Impact of biodiesel on fuel system materials durability

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Biodiesel, an alternative diesel fuel, comprising of alkyl monoesters of fatty acids obtained from contemporary feedstock such as vegetable oils, animal fats and waste cooking oils, has been the focus of a considerable amount of recent research. This interest is based on a number of benefits including the fact that it is renewable, biodegradable, non-toxic and has the potential to reduce certain exhaust emission. It is essential, while experimenting with abiodiesel, to strike a balance between the several conflicting parameters that might exist. This may include not only the performance and emission characteristics of the engine, but also the gross life of the engine system. In an automotive fuel system, mainly ferrous alloys, non-ferrous alloys and elastomers come in contact with the fuel. The degradation behaviour, occurring in relation to fossil fuels, has been sufficiently studied and documented. However, the impact of biodiesel on the degradation behaviour of fuel system materials has been rarely investigated. This paper aims to present a systematic retrospect of a total of 52 papers from the year 1995 to 2012 related to the compatibility of automotive materials with biodiesel, including some results obtained in-house.

Keywords: Biodiesel, Diesel, Metals, Alloys, Elastomers

Introduction

Biodiesel is quite similar to fossil-based diesel fuel and possess characteristics similar to that of diesel. As an oxygenated methyl ester, biodiesel burns clean as compared to its conventional counterpart. Also, biodiesel offers high Cetane number and is almost free from sulphur. Moreover, its contribution towards global warming is much lesser relative to diesel fuel. Compared to petro diesel, compounds found in biodiesel viz. free fatty acids, mono and di-glycerides are reported to offer better lubricity, thus providing lower fuel system wear and longer component life. Studies have revealed lower level of emission of pollutants which are potentially harmful to human being, with biodiesel. Owing to these obvious advantages, biodiesel, is technically feasible as an alternate fuel in compression ignition engines. Biodiesel, generally experiences oxidative and hydrolytic degradation, results in problems of inferior storage stability along with lower heating value, poor low temperature flow properties and microbial degradation and higher nitrogen oxide exhaust emissions. Biodiesel has splendid solvent properties. Petroleum diesel forms deposits that remains accumulated in the vehicular fuel systems. Biodiesel, being an excellent solvent, can loosen those accumulated deposits and cause it to migrate. This, however, might clog fuel lines and filters which may eventually lead to the replacement of the filters. Also, biodiesel will react with some elastomers and metals in destructive way and thus leading to engine durability problems like injector cocking, piston ring sticking and severe engine deposits. It has been attempted to present a systematic retrospect related to compatibility of automotive fuel system materials with biodiesel, including some in house experimental results.

Components and Materials of Automotive Fuel Systems

The main components of the diesel fuel system that comes in contact with diesel/biodiesel are the diesel fuel tank, fuel filter, lift pump, plunger pump, priming pump, injection pump and the injection nozzles. Figure 1 shows a CI engine fuel system with common materials in use. In a basic diesel fuel system, the fuel tank stores the diesel fuel and lines deliver the pressurized fuel around the system. The fuel filter removes abrasive and water particles from fuel. The lift pump lifts the fuel from the tank to the injection pump by creating a pressure difference. The injection pump delivers an accurate amount of fuel under very high pressure (about 70 MPa)
to the injectors, along the injector pipes. The injector nozzle atomizes the pressurized fuel and sprays it to the combustion chamber. Leak-off pipes collects and returns the surplus fuel from the injecting system to the fuel tank via fuel filter. A detailed study of the various material of construction of different components is of utmost importance to ensure a better performance and life of the engine.

A large variety of metals and non-metals are used as the material of construction for the various components of the fuel system. The common materials of CI engine fuel system are listed in Table 1. Among them, common ferrous metals are steel and cast-iron, non-ferrous metals are aluminum and copper alloy while the non-metallic substances basically include elastomers. As fuel flows through the system and interact with these materials under diverse static and dynamic conditions of temperature, load, pressure and sliding, it causes wear, deterioration and degradation of the fuel system materials.

