Utilization of Biodiesel for Rail Traction on Indian Railways

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ABSTRACT

The annual expenditure made by Indian Railways on petrodiesel fuel is USD 1 billion, which is approximately 18 percent of total operating expenses of Indian Railways. The consumption of mineral diesel has led to increase in the atmospheric CO₂ levels and the consequent global warming. With a view to reduce the operating costs, enhance service performance, increase economic competitiveness and reduce the environmental impact, use of biodiesel as an alternate fuel for traction purposes has been investigated by Indian Railways. An important caveat for consideration by Indian Railways is that there must be complete transparency of partial substitution of mineral diesel with biodiesel in the existing fueling arrangements. This should not diminish locomotive performance, be price competitive, and not have a significant influence on other important pollutant emissions such as oxides of nitrogen (NOx). Full-scale laboratory testing on a 16-cylinder medium-speed engine on the engine test bed was conducted followed by field trials on diesel locomotive hauled trains. This paper addresses the applicability of Biodiesel as a fuel for locomotives in India and presents the results obtained from the laboratory and field testing in terms of the engine performance and operating parameters.

KEYWORDS: Biodiesel, Indian Railways, Rail Traction

INTRODUCTION

Oil provides energy for 95% of transportation needs in India and the demand of transport fuel continues to rise. India’s requirement of gasoline is expected to grow from little over 7 MMT in 2001-02 to over 10 MMT in 2006-07 and 12.848 MMT in 2011-12 and that of petro-diesel (HSD) from 39.815 MMT in 2001-02 to 52.32 MMT in 2006-07 and little over 66 MMT in 2011-12 [1]. The domestic supply of crude will meet about 22% of the demand and the rest will have to be imported. India’s dependence on imported oil will continue to increase in the foreseeable future. It has been estimated that the demand for crude oil would go up in coming years to 85 MMT from about 50 MMT per annum in 2001-02 [1]. The crude prices and availability are subject to market volatility depending upon the international situation and, therefore, attempt needs to be made to reduce dependence on imports.

Like all fossil fuels the use of HSD also makes net addition of Carbon-dioxide to the atmosphere. In addition, petrodiesel emits particulate matter (PM), especially below 2.5 micron, which gets undetected by the protection system of the human body and get accumulated in the lungs causing reduction in its capacity and other associated respiratory problems. In addition carbon monoxide, hydrocarbon, sulphur-di-oxide and PAH emissions also affect human health.

Indian Railways, the prime mover for passenger and freight traffic in India, have a fleet of about 4000 diesel electric locomotives that consume about 1.7 MMT of petro-diesel fuel annually. Medium speed, large bore heavy-duty diesel engines having power levels ranging from 560-3000 kW are used for these locomotives. Indian Railway's annual expenditure on petrodiesel fuel is US$ 1.00 billion, which is approximately 18% of its total operating expenses. With a view to reduce the operating costs, enhance service performance, increase economic competitiveness and reduce the environmental impact of diesel locomotive emissions, use of biodiesel as an alternate fuel for traction purposes is being actively investigated by Indian Railways.

The ALCO DLW 251 series is one of the main engines for heavy-duty diesel electric locomotives of Indian Railways. Over the last 4 decades, the engine power has grown to 2685 kW using the same bore and stroke. This growth was made possible by constant development of turbocharger, fuel injection, manifolds, power assemblies and all other power assembly components. This engine is the highest production medium speed diesel engine in India with over 150 locomotives produced annually. With a view to evaluate the performance of diesel electric locomotives with biodiesel and its various blends as fuel, laboratory tests and field trials were carried out on the ALCO DLW 251 series engines. The engine power output, specific fuel consumption, exhaust gas temperatures, firing pressures, emissions and injection pressures were some of the parameters monitored during the tests.

BIOFUEL
Vegetable oil esters (Biodiesel) are receiving increasing attention as a non-toxic, bio-degradable, and renewable alternate fuel. Chemical reaction (Transesterification) of vegetable oil or animal fat with any primary alcohol in presence of acidic/ basic catalyst produces esters (biodiesel) and glycerol. Some processes require considerable time and energy while other processes require much less time and reaction takes place at lower temperatures. The glycerol (byproduct) must be separated from the biodiesel. This forms a lower layer of viscous substance, which can be gravity separated.

