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Comparative Study of Engine Oil Characteristics in Utility Vehicles Powered by Turbo-Charged Direct Injection Diesel Engines Fuelled with Bio Diesel Blend and Diesel Fuel

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ABSTRACT

Biodiesel is emerging as a prime source of sustainable alternate renewable energy source globally. Biodiesel has been proved as an alternate to petrodiesel as they do not require any significant modifications in the existing diesel engines. With the usage of biodiesel increasing in transportation vehicles, the effect on the properties of lubrication oil and engine components is still to be understood. In order to assess the condition of the lubricating oil in transportation engines, the study was conducted on 2.49 lit. Direct injection turbocharged diesel engines equipped with mechanical rotary fuel injection pump.

The study was done with 10 and 20 percent blend of biodiesel with normal petrodiesel (B10 & B20 respectively). The biodiesel used in the studies was from the raw material of Jatropha Curcus and Karanja with an objective to understand whether the raw material make any effect on the lubricant degradation. Long-term engine oil durability trials were conducted in the engine test beds as well as on road vehicles. The lubricating oil samples were collected and detailed analysis for assessing the comparative effect of biodiesel blends was carried out.

The oil samples from both biodiesel blend and petrodiesel engines were subjected to physio-chemical analyses viz., Viscosity, TBN, Soot and Wear metal Analysis. The effect of biodiesel and its properties on lubricant degradation is discussed in this paper. Further, tribology study on engine component was also done by engine strip-down analysis before and after trials. This was done to confirm and correlate the results observed during lubricant analysis. With the above test results available it was possible for us to determine the engine oil drain period with each fuel.

*Numbers in the parentheses designate references at the end of paper

INTRODUCTION

Bio-diesel is manufactured from different raw material globally viz., Jatropha, Soybean, Palm, Rapeseed, Fish oil, Used Vegetable oil etc. In India, the two widely used raw materials for Biodiesel manufacturing are Jatropha Curcus and Karanja. Biodiesel is normally manufactured by Trans Esterification process which uses Acid or Alkali catalyst [1]. Since acid catalyzed process is more time consuming, alkali catalyst (NaOH or KOH) is widely used in Trans Esterification process. Excess of alcohol (normally methanol) is used to shift the equilibrium to right as the reaction being reversible [2]. The excess alcohol is washed out in the final stage of process and the moisture is removed by heating at 110 °C under vacuum. Being highly susceptible to moisture ingress, the bio-fuel has to be always stored in a nitrogen / inert atmosphere after production [3]. The moisture ingress in bio-diesel can induce hydrolysis reaction in the fuel which may increase the acidity [3, 4]. This acidity increase in bio-diesel along with moisture content can cause corrosion on engine components and lead to poor oxidation stability also4. Poorly stable biodiesel when blended with petrodiesel may cause engine deposits, ring sticking and lube oil thickening etc on long term usage [5]. Also, bio-diesel is vulnerable to oxidation on long term storage and in high temperature conditions [6]. Very less work has been done on evaluating these adverse effects of bio-diesel on engine lubricant and components [1]. Hence, we initiated the study of effect of Bio-fuel on lubricant performance and engine components.

It is known, on usage, the lubricant oil performance is affected by

a) Oil thickening; which may be due to soot loading or oil degradation by oxidation and high temperature operation

b) Oil thinning; which may be due to fuel dilution or shear of polymers used as Viscosity Modifiers.
c) Deposit formation and Wear; which may be due to depletion of wear protecting / dispersing additives
d) Corrosive wear due to depletion in detergent additives (TBN reduction)

Hence, we decided to conduct the study on engine oil used for Biodiesel endurance and durability tests.

EXPERIMENTAL DETAILS

BIODIESEL PROPERTIES & LUBRICANT SPECIFICATION - It was decided to use Jatropha Curcus as well as Karanja derived bio-diesel blends for our studies. The studies were conducted with neat diesel, 10% and 20% blended bio-diesel fuels. Here after, the neat diesel is denoted as D100, neat Biodiesel as B100, 10% Jatropa bio-diesel blend is denoted as B10 J and 20% blend of Karanja Bio-diesel is denoted as B20 K. Some of the physio-chemical properties of fuels analyzed used for testing are given in the Table 1.

Viscosity, Density, Moisture and Total acid number in the blended fuel have shown higher value than neat diesel while the Sulphur level decreased. This is due to higher Viscosity, Density, Moisture and Total acid number and less Sulphur content in Bio-diesel. Table.2 shows the matrix of fuels used for different tests, types of test conducted with engine dynamometer and on road vehicles.

