.

Keywords: Emissions, Ethanol, Hybrid fuel, Karanja oil, Performance

Introduction

In India, total consumption of crude oil was 103.44 million tonnes (MT) in 2000-01 and 160.03 MT in 2009-10, whereas production was 32.43 MT in 2000-01 and 33.69 MT in 2009-10. Thus increment in production is only 3.7% as compared to increment in consumption of 35.36%\textsuperscript{1}. Transportation and agricultural sectors are major consumers of fossil fuel and biggest contributors to environmental pollution. Current price of vegetable oil worldwide is nearly competitive with petroleum based fuels. Vegetable oils have almost 90% of energy content of diesel fuel and have a favorable output-input ratio of their production\textsuperscript{2}. Brake thermal efficiency (BTE) of engine operated with blends of diesel and karanja biodiesel are reportedly higher than base diesel\textsuperscript{3} and emissions [carbon monoxide (CO), smoke density and oxides of nitrogen (NO\textsubscript{X})] are reduced with an average of 80%, 50% and 26%, respectively. Another sample\textsuperscript{4} of biodiesel from karanja oil showed slightly reduced thermal efficiency for engine operated with karanja oil and its biodiesel. Exhaust gas temperature (EGT), hydrocarbon (HC), CO and NO\textsubscript{x} emissions were found higher for karanja biodiesel than that of diesel.

One prospective method to reduce NOx and smoke simultaneously in normal diesel engines is to use oxygenated fuel to provide more oxygen during combustion\textsuperscript{5}. Blends of biodiesel, ethanol and diesel fuel may improve some properties compared with biodiesel-diesel blends and ethanol diesel blends\textsuperscript{6}. A constant speed stationary diesel engine with ethanol-diesel blends\textsuperscript{7} revealed that up to 20% of ethanol in diesel blends can be used without any modifications. A single cylinder diesel engine with a blend of 80% diesel, 15% biodiesel and 5% ethanol was found to be most suitable ratio for diesohol production\textsuperscript{8} because of acceptable fuel properties and reduction of emissions. Solubility of fossil diesel fuel and ethanol is limited and depends upon moisture content in ethanol\textsuperscript{9}. Anhydrous bioethanol (99.94%) as 10% volume with diesel fuel, used by Lapuerta et al\textsuperscript{10} in a four cylinder 4-stroke, turbocharged, intercooled, direct injection diesel engine, is typical of those used in European cars. Utilization of bio fuels instead of fossil fuels may contribute to sustainable management of natural resources, fulfill greenhouse gas (GHG) emissions reduction and decrease dependency on imported crude oil\textsuperscript{11}.

This study presents comparison in performance and emission characteristics of hybrid fuel blend [diesel-ethanol (anhydrous)-biodiesel (methyl esters of pungamia...
oil) with diesel in a multi cylinder, naturally aspirated, direct injection diesel engine.

**Experimental Section**

**Fuel Preparation**

For transesterification, pungamia oil was heated above 100°C to remove water content in oil and allowed to cool until it reaches to 60°C in a cylindrical vessel. Potassium hydroxide (KOH) (0.7% wt/wt of oil) was dissolved in methyl alcohol (270 ml/l of oil) as catalyst to form potassium methoxide, and this mixture was poured into vessel containing heated pungamia oil while stirring mixture continuously with 600 rpm. A resistance temperature detector (RTD) (±0.5% accuracy) was placed in reacting mixture for measurement of reaction temperature and connected to a digital temperature indicator cum controller. Speed and reaction temperature were maintained for 1 h and products were allowed to settle under gravity for 4 h in a separating funnel. Products of transesterification process [pungamia oil methyl ester (biodiesel) and glycerol] were formed as upper and lower layers. Bottom layer of glycerol was removed, and upper layer of biodiesel was mixed with warm distilled water (10% vol/vol) to remove impurities (unreacted methanol, unreacted oil and catalyst). Mixture was again allowed to settle under gravity for 6 h and lower layer of water containing impurities was drained out. Hybrid fuel comprising diesel-ethanol-biodiesel is prepared by blending these fuels in different proportions. However, in present case 99.99% proof ethanol is used for preparing blends and hence prepared blends are fairly stable.

**Experimental Setup**

A 6 cylinder (Fig. 1) water cooled naturally aspirated diesel engine (type, W06D; make, Ashok Leyland-Hino; bore, 104 mm; stroke, 118 mm; displacement, 6.014 l; maximum output, 70 kW @ 2400 rpm; maximum torque, 324 Nm @ 1600 rpm) was used and loaded by an eddy current dynamometer. Inlet air, exhaust gas, water inlet and water outlet temperatures were recorded with thermocouples fitted on engine. HC, CO, carbon di-oxide (CO₂) and NOx emissions were recorded by AVL-4000 Di-gas analyzer, and smoke opacity was measured by continuous flow (AVL 437) smoke meter working on Hatridge principle. Fuel injection pressure was set to 230 bar and injection timing of 18° bTDC is maintained throughout the experiment. For experimental matrix (Table 1) for base diesel and hybrid fuel blends, engine runs from zero load to full load at a speed of 1800 rpm

![Fig. 1—Layout of experimental setup](image)

Table 1—Experimental matrix

<table>
<thead>
<tr>
<th>S. No</th>
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<th>Blends</th>
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<td>100</td>
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<td>Base</td>
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<td>10</td>
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<tr>
<td>3</td>
<td>80</td>
<td>10</td>
<td>10</td>
<td>D80P10E10</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>50</td>
<td>10</td>
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<tr>
<td>5</td>
<td>10</td>
<td>80</td>
<td>10</td>
<td>D10P80E10</td>
</tr>
</tbody>
</table>
Results and Discussion

Power Output

Power output of engine operated with different fuel blends (Fig. 2) indicated a maximum power of 54.686 kW @ 1900 rpm for engine that runs on hybrid fuel blend of D80P10E10. For comparison, this power is taken as full load, which is higher than engine operated with base diesel fuel of 54.45 kW. Power output of engine operating with hybrid fuel blends of D50P40E10 and D10P80E10 are 53.88 and 53.37 kW respectively, although power output are more or less same.