Biodiesel is fatty acid ethyl or methyl ester and has properties similar to petroleum diesel fuels. Biodiesel can be mixed with any diesel in any proportion. Cetane number (CN) of the biodiesel is in the range of 48-60 and the sulphur content is typically less than 25 ppm, which makes it an attractive and environment friendly fuel. The physical properties of biodiesel vis-à-vis petroleum diesel are shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel composition</td>
<td>Hydrocarbons</td>
<td>FAME*</td>
</tr>
<tr>
<td>Carbon chain length</td>
<td>C10-C21</td>
<td>C12-C22</td>
</tr>
<tr>
<td>Specific gravity (kg/L @ 15°C)</td>
<td>0.845</td>
<td>0.880</td>
</tr>
<tr>
<td>Kinematic viscosity @ 40°C</td>
<td>2.2 to 4.8</td>
<td>3.7 to 5.8</td>
</tr>
<tr>
<td>Cetane number</td>
<td>40 to 45</td>
<td>48 to 60</td>
</tr>
<tr>
<td>Higher heating value (MJ/kg.)</td>
<td>42</td>
<td>38.5 to 41.7</td>
</tr>
<tr>
<td>Lower heating value (MJ/kg.)</td>
<td>40.6</td>
<td>36.4 to 38.8</td>
</tr>
<tr>
<td>Sulfur, % mass</td>
<td>0.04 to 0.25</td>
<td>0.0 to 0.0024</td>
</tr>
<tr>
<td>Cloud point (°C)</td>
<td>**</td>
<td>−1.1 to −3.9</td>
</tr>
<tr>
<td>Pour point (°C)</td>
<td>**</td>
<td>−40 to 13</td>
</tr>
<tr>
<td>Flash point (°C)</td>
<td>40 to 60</td>
<td>100 to 170</td>
</tr>
<tr>
<td>Iodine number</td>
<td>NA</td>
<td>60 to 135</td>
</tr>
<tr>
<td>Carbon wt (%)</td>
<td>86.5</td>
<td>77</td>
</tr>
</tbody>
</table>

* Biodiesel fuel typically contains upto 14 different types of fatty acids that are chemically transformed into fatty acid methyl esters (FAME).

** Cloud point and pour point are to suit the locale where the fuel is to be consumed.

The preferable feed-stocks being used are non-edible oils such as Jatropha Cucurs and Karanja. Since India is essentially a net importer of edible vegetable oil, therefore it is essential that only non-edible oil sources be used for production of biodiesel in India [1]. For better availability of biodiesel on a commercial scale, it shall be required to have a broad basing of the feedstocks for transesterification and research with other non-edible oils like Neem, Mahua, Rice-Bran, Honge, Linseed, Rubber-seed, Pongamia pinnata etc.

The American Society for Testing and Materials (ASTM) published specifications for ensuring quality of biodiesel (ASTM D 6751), which are also given in Table 1. The German specifications for biodiesel are DIN 51606. These standards are independent of any manufacturing process or feedstock. Indian specifications for biodiesel are currently under development. The Canadian General Standards Board (CGSB) has work in progress toward producing a standard for a 20 percent biodiesel blend. Similarly ASTM has a provisional standard for a 20 percent biodiesel (ASTM-PS 121).

The flow chart for transesterification is shown in figure 1. Both basic and acidic catalysts are used for conversion of vegetable oils into esters, alcohol in excess quantity is used with both type of catalysts.

![Flow Chart of Transesterification](image)

As depicted in figure 1, the triglycerides are reacted with primary alcohol in the presence of a catalyst, which can be basic or acidic. Esters(biodiesel) are produced in the reaction and glycerol(byproduct) is removed by gravity in a settling tank or with the use of a centrifuge. Excess alcohol from esters is removed by vacuum distillation. Biodiesel is then washed with water to remove catalyst and then treated with anhydrous sodium sulphate or heated to remove moisture to produce B100(neat biodiesel).

LITERATURE REVIEW

A numbers of studies have been carried out in the areas of production, characterisation and engine performance of the Biodiesel fuels. The landmark research by Freedman et al. (1984)[2] has optimised the transesterification reaction for maximum yield of cottonseed, peanut, soybean and sunflower oil. They have found that higher temperature increases the rate of conversion, molar ratio less than 6:1 results in less yield,
the base catalysed esterification was faster than acid catalyst, and that the base catalysed conversion is affected by the presence of Free Fatty acids(FFAs) and moisture which tend to reduce the conversion efficiency. It was also reported by Freedman that the conversion percentage for refined oil was more than the crude oil. Freedman also established that with Acid catalysed conversion, much higher molar ratios (30:1) were required. The above findings were quite significant in establishing the optimum process parameters for Transesterification process.