**Corrosion behaviour of Metals and Alloys with Biodiesel**

Corrosion is the gradual degradation of a material, usually metal, by a chemical reaction with its surroundings which causes the deterioration of one or more of its desired properties. Biodiesel has been stated to be more corrosive than fossil based diesel fuel. Biodiesel also has a higher electrical conductivity and is more hygroscopic than conventional diesel fuel. This means that, when stored for a long time, it absorbs more water, which in turn leads to the hydrolysis of the ester bonds and thus, to the formation of Free Fatty Acids (FFA) owing to an incomplete transesterification reaction. Besides this, auto-oxidation of biodiesel can augment its corrosive characteristics. The pH value falls and the microbiological activity responsible for degradation increases. With the biotic degradation reactions, the properties of the biodiesel also change; in particular, the...
corrosion potential at the material-fuel interface increases. The materials, along which fuel is conveyed, especially, can suffer considerable damage due to corrosion. The corrosion behaviour occurring in relation to fossil fuels has been sufficiently studied and documented, but the systematic studies of biodiesel corrosion are still deficient to a large extent. Owing to the difference in their chemical and physical properties, influence on the corrosion behaviour at the material-fuel interface also varies for fossil fuels and biodiesels. Corrosion characteristics of biodiesel are significant for long term compatibility of CI engine fuel system parts, and information available in this avenue is quite limited.

There is a close interaction between a wide variety of engine parts including fuel pump, gaskets, fuel injector, filters, fuel liners, bearing, piston, piston rings, etc. and the fuel. Among them, copper alloy based parts like fuel pump, bearing, bushing, etc. are extensively influenced by the fuel. The corrosive effect of biodiesel on sintered bronze filter of an oil nozzle was reported. It was found that pitting corrosion occurred on bronze when the nozzle operated at 70°C for several hours. Corrosive character of biodiesel seems to be attributed to its FFA elements and impurities remaining after conversion processing. Biodiesel degrades through oxidation, moisture absorption, attack by microorganisms, etc. during storage or use and thereby becoming more corrosive. Experiments were carried out by Tsuchiya et al. on the corrosion behaviour of terne sheet steel by immersing it in a 5% fatty acid methyl ester (FAME) blended diesel fuel at 80 °C. Terne sheets were Pb–8% Sn coated rolled steel sheets, commonly used in fuel tank fabrication. After 500 h, pitting corrosion was found on the surface of the sample immersed in 5% FAME blended diesel. Corrosion was observed even when a 2% FAME biodiesel sample was used. The oxidation process reconverts esters into fatty acids such as formic acid, acetic acid, propionic acid, caproic acid which are extremely corrosive.

Moreover, experimentation was carried out with static immersion test (300 days at 15-40 °C) by Kaul et al. to study the corrosion behaviour of piston metal and piston liner metal by using diesel and biodiesel derived from Jathropacurcas, Pongamia glabra (Karanja), Madhucaindica (Mahua), Salvadoralaeoides (Pilu). Relative to diesel, higher corrosion occurred in both Salvadoralaeoides and Jathropacurcas. Corrosion, in other biodiesel, was, however, similar to that of diesel. The liner metal was more significantly influenced than piston metal. Study showed that, corrosion resistance of aluminium alloy was more for all the biodiesels tested. However, the corrosion rates of both metals were found to be within acceptable limit. Furthermore, investigations were carried out by Geller et al. to explore the corrosion behaviour of a number of metals in poultry fat-diesel mixture of varying composition. The static immersion tests showed that carbon steel and stainless steel did not undergo any weight loss during corrosion tests. Gray cast iron showed no weight loss in 20% biodiesel but moderate loss in 80% biodiesel. Among the materials tested, copper exhibited maximum weight loss followed by brass. Pitting was observed in both copper and brass. On the sintered bronze filters, pitting corrosion was established, in oil nozzle after 10 h of operation with biodiesel at 70 °C. Corrosive nature of biodiesel also depends on its feedstock. In one report, it has been stated that copper, brass, bronze, lead, tin and zinc are corroded by biodiesel. These elements accelerate oxidation of biodiesel and hence should be avoided in the fuel system. On the other hand, stainless steel, carbon steel and aluminium have been recommended for use in biodiesel fuel system.

