Study of stability, physical properties and engine performance of alcohol blended fuels

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The role of bio-derived, eco-friendly products such as butanol and ethanol as an additive in petro-diesel has been studied. Dispersion properties and physical stability of the blends have been ascertained with the aid of transmittance and backscattering profiles. Combustion phenomenon of blended fuel when monitored shows rapid ignition as compared to diesel, thereby suggesting reduction in ignition delay. Engine performance experiments are carried out in single cylinder compression ignition (CI) engine and the results show marginal reduction in brake thermal efficiency and exhaust gas temperatures as compared to diesel. A reduction of 3.5% in fuel consumption is observed with blend as compared to that with diesel for generating equivalent brake power. Physical properties such as density, viscosity, net calorific value, cetane index and copper strip corrosion are determined and found in accordance with ASTM standards. Reduction in size of soot particles is observed at the end of blend combustion.

Keywords: Alcohol blends, Backscattering profile, Biofuel, Dispersion stability, Engine performance

Dwindling fossil resources, increasing dependency on imported crude oil and deteriorating environmental balance have led to the use of bioenergy from biofuels as an ideal alternative. Considerable attention has been paid in the development of alternative fuel sources in various countries, with emphasis on bio-fuels that possess the added advantage of being renewable. As biofuels are produced from agricultural products (oxygenated by nature), and offer benefits in terms of reduced emissions. Amongst these bio-derivatives bio-alcohols such as ethanol and butanol are considered as next generation fuels. Utilization of ethanol as a blending agent in gasoline driven spark ignition engine is known since last few decades due to its high octane number, but it is also true that alcohols, mainly ethanol and to a much lesser extent methanol, can be considered as alternative fuels for diesel engines too. While anhydrous ethanol is soluble in gasoline, additives must be used in order to ensure its solubility in diesel fuel under a wide range of conditions, especially at lower temperatures when the miscibility is limited. Various techniques have been developed to improve the solubility of ethanol in diesel, one of which is formation of emulsion blends by adding emulsifier in order to prevent phase separation. Different types of emulsifying agents such as biodiesel and span 80 to the mixture of diesel and ethanol for attaining better blend stability has been reported earlier. The work also proved that adding only ethanol to diesel fuel can reduce lubricity, viscosity and calorific value, and create potential wear problems in sensitive fuel pump designs, which to a greater extent be reduced by using biodiesel as a blending agent. Researchers have also worked on interpreting the performance results of ethanol/diesel blends for assisting the multi-zone combustion modeling and heat release analysis for the relevant combustion mechanism. Also the same group evaluated the combustion characteristics using experimental-stochastic techniques and its propensity for combustion cyclic irregularity due to the low cetane number of ethanol. However, butanol is of particular interest as a renewable bio-fuel due to its hydrophilic properties along with higher heating value and cetane number, lower vapor pressure and higher miscibility than ethanol, making it preferable to ethanol for blending with conventional diesel fuel. The innovative processes adapted to convert crude glycerol, co-product from the biodiesel production to the value added products such as butanol, 1, 3 propanediol and propanol have resulted in the economization of butanol production as compared to its chemical synthesis. The literature concerning the use of butanol/diesel fuel blends in diesel engines and its effects on their performance and exhaust emissions is found scanty. In order to fill this

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gap, Mehta et al.\textsuperscript{11} studied the stability, engine performance and emission studies of butanol/diesel/biodiesel blends in comparison with virgin diesel. The blends when subjected to four cylinder four strokes CI engine, showed a reduction in %CO and NOx emissions. Also the beneficial effects of using butanol with diesel in naturally aspirated CI diesel engine resulting into better engine performance and reduced emissions have been studied\textsuperscript{12}. Another work illustrated analysis of heat release and related parameters in the combustion chamber when blended either with ethanol or butanol\textsuperscript{13}. Thus, the present paper reports study on the probable substitution of petro diesel with bio derived fuels, namely ethanol and n-butanol.