Over the past few years, considerable research has been conducted to develop a suitable transesterification process and investigate the properties of Biodiesel and its performance in engines.

Muniyappa [3] (1996) has experimented with transesterification of Soybean oil and Beef tallow at different catalyst concentrations. They have reported that catalyst concentration > 0.5% to 0.05 % had no significant effect on conversion and cloud point was higher for beef tallow. The pH of the products increases with the concentration of catalyst. Diasakou et al (1998)[4] studied the non-catalytic, super critical Transesterification of Soybean oil with methanol at high temperature (220 to 235º C) and pressure (55-62 bar initial pressure) and varying molar ratio of methanol to oil (6:1 to 27:1). 85.5% ester content was obtained after 10 hours reaction time at 235º C and 27:1 molar ratio. Canakci & Van Gerpan (1999)[5] have examined the acid catalysed transesterification of Soybean oil using 3% sulphuric acid as catalyst. They found that the conversion process was much slower with a high molar ratio of 30:1 and at room temperature the reaction was very slow. Alcantara et al. (2000)[6] studied the effect of different stirring speeds on the conversion process. They reported very low conversion at 360 rpm (12% in eight hours) and about 95% conversion at 600 rpm in one hour. They also brought out very low conversion with acid catalysed process. Darnoko et al. (2000)[7] reported increase in reaction rate with reaction temperature. Saka & Kusdiana (2003)[8] presented the effect of water on conversion in catalyst free super critical methanol method. They established that water had no significant effect, and certain amount of water enhanced conversion. They reported that crude vegetable oils and waste oils could readily be used in their process.

Vicente et al. (2003)[9] have compared different basic catalysts - sodium methoxide, potassium methoxide, sodium hydroxide and potassium hydroxide in Sunflower oil Transesterification. They found that the yield losses were due to triglyceride saponification & methyl ester dissolution in glycerol. It was observed that the fastest reaction was with sodium hydroxide as catalyst. Zhang et al. (2003) [10] have developed four continuous production flow sheets for conversion of virgin vegetable oil and waste cooking oil under acidic or alkaline conditions. They have enumerated the operating conditions and equipment design for each process. They found that the acid catalysed process with waste cooking oil was technically feasible, less complex than alkali process and cost competitive. Ramadhas et al. (2004)[11] have worked on pre-treatment of high FFA rubber seed oil to reduce the % percentage of FFA from 17% to less than 1%. They have propounded a two-step process – acid esterification followed by alkaline esterification. Karmee et al. (2005)[12] have undertaken conversion of non-edible oil of Pongamia pinnata and seen the effect of tetrahydrofuran (THF) co-solvent and solid acid catalysts like Zeolite, Montmorillonite etc. on the conversion efficiency. Increased conversion efficiency was reported with use of co-solvent.

Effect on engine performance with Biodiesel and its blends as fuel has been studied extensively on different types and sizes of diesel engines. Alfuso et al. (1993)[13] studied the effect of rapeseed methyl ester on 4-cylinder DI engine optimized for petrodiesel. It was reported that NOx increases and smoke decreases with Biodiesel. A significant finding was that the PM was higher at light load and lower at high load due to high SOF. It was also brought out that the PM-NOx curve is flatter with Biodiesel. Scholl & Sorenson (1993)[14] have studied the combustion, performance and emission characteristics of a DI engine (4-cylinder, 4-stroke, NA) powered by soybean oil methyl ester (SOME). They used two injector orifice diameters (0.279 and 0.229 mm) and two injection timings (standard and 5° retard). It was reported that all relevant combustion parameters i.e. Ignition Delay, Pmax, (dP/dθ)max were close to petrodiesel. It was found that the ignition delay was more sensitive to changes in injection timing and nozzle diameter. The thermal efficiency was found to be comparable. Last et al. (1995)[15] have evaluated the effect of SOME on a DI, turbocharged, electronic control engine and found results similar to petrodiesel. They have reported that although NOx and fuel consumption increase, by suitably modifying injection parameters, NOx can be reduced without much penalty in fuel consumption and PM emission. They have established shifting of the PM-NOx curve with use of Biodiesel as fuel. Spataru et al. (1995)[16] have shown that material used in fuel transfer, hoses made of polyurethane and storage drums made of plastic were found to be incompatible with SOME.