Investigation on the corrosion of pure aluminium in canola-based biodiesel by electrochemical technique recorded that the corrosion rate of aluminium strongly depends on the level of impurities in biodiesel that has been derived from the transesterification process. Cleaning of biodiesel by water wash greatly decreases the corrosion rate. In addition, biodiesel is hygroscopic in nature and can absorb moisture from air and thereby can increase the water content. The corrosiveness of biodiesel can be reduced by using additives. Investigations carried out by Haseeb et al. to study the corrosion behaviour of copper and leaded bronze in palm biodiesel established that in biodiesel, copper was more vulnerable to corrosion than leaded bronze. The oxidized biodiesel was found to be more corrosive than as-received/fresh biodiesel. According to the review done so far, it can be stated that biodiesel is more corrosive than conventional diesel. As the concentration of biodiesel in the blend increases, the corrosive nature of biodiesel also increases. Copper alloys are more affected by corrosion than ferrous alloys and aluminium alloys. Lead alloys on terne steel sheet are also affected by biodiesel. The corrosive nature of biodiesel is increased with the increase in presence of impurities and water. The indicators of corrosiveness namely copper strip corrosion and TAN value were found to be less effective.
In-house results for filter

In-house laboratory results indicated that higher clogging level in fuel filter when the engine was operated with jatropha biodiesel for a period of 512 hours. Approximately 40% weight gain was observed with biodiesel fuel filter as compared to diesel fuel filter. Weight gain in clogged filter is shown in figure 2. Solvent property of biodiesel results into clogging of fuel filters. Hence, any deposits in the filters and in the delivery systems may be dissolved by biodiesel and result in replacement of filters. Petroleum diesel forms deposits in vehicular fuel systems, and because biodiesel can loosen those deposits, they can migrate and clog fuel lines and filters. Also, biodiesel becomes acidic due to oxidation and results into insoluble gums and sediments that can plug fuel filters. Moreover, higher head loss and lower discharge was observed in case of biodiesel operated engine filter as compared to that of diesel operated fuel filter. These results are in line with the results obtained by Bari et al. 25.

Laboratory wear test

The experimental results by Masjuki and Maleque 26 concluded less wear of EN31 steel ball at 5% POME (act as lubricant) as contrasted to 0% POME. But, a more than 5% POME blended lubricant triggered higher wear damage. Laboratory experiments with four-ball wear machine, pin-on-disc wear testing machine, High Frequency Reciprocating Rig (HFRR) etc. were conducted by Maleque et al. 27 to evaluate the wear characteristics of metal and alloys in diesel and biodiesel. Experimental study on the wear behaviour under 5% palm oil methyl ester (POME) blended lubricant demonstrated that the specific wear rate and Total Acid Number (TAN) increased with the increase in temperature. The anti-wear characteristics of palm oil methyl ester (0%, 3%, 5%, 7%, and 10%) was investigated in lubricant using a conventional four-ball wear testing machine with different loads at 1500 rpm for 1 min at ambient temperature (28°C). To explore the impact of biodiesel and its blend on the lubrication properties, experimentation were carried out by Anastopoulos et al. 28 for acetoacetic esters and dicarboxylic acid esters blended diesel with HFRR. It was reported that, as the concentration of esters in diesel increased, the Wear Scar Diameter (WSD) decreased. The fuel dilution, as a consequence of oxidation, can also cause higher wear and friction loss in automotive parts. 29

Couple of studies 30, 31 revealed that lubricity of biodiesel was improved by fatty acid methyl esters, FFAs and mono-glycerides. The wear of rotary pump components in rapeseed methyl ester (B5, B20) and soybean methyl ester (B5, B20, oxidized B5, oxidized B20) for 500 h were investigated by Terry et al. 32. This study testified that the rotary pump test in B20 oxidized soy biodiesel failed to operate for full duration of test, stopping after 66 h. Due to high level of oxidation, biodiesel blends can separate into two phases, causing problems in the fuel pump and in injector operation. But the wear rates in B5 Rapeseed Methyl Ester (RME) and B5 Soybean Methyl Ester (SME) were similar to that of diesel. However, for B5 SME oxidized, B20 RME and B20 SME, the wear rates were higher than that in diesel. The lubrication properties of biodiesel reviewed above are, mainly of, short term duration tests. Lower friction and wear behaviour was offered by biodiesel in short duration tests. However, the tribological properties are grossly affected due to the oxidation of biodiesel and also by the test temperature.
According to another study, oxidation can boost the formation of corrosive acids, which may cause increased wear of the components. Likewise, study carried out by Haseeb et al. revealed that, as the concentration of biodiesel in diesel blends increased, the wear rate reasonably decreased. However, lubrication property of biodiesel at higher temperature decreases comparatively. This decrease in lubricity of biodiesel can be attributed to the increase of oxidation rate as well as the water content which may cause corrosive wear.