**Experimental Procedure**

Certified diesel, n-butanol (99.9% pure, Merck India) and ethanol (99% pure) were used in the above experimental study. Three different blends of diesel, ethanol and butanol were prepared and checked for the phase separation at 20°C for 24 h. The blends formulated in vol% of diesel/ethanol/n-butanol are $B_1$ (60:10:30), $B_2$ (50:15:35), $B_3$ (70:5:25). In order to ascertain the most stable blend, back scattering profiles were analyzed by scanning the samples for 20 m using light rays of 880 nm wavelength of Turbiscan Classic MA 2000 equipment. Density, kinematic viscosity, flash point and copper strip corrosion tests were performed using an Anton Parr densitometer (model DMA 4500), Herzog kinematic viscosity (model HCP 852), closed-cup Pensky Martens apparatus and copper strip corrosion test apparatus. Net calorific values of the most stable blend were calculated using ASTM-D4868-90 standard, neglecting the mass fraction of water, ash and sulfur content of the blend. Also cetane index was calculated by D-4737 method, whereby the data obtained from ASTM distillation was utilized. All these tests were performed in accordance with ASTM standards. In order to check the burning mechanism of alcohol blended fuels their combustion study was carried out. Zahabi make muffle furnace (microprocessor based temperature indicator cum controller) with heating range upto 1000°C was used as setup. The fuel drop from micropipette was made to fall on a small stainless steel plate placed inside the furnace. The droplets were ignited in air at atmospheric pressure. The droplet formation and burning process were recorded by a high speed digital camera (NIKON D3X with a speed of ISO-600 at a resolution of 164-164 dpi). The camera was kept just in front for imaging combustion phenomenon.

**Engine test setup**

Most stable blend ($B_2$) was introduced in a direct injection single cylinder; four stroke and constant speed (1500 rpm) compression ignition engine (Fig. 1) in order to study its engine performance. The specifications of the engine are given in Table 1. The shaft of the engine was coupled to eddy current type dynamometer for determining the engine torque. The engine speed was measured by an electromagnetic speed sensor installed on the dynamometer and was equipped with an orifice meter connected to a manometer to measure mass flow rate of the intake air. The exhaust gas temperature was measured with the help of RTD sensor. Engine tests were conducted at different load conditions, starting with pure diesel at no load condition. Then the fuel feed line was filled with the most stable blend and the tests were conducted to determine fuel consumption, exhaust gas temperature and air intake at different engine loads. Before running the engine with new fuel, it was allowed to run for sufficient time to consume the remaining fuel from previous experiment. The performance parameters such as brake specific fuel consumption (BSFC), brake

![Fig. 1— Compression ignition engine setup](image)

**Table 1 — Specifications of test engine**

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Engine make</th>
<th>Engine model/type</th>
<th>Cylinder bore, piston stroke</th>
<th>Compression ratio (cm$^3$)</th>
<th>Combustion chamber</th>
<th>Rate power output</th>
<th>Dynamometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Engine</td>
<td>Kirloskar</td>
<td>Model AV1/1 cylinder, 4 stroke, water cooled, diesel</td>
<td>Bore 70 mm, Stroke 100 mm</td>
<td>14:1</td>
<td>Direct injection</td>
<td>5 BHP at 1500 rpm/3.68 KW</td>
<td>Dyna-speed/SPR 36</td>
</tr>
</tbody>
</table>
thermal efficiency (BTE) and A/F ratio were calculated and compared with those of standard diesel. The readings were taken thrice and then averaged to ensure the reproducibility of the results.

Results and Discussion

Blend stability

Blends of diesel/ethanol/n-butanol were first tested for physical stability in order to ensure single phase as they contained ethanol which is having higher affinity for water making the blend more susceptible to phase separation. The results indicate that blends B\textsubscript{1} and B\textsubscript{3} show water droplet formation within 24 test hours, as shown in Fig. 2 (a). As a single clear phase is required for fuel application, these two blends are discarded and only blend B\textsubscript{2} has been considered for further tests. The stability of blend B\textsubscript{2} is also ascertained by scanning the sample in cuvette (60 mm) for a period of 20 min. The Backscattering (BS) profile of the blend B\textsubscript{2} is elucidated in Fig. 2 (b), where the left-hand ordinate shows the percentage of backscattering, the right-hand ordinate shows time in minutes, and the abscissa shows the length along the test cuvette (mm). As the figure depicts, the backscattering profiles at different time intervals superimpose, thereby confirming the fact that the blend remains stable and does not segregate into different phases, thereby fulfilling the requirement of a single phase fuel substitute. The blend also appears clear and no water emulsions are formed.