Zhang & Van Gerpan (1996)[17] have reported abnormal commission behaviour with Isopropyl ester blends due to presence of monoglycerides. The normal mass-burning rate with Isopropyl ester blends with is found to be much higher than with petrodiesel and is an abnormal behavior.Akasaka et al. (1997)[18] tested blends of SOME on heavy-duty diesel engine and added kerosene (40:40:20) to increase the lighter fraction of hydrocarbon. This led to reduction of PM by 24% and no increase in NOx even at low loads. The HC and CO were however, slightly increased. Staaz & Gateau (1995)[19] examined the effect of rapeseed oil methyl ester (ROME) on unregulated pollutants from a 6-cylinder turbocharged,
D1 diesel engine. It was reported that while Aldehyde 
and Ketone remained unmodified with 30% blend, there 
was slight increase with 50 % ROME. It was also 
reported that there was a strong rise of acrolein, 
sometimes, due to residual glycerides in the ROME.

Altin et al. (2000)[20] have reported decrease in NOx as 
compared to petrodiesel on using methyl esters of 
sunflower, cottonseed and soybean oils on a single 
cylinder DI diesel engine. This shows that the production 
of NOx is also dependent on the type of engine. 
McCormik et al (2001)[21] has done research on the 
correlation of NOx and PM emissions on the fatty acid 
structure of the Biodiesel base oils. They have reported 
that NOx and PM are functions of fatty acid chain length 
and number of double bonds. Their findings are that 
NOx increases with increasing fuel density or decreasing 
fuel Cetane number and also increases with the number 
of double bonds (lOdine number). One landmark 
conclusion is that increased NOx for some Biodiesel 
fuels is not explained by NOx/PM trade off and not 
driven by thermal NO formation. Kalam & Masjuki 
(2002)[22] have also reported reduction of NOx in a 
variable speed engine when using palm oil methyl ester 
and anticorrosive additive. Turrio-Baldassari et al. 
(2003)[23] have reported significant increase of 
Formaldehyde (18%) with use of Biodiesel on a 
Turbocharged EURO 2 heavy-duty diesel engine.

Agarwal & Das (2001)[24] have experimented with 
Linseed oil methyl ester (LOME) on a single cylinder 
constant speed DI engine (4 kW). They found that the 
thermal efficiency was higher with LOME at all loads, 
Exhaust temperatures increase with the concentration of 
LOME in blend and that NOx emissions increase with 
engine load and NOx is higher (5%) for LOME. In 2003 
Agarwal et al.[25] have carried out long-term endurance 
tests on B20 LOME. They have reported substantially 
lower carbon deposits on piston cylinder head and 
injector tip with B20 LOME. Ferrography showed smaller 
size, lower concentration of wear debris for B20 and 
physical wear of various vital parts substantially lower. 
They also found that the ash content with B20 was 15% 
lower. AAS confirmed lower wear & improved life for 
Biodiesel operated engines.

The University of British Columbia (2004)[26] has 
examined compatibility of Biodiesel with engine 
materials. They have reported that brass, bronze, 
copper, lead, tin and zinc oxidise Biodiesel and 
petrodiesel and create sediments. They have 
recommended use of stainless steel in place of copper, 
bronze and brass. It has also been shown that Biodiesel 
afflicts seals, gaskets and adhesives particularly from 
natural / Nitrile rubber.

Usta et al. (2004)[27] have carried out experiments by 
transesterifying high FFA hazelnut soapstock/waste 
sunflower oil by two-stage conversion. They have found 
significant reduction in SO2 due to lower sulphur content. 
Usta et al in 2005[28] conducted tests with tobacco seed 
methyl ester on a turbocharged IDI engine and reported 
slightly lower exhaust and lubricating oil temperature. 
Raheman et al. (2004)[29] used Karanja methyl ester 
blends and have found brake power output increase of 
6% with B40 blend. Transportation Development Center 
in Canada [31] has undertaken laboratory tests and field 
trials on Biodiesel fuelled medium speed diesel engines 
used by Canadian Railways, particularly those 
manufactured before 2000. The Transportation 
Development Center has reported reduction of un burnt 
HC, particulate matter, CO and CO2 and increase of 
NOx with use of Biodiesel as fuel on heavy duty diesel 
locomotive engines.