**Static Engine Tests and Field Trial**

Sliding contact operation between static and dynamic components is always followed by wear, which produces minute wear particles of metal. These wear particles are flushed away by the lubricating oil and is accumulated in the lubricating oil. Adequate information about wear rate, resource of element and engine condition can be forecasted by analysing the concentration of the metallic particle in the lubricant oil after certain period of engine operation. Generally, metallic elements such as aluminium (Al), chromium (Cr), copper (Cu), iron (Fe) and lead (Pb) are observed in lubricating oil sump. Wear analysis in engine can be classified into two groups.

(i) Static engine lab test in which, experiments are conducted for a specific periods of time. After the test, oil is collected and analysed for wear debris.

(ii) Field trial i.e. on road engine test in which vehicles are operated for a specific length of time or road distance (km). At the end of the test, oil is collected from oil sump and analysed for wear debris.

Results obtained from static and field trial are summarized in table 2. Higher wear was indicated for B100 in table 2. According to wear studies, iron, the main elements of the most significant components in automobiles engine, showed less or similar wear except in one study conducted by Daryl and Peterson. In contrast, copper shows higher wear in numerous cases. Similar or less wear was observed for the metal Pb and Al in biodiesel. It is remarkable that non-ferrous metals experienced higher wear loss.

**In-house results for wear measurement**

Moreover, in-house wear measurement of piston rings were carried out on engine fuelled with diesel and biodiesel (B100). The piston rings composition was determined by infrared absorption and gravimetric method. Infrared absorption method showed 3.189% of carbon in cylinder liner and 3.595% in piston ring liner. Also, this method found 0.06355% and 0.08451% of

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**Table 2—Summary of wear analysis by static and field trial in biodiesel compared with diesel**

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Biodiesel</th>
<th>Engine run (h) / (km)</th>
<th>Wear components and wear rate</th>
<th>Feedstock</th>
<th>Biodiesel</th>
<th>Engine run (h) / (km)</th>
<th>Wear components and wear rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapeseed</td>
<td>B20</td>
<td>512 h</td>
<td>LW</td>
<td>Rapeseed</td>
<td>B20</td>
<td>512 h</td>
<td>LW</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>B100</td>
<td>45000 km</td>
<td>SW</td>
<td>Rapeseed</td>
<td>B100</td>
<td>45000 km</td>
<td>SW</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>B100</td>
<td>1000 h</td>
<td>LW</td>
<td>Rapeseed</td>
<td>B100</td>
<td>1000 h</td>
<td>LW</td>
</tr>
<tr>
<td>Palm</td>
<td>B50</td>
<td>100 h</td>
<td>LW</td>
<td>Palm</td>
<td>B50</td>
<td>100 h</td>
<td>LW</td>
</tr>
<tr>
<td>Palm</td>
<td>B7.5</td>
<td>100 h</td>
<td>LW</td>
<td>Palm</td>
<td>B7.5</td>
<td>100 h</td>
<td>LW</td>
</tr>
<tr>
<td>Palm</td>
<td>B15</td>
<td>100 h</td>
<td>LW</td>
<td>Palm</td>
<td>B15</td>
<td>100 h</td>
<td>LW</td>
</tr>
<tr>
<td>Palm</td>
<td>B100</td>
<td>200000 km</td>
<td>LW</td>
<td>Palm</td>
<td>B100</td>
<td>200000 km</td>
<td>LW</td>
</tr>
<tr>
<td>Palm</td>
<td>B50</td>
<td>200000 km</td>
<td>LW</td>
<td>Palm</td>
<td>B50</td>
<td>200000 km</td>
<td>LW</td>
</tr>
<tr>
<td>Soybean</td>
<td>B20</td>
<td>161000 km</td>
<td>LW</td>
<td>Soybean</td>
<td>B20</td>
<td>161000 km</td>
<td>LW</td>
</tr>
<tr>
<td>Soybean</td>
<td>B100</td>
<td>30000 km</td>
<td>-</td>
<td>Soybean</td>
<td>B100</td>
<td>30000 km</td>
<td>-</td>
</tr>
<tr>
<td>Soybean</td>
<td>B20</td>
<td>965606 km</td>
<td>SW</td>
<td>Soybean</td>
<td>B20</td>
<td>965606 km</td>
<td>SW</td>
</tr>
</tbody>
</table>

SW=Similar Wear, LW=Lower Wear and HW=Higher Wear compared to that in diesel

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**Table 3—Summary of weight loss measurement of piston rings in biodiesel compared with diesel**