**BRAKE THERMAL EFFICIENCY (BTE)**

BTE of engine increases with load for all fuel blends (Fig. 3), may be due to higher gas temperature and pressure inside combustion chamber at higher loads. BTE of engine operated with hybrid fuel blends are slightly higher than engine operated with diesel fuel. For an engine operating with hybrid fuel blends consumes lower energy for same power output when compared with base diesel fuel operation. Also, higher bulk modulus of biodiesel in blends leads to an advance fuel injection timing as fuel injection system used in this study is inline fuel system. Moreover, stoichiometric air-fuel ratio of blends, which is less than that of diesel, leads to higher amount of excess air inside cylinder and hence longer combustion duration. BTE of engine operated with different fuels are as follows: base diesel, 34.69; D90E10, 34.89; D80P10E10, 33.60; D50P40E10, 35.75; and D10P80E10, 36.794%.

Smoke Opacity

Smoke opacity is increased with load (Fig. 4), might be due to shorter residence time of gases in combustion chamber at higher loads. Smoke opacity of D90E10 blends was lower for all loads than all fuels tested. Addition of 10% ethanol with diesel causes charge cooling, which increases ignition delay and enhances mixing of diesel and ethanol during premixed phase. At 75% load, smoke opacity were: diesel, 25; D90E10, 19; D80P10E10, 23; D50P40E10, 27; and D10P80E10, 28 HSU (Hatridge smoke units). Above 95% of load, smoke emission of all hybrid fuel blends is lower than base diesel. Compared with diesel fuel operation at maximum load, reductions
in smoke opacity were: D90E10, 21.4; D80P10E10, 16.2; D50P40E10, 18.2; and D10P80E10, 13.96%. These reductions are due to addition in blends of oxygenated fuels that increases excess air, which will limit primary smoke formation at higher loads. These results are in accordance with reported results $^{13,14}$.

**Oxides of Nitrogen (NOx)**

NO$_x$ formation is highly depends on gas temperature inside cylinder and availability of oxygen$^{15}$. NO$_x$, for all tested fuels increased linearly with load (Fig. 5), may be because with increasing load, temperature of combustion chamber increases$^{15}$. At full load, NO$_x$ for diesel fuel operation is 1960 ppm; with 10% addition of ethanol in diesel fuel, NO$_x$ is reduced to 1820 ppm. However, with increase of bio-diesel in blends, NO$_x$ emission is almost similar to base diesel fuel operation, may be due to diesel and vegetable oil are having comparable cetane number, and heating value. Temperature in combustion chamber is higher due to higher peak pressure of diesel-biodiesel-ethanol blends$^{12}$ compared to diesel fuel. Combined effect of higher excess air leads to more quantities of NO$_x$ in biodiesel fueled engines.

**Hydrocarbons (HC)**

HC emission is increased (Fig. 6) when engine operated with D90E10 blend than all other blends. An average of 18% increase in HC emission for engine operated with D90E10 fuel blend than diesel for all loads, might be due to addition of ethanol, which causes charge cooling due to its high latent heat of vaporization. However, for hybrid fuel blends, addition of methyl ester in blends of diesel and ethanol, HC emission is reduced. Vegetable oils have cetane number comparable with that of diesel and availability of oxygen (%) in fuel may lead to complete combustion and reduce unburned HC in exhaust. At 80% load, HC emissions were as follows: diesel, 20.5; D90E10, 22.5; D80P10E10, 22; D50P40E10, 19; and D10P80E10, 16 ppm.

**Carbon Monoxide (CO)**

At lower loads, availability of oxygen and combustion chamber temperature is low and hence higher CO emissions. At part load, CO emission is reduced due to more amount of excess oxygen. At higher loads, more quantity of fuel is injected with shorter residence time and hence increased CO emission. At lower loads, due to lower combustion temperature and less air utilization, CO emissions of hybrid fuel blends are higher than diesel (Fig. 7). However, at higher loads, better air utilization is possible in locally-rich zone for engine operated with hybrid fuel blends, which reduces CO emissions$^{9}$. 
Carbon Dioxide (CO$_2$)

Emissions of CO$_2$ are increased linearly with load of engine (Fig. 8), might be due to more complete combustion at higher loads. There is no significant difference for CO$_2$ emissions for all fuel blends tested. However, CO$_2$ emitted from biodiesel is entirely different with CO$_2$ emitted from fossil fuel operation. Since CO$_2$ emitted by former can be utilized for respiration in plants and it is recycled. Also, this CO$_2$ is decomposed in atmosphere within short period of time, but CO$_2$ emitted by later is retained over several 100 years and can cause ozone layer depletion.

Conclusions

Power output (54.686 kW) of engine operated with hybrid fuel D80P10E10 at 1800 rpm, is slightly higher than base diesel fuel operation. BTE for D10P80E10 fuel operation is 2% higher than diesel fuel. At maximum load, smoke emission for hybrid fuel blend is lower than diesel fuel operation. Addition of 10% ethanol (by vol) with diesel reduces NO$_x$ and increases HC emissions. However, these trends are changed when pungamia oil(%) is increased in blend. CO emission is lower for hybrid fuel blends than base diesel and CO$_2$ emissions are similar that of diesel fuel operation. Thus renewable hybrid fuel blend is a suitable substitute for conventional diesel fuel.

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References