In most of the engine studies higher brake specific fuel 
consumption, lower emissions of HC, CO, CO2; lower 
smoke number and higher NOx emissions have been 
reported. As compared to the petrodiesel fuel similar / 
better thermal efficiencies have been found on the 
Biodiesel fuelled DI diesel engines. It has also been 
reported that due to higher cetane number and higher 
viscosity of Biodiesel the injection advance and the fuel 
injection pressures need to be modified.

Many economic evaluations of Biodiesel used have been 
performed in the past. The cost of Biodiesel depends on 
the source of the feed stock, the agricultural and other 
techniques that are used, the process technology 
considered to produce the Biodiesel as well as the 
intermediate process that are required. The average 
cost of Biodiesel in the world has been reported to be 
about two to three times higher than that of petrodiesel 
fuel.

**EXPERIMENTAL SET-UP**

The engine used for the tests is a 16 cylinder, V-configuration, water-cooled, supercharged diesel engine. 
Detailed specifications of the engine are shown in Table 
2.

<table>
<thead>
<tr>
<th>Engine</th>
<th>16 cylinder ALCO DLW 251</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating (kW)</td>
<td>2315</td>
</tr>
<tr>
<td>Engine Speed (RPM)</td>
<td>400-1050</td>
</tr>
<tr>
<td>Manifold</td>
<td>Stream lined – 3 entry</td>
</tr>
<tr>
<td>Cam shaft</td>
<td>140 degree valve overlap</td>
</tr>
<tr>
<td>Fuel injection pump</td>
<td>17 mm plunger diameter, 157-degree nozzle spray angle having 0.350 mm dia. holes</td>
</tr>
</tbody>
</table>

The tests were conducted on the 16-cylinder engine test 
bed. A Zollner hydraulic dynamometer controlled by AVL
A microprocessor-based test commander was coupled with the engine. The engine can be operated in either the manual or semi-automatic or automatic mode. Schematic layout of the experimental setup is illustrated in figure 2.

Figure 2: Schematic layout of the experimental setup

The test data were logged by the transducers and fed into the microprocessor-based high-speed data acquisition system of the test commander for further analysis. The test sequences were created on the test commander and implemented by the control system of the test commander, engine, and dynamometer. The engine performance was observed on desired load/speed combinations. The load speed combination used in the tests is shown in Table 3.

Table 3: Load speed combination used for experiments

<table>
<thead>
<tr>
<th>Notch</th>
<th>RPM</th>
<th>Load(N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8th</td>
<td>1050</td>
<td>21600</td>
</tr>
<tr>
<td>7th</td>
<td>950</td>
<td>19082</td>
</tr>
<tr>
<td>6th</td>
<td>850</td>
<td>16018</td>
</tr>
<tr>
<td>5th</td>
<td>750</td>
<td>13826</td>
</tr>
<tr>
<td>4th</td>
<td>650</td>
<td>10616</td>
</tr>
<tr>
<td>3rd</td>
<td>550</td>
<td>8138</td>
</tr>
<tr>
<td>2nd</td>
<td>450</td>
<td>5471</td>
</tr>
<tr>
<td>1st</td>
<td>350</td>
<td>2984</td>
</tr>
<tr>
<td>Idle</td>
<td>350</td>
<td>2131</td>
</tr>
</tbody>
</table>

Necessary instrumentation was done for measuring the exhaust gas temperature, engine oil temperature, fuel consumption and various other engine parameters. The performance of biodiesel was evaluated in terms of fuel consumption, exhaust emissions, and power. The engine was run for a sufficiently long duration to ensure thermal stabilization before the measurements.

RESULTS AND DISCUSSIONS

The physical and chemical properties of biodiesel were tested as per ASTM 6751 norms and the test results are given in Table 4.