The Engine oil used for the study purpose meets the API CH-4, ACEA A3/B4; SAE 15W-40 specification.

TEST CYCLE, ENGINE AND VEHICLE SPECIFICATIONS - The endurance engine test cycle includes Max torque, Full load, intermittent speed, Low and High Idling conditions as per Mahindra standard test cycle. The vehicle test cycle follows City drive, Highway drive and High speed drive as per Mahindra Standard cycle. The specifications of the engine used for test are given in the Table. 3

LUBRICANT ANALYSIS - The oil samples from the durability engines and vehicles were drawn and analyzed at regular intervals. Following analyses were conducted to know the effect of biodiesel on engine oil used.

e) Kinematic Viscosity @ 100°C
f) Total Base Number by ASTM D4739 method
g) Soot, Fuel and moisture contamination
h) Wear metal analysis (Fe, Cu, Cr, Ni, Pb, Al and Si)

These tests gave us information about the oil quality in use. Widely used modern analytical techniques Viz., Fourier Transform (FTIR) spectroscopy and Atomic Absorption Spectroscopy (AAS) are used for determining Soot content and Wear metal analysis respectively. Apart from Soot analysis, Fuel and moisture Contamination analysis also was done with FTIR parallely. Energy Dispersive X Ray Fluorescence (EDXRF) instrument was used for measurement of Blended Fuel Sulphur levels. All the above instrument and apparatus were standardized and calibrated before each analysis.

LUBRICANT AND ENGINE COMPONENT ANALYSIS

Following are the analysis results of lubricating oils.

KINEMATIC VISCOSITY - Kinematic Viscosity measurement of lubricating oil is vital information to understand the rheological changes of engine oil. This gives the information about oil thickening due to Soot ingress, oil oxidation and oil degradation; oil dilution / contamination with fuel or with water, coolant. Proper lubrication to the engine components is available only when the viscosity changes in the oil is in control which in turn will keep the engine wear in control. Kinematic viscosity of engine oils may decrease in the beginning due to shear stress of the Viscosity improver and start increasing later on due to oil oxidation or Soot ingress.

Kinematic Viscosity at 100°C of oil the samples used for trial was analyzed as per ASTM D445. Viscosity at 100°C showed increasing trend. Ref. Fig.1. In the endurance test bed, the viscosity increase at 100°C observed with diesel fuel engine was 4.23% (average) where as with the B10-J fuel was 12.5% (average). Even though both the values are within acceptable limit, the higher increase in viscosity with B10-J may be due to poor oxidation stability of the fuel. (Ref. Table 1).

Poor oxidation stability of fuel may induce engine oil oxidation / detoriation due to blow by gases contact with oil5. In case of vehicle, the increase in viscosity is at same level between diesel and Bio-diesel vehicles. This may be due to comparatively better oxidation stability of the fuel B20-K used (Ref. Table 1). These results indicate the importance of bio-fuel oxidation stability and impact on lubricant viscosity. From the Viscosity data, it is observed that usage of Bio-diesel blend up to 20% does not have any impact on oil rheology provided; the B100 used for blend should meet the required specifications of IS 15607. Poor oxidation stability of B100 seems to have effect on engine oil viscosity.

TOTAL BASE NUMBER (TBN) - The TBN values are indicative of reserve alkalinity in the fresh and used oil samples to neutralize the acidic by-products of combustion in the engine. The TBN is due to the presence of alkaline additives, mainly detergent and due to some dispersant and corrosion preventives. The TBN show a decreasing trend normally due to additive depletion as the usage of oil increase. We followed ASTM D4739 method for determination of TBN, as it estimates only useful alkalinity reserve left out with the used oil.

The trend of TBN depletion is shown in Fig 2 and 3. In general the TBN values were within acceptable limits for both the oil samples received from engine test bed and vehicles tested with Biodiesel. But there is a clear distinction in TBN between the oil samples tested with biodiesel of poor and better oxidation stability. B 10 J engine oil sample has shown faster TBN depletion compared to D 100 petrodiesel engine oil sample. The reason may be poor oxidation stability of B100 used for B10 J blend, which has resulted in acidity increase of engine oil. The TBN depletion observed was 26% with the B10 J Bio-diesel and 13% with D 100 diesel fuel. In the case of vehicle engine ran with B20 K, which has better oxidation stability, the TBN depletion was 9% with Biodiesel compared to 11% with D 100 petrodiesel after 15,000 km.