<table>
<thead>
<tr>
<th>Piston Rings</th>
<th>Diesel Engine Endurance Test</th>
<th>Biodiesel Engine Endurance Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before test</td>
<td>After test</td>
<td>Before test</td>
</tr>
<tr>
<td>Weight loss</td>
<td>Weight loss</td>
<td>Weight loss</td>
</tr>
<tr>
<td>Top</td>
<td>14.2689 gm</td>
<td>14.2053 gm</td>
</tr>
<tr>
<td>Compression</td>
<td>15.1855 gm</td>
<td>15.1326 gm</td>
</tr>
<tr>
<td>Scrap</td>
<td>16.9808 gm</td>
<td>16.9541 gm</td>
</tr>
<tr>
<td>Oil</td>
<td>15.8970 gm</td>
<td>15.8842 gm</td>
</tr>
</tbody>
</table>
Sulphur in cylinder liner and piston ring liner respectively. Gravimetric method revealed 1.76% of silicon in cylinder liner while piston ring liner possessed 1.32% Si. Balance percentage was iron. In this experimental work, piston rings were weighted after 512 hours of engine run and wear was quantified. The weight loss was measured with a balance having accuracy of ± 0.1 mg. It has been observed that top compression ring has maximum weight loss in both the cases followed by compression ring. Table 3 shows the summary of results on wear of different piston rings. The top compression ring faces highest amount of thrust of combustion gases and it works in the highest temperature zone, therefore top compression ring faces maximum wear. Although, lubricity of biodiesel is better than diesel, however, during long term endurance test with B100, higher crankcase dilutions was observed resulting in decrease in viscosity of lubricating oil and hence higher wear.

Figure 3 shows the wear of different piston rings from diesel and biodiesel fuelled CI engines. After the endurance test, in both the cases, black hard deposits were observed on top ring and compression ring. On the scrap ring and oil ring, however, no such deposits were observed. Maximum weight loss of top ring and compression ring was observed in both cases. The oil ring wear, on the other hand, was observed to be the least. However, the weight loss in case of biodiesel engine piston rings was more as compared to diesel piston rings wear.

**Elastomer compatibility with Biodiesel**

Application of renewable fuels and changes in fuel composition often results in troubles in gaskets, seals, elastomers and O-rings of the engine fuel system. Compatibility of various automotive fuel system materials with biodiesel is different from that with fossil based diesel fuel. The compatibility of automotive fuel system components like seals, gaskets and hose materials using conventional fossil-based diesel has long been recognized. However, there is limited literature available on the compatibility or incompatibility of elastomeric engine components with biodiesel. Investigations were carried out by Bessee and Fey to find the effect of methyl soy ester and diesel blends, on the tensile strength, elongation, hardness and swelling of several common elastomers. It was reported that nitrile rubber, nylon 6/6, and high-density polypropylene all showed changes in physical properties whereas Teflon, viton401 C and viton GFLT remained unchanged. As a consequence of the different chemical structure of biodiesel, varied effect on the elastomers were observed. Biodiesel is a mixture of alkyl esters while diesel is a mixture of hydrocarbons.

Elastomer compatibility may also depend on the feedstock used for the production of biodiesel. Investigation was carried out by Frame and McCormick for the degradation characteristics of elastomers, like peroxide-cured nitrile rubber (N1059), nitrile rubber (N674), high aceto-nitrile content rubber (N0497), fluorocarbon filled with carbon black (V747) and fluorocarbon without carbon black (V884), in diesel, diesel blend with 15% ethanol and 20% soybean biodiesel. It was observed that these elastomers were entirely compatible with B20 and diesel fuel but not in 15% ethanol blend. Moreover, biodiesel is more prone to oxidation when exposed to air as well as in various storage conditions. Also, the biodiesel possess
unsaturated fatty acids. Alkyl esters, the main components of biodiesel can hydrolyse in presence of water to form carboxylic group, have immense influence on elastomers.