Table 4: Properties of Biodiesel

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Property</th>
<th>ASTM method</th>
<th>ASTM 6751 Limits</th>
<th>Biodiesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flash point, °C</td>
<td>D-93</td>
<td>Min. 130</td>
<td>163</td>
</tr>
<tr>
<td>2</td>
<td>Water and sediments, % vol.</td>
<td>D-2709</td>
<td>Max. 0.050</td>
<td>Nil</td>
</tr>
<tr>
<td>3</td>
<td>Kinematic Viscosity at 40°C</td>
<td>D-445</td>
<td>1.9 – 6.0</td>
<td>4.05</td>
</tr>
<tr>
<td>4</td>
<td>Sulphated ash, % wt.</td>
<td>D-874</td>
<td>Max. 0.020</td>
<td>0.001</td>
</tr>
<tr>
<td>5</td>
<td>Sulphur % mass</td>
<td>D-5453</td>
<td>Max. 0.05</td>
<td>0.0014</td>
</tr>
<tr>
<td>6</td>
<td>Copper strip corrosion at 100 - 3 hrs.</td>
<td>D-130</td>
<td>Max. 3</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Cloud point, °C</td>
<td>D-2500</td>
<td>-</td>
<td>+2 °C</td>
</tr>
<tr>
<td>8</td>
<td>Cetane no.</td>
<td>D-613</td>
<td>Min. 47</td>
<td>68</td>
</tr>
<tr>
<td>9</td>
<td>TAN, mg KOH/gm</td>
<td>D-664</td>
<td>Max. 0.80</td>
<td>0.1</td>
</tr>
<tr>
<td>10</td>
<td>Carbon residue, % wt.</td>
<td>D-4530</td>
<td>Max. 0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>11</td>
<td>Temp. at which 90 % recovery °C</td>
<td>D-1160</td>
<td>Max. 360</td>
<td>324</td>
</tr>
<tr>
<td>12</td>
<td>Power point °C</td>
<td></td>
<td></td>
<td>3°C</td>
</tr>
</tbody>
</table>

Table 4 reflects that the biodiesel used in the engine tests meets the ASTM 6751 specifications.

The data acquired from the engine is analyzed for performance, emissions, and combustion parameters and the results are presented in the following paragraphs.
Figure 3: Maximum engine power for different biodiesel blends

Figure 3 shows the maximum power (obtained at 8th notch) with different biodiesel blends vis-à-vis mineral diesel as fuel. It can be seen that the maximum engine power is not affected significantly by changing to biodiesel blends and the engine power remains within ±1% of that of mineral diesel. The combustion of biodiesel blends remains almost similar to diesel and this is reflected by the P-θ diagram shown later.

Figure 4: bsfc for biodiesel blends

The brake specific fuel consumption (g/bhp-hr) for different engine notches for various blends are presented in Figure 5. As anticipated, the bsfc is highest with B100, followed by B50 and the lowest bsfc is obtained with petro-diesel. The bsfc is lowest at the 8th notch and increases progressively as the notch is decreased. This is because the diesel engine has highest thermal efficiency at high loads and also the fuel injection is optimized for operation at higher notches. The bsfc trend with biodiesel blends are however similar to petro-diesel. There is no appreciable difference in bsfc with B10 and B20 blends as compared to the regular petro-diesel suggesting that using these blends will not have any penalty in terms of volumetric fuel consumption.

Figure 5: Thermal efficiency for biodiesel blends

Figure 5 shows the thermal efficiency obtained with biodiesel blends. It can be discerned that the B0 blend gives the minimum thermal efficiency followed by B100. Thus biodiesel can be concluded to have improved combustion efficiency.

Figure 6: Exhaust temperatures for biodiesel blends

Figure 6 shows the exhaust gas temperatures of various fuel blends at 8th notch. In general, the exhaust gas temperatures have shown a downward trend, decreasing progressively with higher percentage of biodiesel. Complete combustion of the fuel with biodiesel blends (due to presence of oxygen in biodiesel) is the possible reason, and may indicate better combustion efficiency. This aspect however needs to be investigated further.
Since the temperature of the exhaust gas reduces on using biodiesel blends, the boost air pressure (Pressure at the exit of compressor) is also observed to reduce (Figure 7) due to reduced energy content of the exhaust gases. Decrease in the BAP, however, has no visible effect on the maximum power output of the engine. Reduced exhaust gas temperatures however has a positive effect on the reliability of the power assembly components and turbocharger.

Figure 8 depicts the fuel injection pressures obtained with different biodiesel blends in an unaltered fuel system, which is optimized for petro-diesel. There is a significant increase in the fuel injection pressures for biodiesel blends. With B100, the fuel injection pressure has crossed the injector’s design limit of 1000 bar. Figure 8 shows the kinematic viscosity of different biodiesel blends as well as fuel injection pressure. Biodiesel blends viscosity varies from 3-4 cSt from B0 (petro-diesel) to B100. This entails relook into the design of the injection system and their warranty issues. Higher injection pressures are however suitable for improved fuel atomization resulting in improved combustion efficiency leading to reduction in visible smoke.