SOOT CONTENT - The absolute values of soot measured in the lubricant used in biodiesel engines were found to be almost 50% lesser than the petrodiesel engine (Fig No. 4). Due to better combustion properties of bio-diesel blend, the engine oil from biodiesel engine and vehicle showed comparatively lower Soot loading in the oil. Soot is formed due to incomplete combustion product of fuel which comes in to oil through blow by gases in to the crank case. Bio-diesel is found to be richer in oxygen when compared to petrodiesel fuel. Consequently when blended with diesel fuel will have better combustion properties and lesser particulate or soot formation. These observations were found true in our internal emission studies [7]. This indicates, the usage of bio-diesel blend reduces the oil thickening by soot loading.

WEAR ANALYSIS - The engine components wear with usage. Measurement of wear elements viz., Fe, Cu, Cr, Ni, Pb, Al and Si in the engine oil sample at various intervals of engine / vehicle run helps us to decide on the oil change period. This wear analysis also helps us in anticipating pre-matured failures and forecast critical issues with engine components also. It is observed that the wear elements viz., Cr, Ni, Pb, Al were too insignificant to report. Silicon content was well within control. The Silicon ingress was well controlled by proper maintenance of Air-filter. Hence, we discuss only the Fe and Cu wear observed with test bed engines and vehicles (Refer Fig 5 & 6).

In general, iron wear pattern in both the cases were well in the control. It is observed the average Iron wear rate with both the endurance engines were same level. In Biodiesel engine, the iron wear was 0.29 ppm per hour compared to 0.28 ppm per hour with petrodiesel engine. This shows the wear pattern with both the engines is comparable. In the vehicles, the average iron wear in the biodiesel vehicle was 4.78 ppm per 1000 km and diesel vehicle was 4.97 ppm. This shows iron wear in the biodiesel vehicle is slightly lower than the petrodiesel engine. The less iron wear pattern found in endurance engine and durability vehicle may be because of less soot formation in both the biodiesel engine and hence less abrasive wear.

Copper wear with B10-J engine was 0.15 ppm per hour and D100 engine was 0.11 ppm per hour. I.e., almost 36% high copper wear found in B10 J endurance engine. In the B20 K vehicle engine copper wear was 30% more than the D100 vehicle engine i.e., Copper wear in B 20 vehicle was 1.6 ppm per thousand km and D100 vehicle was 1.23 ppm. This high copper wear in the B10 J endurance engine case may be due to the combined effect of TBN depletion of engine oil (acidity increase) and acid value of biodiesel blow by gas entering in to the oil sump and coming in contact with the bearing. In the case of B20 K vehicle, the copper wear is predominantly due to acidity of blow by gas contact with the bearing. It should be noted that B20 K vehicle engine has shown comparatively less copper wear increase than B10 J engine even though the biodiesel concentration is higher in the former case. This is due to the better oxidation stability of B20 K which has compensated and controlled the corrosive wear induced through blow by gas contact.

OIL DRAIN EXTENSION - With better oxidation stability biodiesel B20 K, we were able to extend the engine oil drain period to 20,000 km in the vehicle which is normally drained out at 15,000km with D100. It was found the Viscosity increase, TBN depletion, Soot value and Wear parameters were within control even up to 20,000 in one of the trial.

ENGINE STRIP DOWN ANALYSIS - The strip down analysis of the engine and fuel system components removed from the Test Bed Engines after 1000 hrs of the durability test cycle and On road vehicle engines from Field Trials Vehicles was conducted and wear and deposits formation characteristics were compared in D100, B10 J and B20 K operated engines. The Engine strip down analysis was down for all vital engine parts out of which two critical components are discussed in this paper.

<u>Cylinder head and combustion chamber</u> - The strip down analysis of the Cylinder Head and combustion chamber shows no significant difference in Test bench Engine and in the engines removed from the on-road vehicles. The cylinder head combustion chamber area of all the four cylinders was clean and no abnormal deposits were reported during analysis (Ref Fig 7). The intake and exhaust valves were clean with light carbon deposits on the sealing surfaces and normal build-up on the valve heads.

The pistons of all the engines were in good conditions. One can hardly notice any significant difference in the carbon deposits in the pistons removed from D100, B10 and B20 operated engines. One of the Pistons received after test, from the endurance test bed operated with B10-J fuel is shown in the Fig. 8.