Typically, low pressure fuel lines in CI engine are made from synthetic rubber flexible hoses and high pressure fuel lines from steel. Gaskets are made from gasket paper. The commonly used rubber components are NBR (Nitrile Rubber), HNBR (Hydrogenated Nitrile Rubber), PVC (Polyvinyl Chloride), Acrylic rubber, Co-polymer FKM, terpolymer FKM, polychloroprene, Fluoroviton A, Buna, EPDM (Ethylene Propylene Diene Monomer), CR (Chloroprene), SR (Synthetic Rubber) and PTFE (Poly Tetra Fluro Ethylene) or Teflon.

cr: Immersion tests were conducted by Trakarnpruk and Porntangjitlikit for 1008 hour at 100°C with six types of commonly used elastomers viz. nitrile rubber (NBR), hydrogenated nitrile butadiene rubber (HNBR), NBR/PVC, acrylic rubber, co-polymer fluorooelastomer (FKM), terpolymer FKM and PTFE (Poly Tetra Fluro Ethylene) or Teflon. cr: Immersion tests were conducted by Trakarnpruk and Porntangjitlikit for 1008 hour at 100°C with six types of commonly used elastomers viz. nitrile rubber (NBR), hydrogenated nitrile butadiene rubber (HNBR), NBR/PVC, acrylic rubber, co-polymer fluorooelastomer (FKM), terpolymer FKM and PTFE (Poly Tetra Fluro Ethylene) or Teflon. cr: Immersion tests were conducted by Trakarnpruk and Porntangjitlikit for 1008 hour at 100°C with six types of commonly used elastomers viz. nitrile rubber (NBR), hydrogenated nitrile butadiene rubber (HNBR), NBR/PVC, acrylic rubber, co-polymer fluorooelastomer (FKM), terpolymer FKM and PTFE (Poly Tetra Fluro Ethylene) or Teflon.

A couple of studies were undertaken on the degradation behaviour of different elastomers by Haseeb et al.

Table 4—Summary of compatibility of different elastomers with biodiesel

<table>
<thead>
<tr>
<th>Biodiesel</th>
<th>Elastomers</th>
<th>Compatibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl soyester</td>
<td>Teflon,</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>viton401 C and vitonGFLT</td>
<td>✓</td>
</tr>
<tr>
<td>Methyl soyester</td>
<td>Nitrile rubber, nylon 6/6, and high-density polypropylene</td>
<td>✓</td>
</tr>
<tr>
<td>Soybean</td>
<td>Nitrile rubber (N1059), nitrile rubber (N674), high aceto-nitrile content rubber (N0497), fluorocarbon filled with carbon black (V747) and fluorocarbon without carbon black (V884)</td>
<td>✓</td>
</tr>
<tr>
<td>Palm</td>
<td>NBR, NBR/PVC</td>
<td>×</td>
</tr>
<tr>
<td>Palm</td>
<td>Hydrogenated nitrile butadiene rubber (HNBR), acrylic rubber, co-polymer fluorooelastomer (FKM), terpolymer FKM</td>
<td>×</td>
</tr>
<tr>
<td>Palm</td>
<td>Polychloroprene (CR), EPDM</td>
<td>×</td>
</tr>
<tr>
<td>Palm</td>
<td>Polychloroprene (CR), NBR</td>
<td>×</td>
</tr>
<tr>
<td>Waste vegetable oil</td>
<td>Gasket, camshaft seal, crankshaft seal</td>
<td>✓</td>
</tr>
</tbody>
</table>

were conducted at room temperature (25°C) for 1000 h. Different physical properties like, changes in weight and volume, hardness and tensile strength were accounted at every 250 h of immersion time in palm biodiesel. The results of this analysis revealed that overall sequence of compatible elastomers in palm biodiesel was found to be PTFE > SR > NBR > EPDM > CR. A second study was conducted to explore the impact of palm biodiesel on the degradation behaviour of elastomers such as nitrile rubber (NBR), polychloroprene, and fluoro-viton. Static immersion tests in B0 (diesel), B10 (10% biodiesel in diesel), B100 (biodiesel) were carried out at room temperature (25°C) and at 50°C for 500 h. At the end of immersion test, degradation behaviour was investigated by measuring mass, volume, hardness as well as the tensile strength and elongation as per ASTM. After immersion, it was observed that tensile strength, elongation and hardness were significantly reduced for both nitrile rubber and polychloroprene while very negligible changes were recorded for fluoro-viton.

The real time study explored the influences of palm, soybean, sunflower and canola biodiesel on tractor engine fuel system parts and engine components for long term conditions. It was observed that if biodiesel is to be used, owing to the hardening problem, elastomeric fuel pipes are required to be replaced by metallic ones.