Exhaust gas analyzer (Make: AVL, Austria, Model: DiGas 4000) was used for measuring CO, CO₂, NOₓ, and HC in the engine exhaust. The NOₓ emissions obtained with different biodiesel blends is shown in figure 9. The NOₓ emissions increase up to the 4th Notch and decrease thereafter. The emissions are lowest with the B10 followed by petro-diesel whereas this was found to be highest with B50.

Figure 8 shows the gaseous hydrocarbon emissions for different biodiesel blends. Gaseous hydrocarbons show
a generally downward trend from B0 to B100. The hydrocarbons show a declining trend because of improved combustion characteristics of biodiesel as also corroborated by earlier research.

Figure 11: CO emissions of different blends notch-wise

Figure 11 illustrates the trend of CO emissions, at lower notches the CO emissions from all the blends are comparable and less than 0.2 gm/hr. However for B100 the CO emissions at 8th notch are significantly higher than other blends. This is not explained by the oxygen content of the biodiesel, however a plausible reason is optimization of fuel injection system for petro-diesel and lesser volatility of biodiesel.

Combustion Analysis

The combustion analysis with different blends of biodiesel has been carried out and the cylinder pressure and fuel injector needle lift vs. crank angle diagrams with different biodiesel blends are shown in figures 11-13. The tests were conducted at 8th Notch. It can be seen that with the normal petro-diesel, the peak firing pressures were about 130 bar whereas with B20 and with B100, the peak firing pressures were found to be less than 110 bar. This can be possibly due to reduction in the premixed combustion with biodiesel blends due to poor volatility of biodiesel. These results correlate well with the research findings of Zhang & Van Gerpan (1996) [17]. Also it can be observed that the combustion starts early with biodiesel blends, at −17° CA BTDC as compared to −10° CA BTDC for petro-diesel suggesting lower ignition delay for biodiesel. These findings are also in line with the findings of Zhang & Van Gerpan (1996) [17].

On consideration of the fuel injector needle lift vs. crank angle diagrams, it is observed that in the case of petro-diesel, the Needle lift is less than 0.2 mm whereas with the Biodiesel blends it is more than 0.6 mm. Also the pulse of fuel injection is more in the biodiesel blends as compared to petro-diesel. This is corroborated by the fact that the calorific value of biodiesel is about 10% lower than petro-diesel, and to produce the same engine power, more fuel mass and therefore volume of the biodiesel blends is required to be injected into the engine cylinder. Another reason for more needle lift can be higher fuel injection pressures due to higher kinematic viscosity of biodiesel.

Field Trials

A locomotive, which was used to haul the prestigious Shatabadi Express from New Delhi to Amritsar has been fuelled with B05. No adverse effect was observed during the test-run in terms of haulage capacity, abnormal
engine performance etc. After the completion of nearly 700 km return trip, no unusual deposits were noticed in the fuel filters. The fuel injection pumps and injector nozzles were also found to be in satisfactory condition and free from any gum or resinous deposits. The specific fuel consumption during the trip was 4.56 litres/thousand GTKM (Gross ton kilometer).

CONCLUSION

A 2315 kW ALCO DLW 251 B Series 16 cylinder engine was tested with various biodiesel blends. No significant power loss is observed for various biodiesel blends including B100, i.e. pure Biodiesel. The specific fuel consumption was higher with higher blends of biodiesel, although at lower notches the bsfc was similar or better than petro-diesel (B00).

With biodiesel blends, the exhaust gas temperatures have shown a downward trend and the boost air pressures have also continually reduced with increasing percentage of biodiesel in the blends. This has however not affected the power produced by the engine. The NOx emissions are found to be highest with B50 and lowest with B10. Gaseous hydrocarbons in general show a downward trend with increasing biodiesel percentage except for B50, and this abnormal behavior requires further research.

Combustion analysis has revealed that the peak cylinder pressures are higher with petro-diesel as compared to biodiesel blends. The needle lift and the duration of the fuel injection pulse was found to be higher with biodiesel blends, the fuel injection pressures were also correspondingly higher.

REFERENCES