DISCUSSIONS

Studies elsewhere with biodiesel blend has identified the prime concerns are engine cleanliness and fuel dilution in the engine oil i.e., contamination of biodiesel in the engine oil1. Earlier studies found the lower volatility of bio-diesel compared to diesel fuel, results in different spray pattern which may cause passing of bio-diesel through piston rings in to the cylinder liner in turn to the crankcase. The un-burnt bio diesel passing to the crankcase may reduce lubricant viscosity over time, which in turn reduce lubricant film thickness and ultimately increases component wear. But our findings evolved from this study do not substantiate the earlier findings as there is no evidence of fuel dilution found up to 20% blend of biodiesel. Our study shows the importance of biodiesel oxidation stability used for blend. Poor oxidation stable biodiesel has induced the formation of oxidative products in turn led to relatively quicker acidity increase (TBN depletion) and Viscosity increase. Soot values of Engine oil with B10 and B 20 blend are almost 50% lesser than D 100 engine. The iron wear observed with biodiesel engines is at par or lower compared to petrodiesel engines. This strengthens our finding of lower soot formation has helped in reducing the abrasive wear . Even with 50% lesser soot level in the B10 J engine, engine oil viscosity increase was observed. This is due to poor oxidation stability of the biodiesel used for B10 J blend. However, if B100 oxidation stability and other fuel parameters are controlled within the specification no adverse effect is observed e.g. B20 K. In this case, except higher corrosive wear of Copper, no other significant issues are observed with used lubricant properties.

CONCLUSION

Endurance trials and durability tests carried out with direct injection, turbo charged diesel engine has shown biodiesel blend up to 20% is not affecting the Engine oil performance with respect to Viscosity, TBN, Soot and Wear provided; biodiesel used for blend should meet all the required specifications of IS 15607 to obtain optimum performance of biodiesel blend. It is observed the Biodiesel blend reduce the soot generation in the diesel engine; better engine cleanliness, less abrasive component wear and hence extended engine oil drain period. The biodiesel engine strip down analysis confirmed the lubricant analysis finding. It is concluded issues like low oxidation stability and high moisture content of biodiesel used for blend affect the lubricant performance and drain period.

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Table 1 Fuel Properties

Sample Name	HSD BSII	B100 J	B 10 J	B100 K	B20 K
Appearance	Clear & Bright				
Kinematic Viscosity@40° C cSt	2.73	4.13	2.90	4.42	3.02
Density @ 15°C, Kg / m3	829	883	837	881	839
Flash Point, oC, PMCC	42	164	49	158	45
Moisture, ppm	101	1197	195	632	175
Sulphur, ppm	265	75	240	5	230
Total Acid number, mg KOH/g oil	0.02	0.67	0.2	0.64	0.14
Oxidation Stability, hrs	NA	1.00	NA	6.00	NA

Table 2 Test Matrix

Diesel Type	Test Done	Duration
D100	Engine Endurance	1000 hrs
B10-J	Engine Endurance	1000 hrs
D 100	Vehicle Trials	50,000 km
B20-K	Vehicle Trials	50,000 km

Table3. Engine Specifications

Type	4 stroke, Turbo-charged, DI, Diesel Engine
Cubic Capacity	2509 cc
Max Gross Power	63 BHP (46.5 kW) @ 3200 rpm
Max Gross Torque	18.4 kgm@1500 rpm
Emission Compliance	EURO II / BS II
Gear box	5 speed, Manual

Fig 1 Viscosity increase comparison

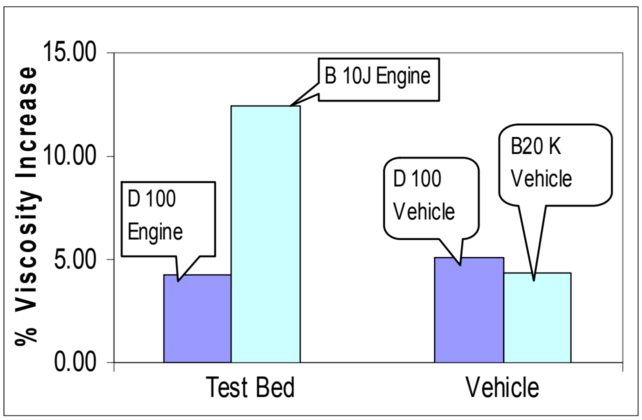

Fig 2. TBN comparison (Test Bed)