Another study explored the degradation behaviour of elastomers like gasket (for protective cover of camshaft), camshaft seal and crankshaft seal in ultra-low sulphur diesel, B10, B40 and B100 (biodiesel from waste vegetable oil). Immersion tests were conducted by Munoz et al. at 90°C for 22 h, 50°C for 22 h and 50°C for 164 h. The resulting deterioration of the
elastomers was determined by measuring the changes in properties before and after immersion according to ASTM D471. It was found that the three elastomeric materials used, were very compatible with mixtures that contained up to 40% biodiesel. Gasket showed less compatibility as compared to seals but it had the best performance in pure biodiesel. Table 4 shows the summary of compatibility of different elastomers with different biodiesels.

In-house results for elastomers

In-house experimental studies were conducted to find the degradation behaviour of elastomers like gasket, fuel pipe and O-ring in Jatropha oil, Jatropha oil methyl ester (JOME) and blend of JOME with 20% ethanol by static immersion test for 60 days. Diesel fuel was used as a reference fuel. Change in mass, volume, hardness, tensile strength and elongation were measured as per ASTM. Figure 4 and 5 shows the percentage change in hardness of gasket (NBR) material and percentage elongation change of O-ring (HNBR) out of many experimental results obtained on various concerned durability measurements of tested materials. Change in hardness was measured by shore hardness tester (ASTM D 2240). Hardness change and percentage elongation for both gasket and O-rings material were increased in JOME and blend of JOME+ E20 in comparison with raw jatropha oil. No change in mass, volume, hardness, tensile strength and elongation of elastomers were observed in diesel.

Biodiesel and its higher blend have much different chemical structures than petro diesel and consequent different effects on elastomeric components. FAMEs, the main components of biodiesel, can be simply hydrolyzed in the presence of water to form carboxylic acids. Besides, biodiesel is more prone to oxidation upon exposure to air as well as storage conditions and the amount of unsaturation of fatty acids. Oxidation of biodiesel produces hydroperoxides at the unsaturated points of the fatty acids and these hydroperoxides later decompose to aldehydes, ketones, shorter chain carboxylic acids. Degradation of elastomeric components may be attributed to chemical composition of biodiesel along with these products.

Conclusions

Based on the investigations carried out by several researchers and in house experimental results, the following conclusions have been summarized:

(i) Review on the corrosion behaviour reported that biodiesel is more corrosive than diesel. However, there is no definite evidence if the degree of corrosion observed in biodiesel is within limits acceptable for automotive components. The corrosive nature of biodiesel increases with the concentration of biodiesel in the blend and the level of oxidation. Due to presence of impurities and water also, the corrosive nature of biodiesel may get increased.

(ii) Copper alloys are more prone to corrosion than ferrous alloys and aluminium alloys. Lead alloy coating on terne steel sheet, which is applied for automotive fuel tanks, is severely affected by biodiesel.

(iii) Laboratory test data have suggested that biodiesel offers good lubrication properties. Hence, in short duration tests, it exhibited lower friction and wear. But at higher test temperatures, rate of oxidation of biodiesel increases which negatively influence its
(iv) Fluorocarbons have revealed good resistance and as compared to that in diesel.

...oil methyl ester and blends of JOME with ethanol as compared to diesel piston rings wear. Also, more in case of biodiesel engine piston rings was more with diesel and biodiesel noticed that the weight loss wear measurement of piston rings on engine fuelled with biodiesel fuel for a period of 512 hours. Approximately, 40% weight gain was observed with biodiesel fuel filter when the engine was operated with jatropha. This results into clogging of fuel filter system. This resulted in clogging of fuel filter when the engine was operated with jatropha biodiesel for a period of 512 hours. Approximately, 40% weight gain was observed with biodiesel fuel filter as compared to diesel fuel filter. Moreover, wear measurement of piston rings on engine fuelled with diesel and biodiesel noticed that the weight loss in case of biodiesel engine piston rings was more as compared to diesel piston rings wear. Also, more change in hardness as well as elongation was observed for elastomeric components in jatropha oil methyl ester and blends of JOME with ethanol as compared to that in diesel.

(vi) At present, there is inadequate data available on corrosive behaviour, wear behaviour and elastomeric compatibility of CI engine fuel system materials with higher blends of biodiesel, based on which confident decisions about the durability of fuel system materials could have been made.

References
3. IPCC (Intergovernmental Panel on Climate Change), Climate change 2007, synthesis report; http://www.ipcc.ch/ipccreports/ar4-syr.htm.