Fuel properties of selected blend

Applicability of the blend selected is further justified by determining different fuel properties which are shown in Table 2. Properties of blended fuel show considerable accordance with that of pure diesel, except flash point. A large reduction in flash point of blend could be observed.
as compared to diesel, obviously due to lower flash points of alcohols. ASTM distillation of diesel and blend B₂ depicts almost same trend along with a marginal reduction in initial boiling point of blend.

Combustion phenomenon

Burning mechanism of alcohol blended fuel B₂ shows sequential stages of combustion. Drop first disrupted into smaller fragments followed by ignition [Fig. 3 (a)]. It is observed that the presence of alcohols (oxygenated compounds) promotes clean combustion, resulting into non-sooty flame, whereas diesel is burned with a sooty flame [Fig. 3(b)]. Early ignition of B₂ is observed as compared to diesel, thereby denoting reduction in ignition delay and knocking in engine.

Engine performance

Exhaust gas temperature (EGT)

Figure 4(a) shows increase in exhaust gas temperatures of both diesel and B₂ which may be attributed to the fact that at higher engine loads, rate of combustion accelerates, leading to increase in exhaust gas temperatures. A reduction of 9% in EGT is registered with B₂ as compared to diesel which may be attributed to the fact that the presence of oxygenated components (ethanol and butanol) provides quenching effect which ultimately decreases chamber temperature. Formation of NOₓ in the
exhaust gas increases on availability of oxygen at sufficiently elevated temperature as per Zeldovich mechanism\textsuperscript{14}. Reduction in exhaust gas temperature with B\textsubscript{2} indicates a drop in NO emission.

**Brake specific fuel consumption (BSFC)**

Figure 4(b) illustrates variation in specific fuel consumption with load. B\textsubscript{2} shows marginal reduction of 3.5\% as compared to diesel at medium load condition, whereas at higher load its consumption increases. This increase in the utilization of blend may be attributed to lower calorific values of ethanol and butanol, thereby demanding higher energy input and hence the fuel consumption to produce same brake power as diesel. The engine startup demands higher torque and hence high energy requirement, thereby increasing BSFC initially\textsuperscript{15}. Also at the lower loads more energy is required for heating and vaporization of fuel.

**Brake thermal efficiency (BTE)**

The BTEs of the engine fuelled with blend and pure diesel as a function of speed are depicted in Fig. 5(a). Blend B\textsubscript{2} shows a marginal decrease of 4\% in brake thermal efficiency as compared to pure diesel, which may be due to lower heat of combustion of ethanol and butanol blended fuels. Also full release of thermal energy is retarded due to reduced exhaust gas temperature of B\textsubscript{2} than diesel\textsuperscript{16}.

In order to determine the size and morphology of the carbon soot produced in exhaust gas, a wet Whatman paper was held at the end of the exhaust gas pipe for 1 m. The SEM images of the carbon soot are as shown in

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**Fig. 4**—(a) Exhaust gas temperature and (b) brake specific fuel consumption

**Fig. 5**—(a) Brake thermal efficiency and (b) SEM photos of carbon soot of (1) diesel and (2) B\textsubscript{2} blend
Fig. 5(b). It could be incurred that the soot produced by diesel is having larger particles which agglomerate soon after formation, whereas the soot of blend B\textsubscript{2} shows smaller and scattered particles than that of diesel which may be due to the fact that the presence of alcohols in blends provides excess oxygen for complete combustion, thereby reducing the amount of un-burnt hydrocarbons.

**Conclusion**

Properties of B\textsubscript{2} such as density, kinematic viscosity, net calorific value, cetane index and copper strip corrosion are found in accordance with diesel as per ASTM standards except flash point. Engine performance of B\textsubscript{2} shows reduction in exhaust gas temperature and brake thermal efficiency as compared to pure diesel. However, fuel consumption shows marginal decrease of 3.5% at medium loading conditions as compared to diesel. The reductions observed in the engine parameters are found marginal; hence if the flash point is improved than B\textsubscript{2} could prove to be a probable substitute to petro diesel in CI engine without major modifications. Low soot formation further justifies cleaner burning and hence paves path for a sustainable eco-friendly substitute for petro-diesel.

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**References**