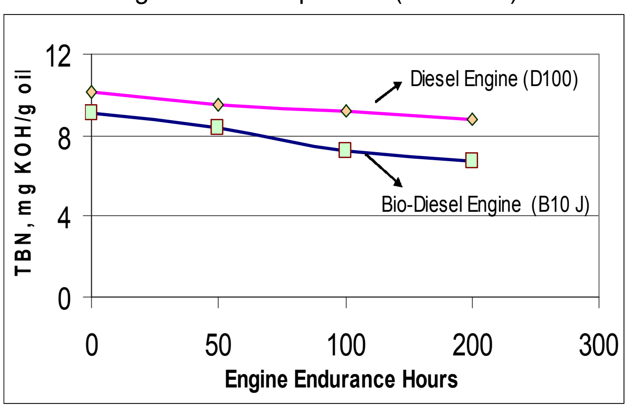

Fig 3. TBN comparison (Vehicle)

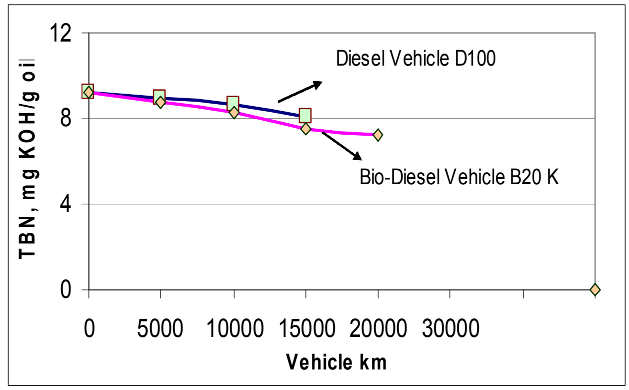

Fig 4 Soot Comparison

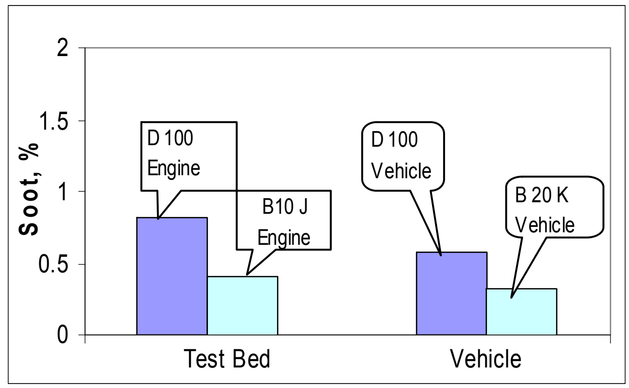

Fig 5 Wear Comparison (Test Bed)

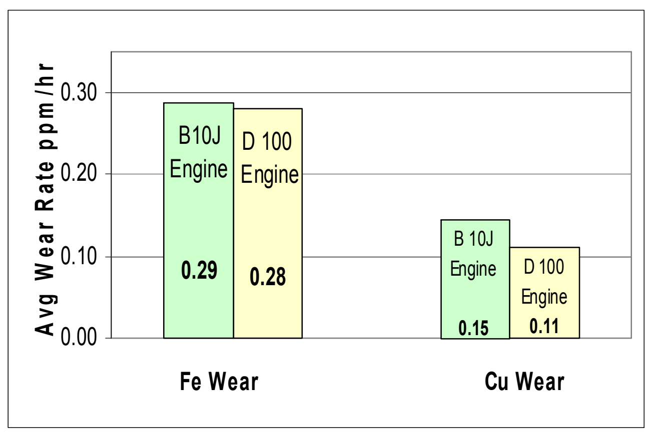

Fig 6 Wear comparison (vehicle)

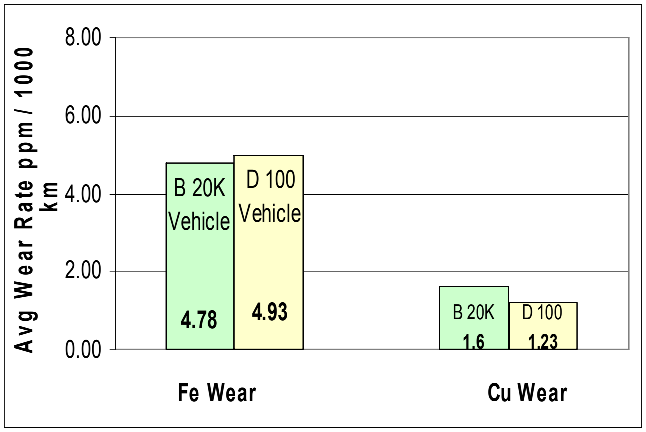

Fig. 7 Cylinder Head after Test

Fig 8 Piston condition after Test