Government of India
Ministry of Railways

Audit of the Biodiesel production facilities at Perambur Loco Works, Southern Railway, Chennai

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SYNOPSIS

Development and utilisation of biodiesel is a mission area for Indian Railways. Chairman, Railway Board vide his D.O. letter number 2004/Fuel/282/14 dated November 7, 2005 has directed the Zonal Railways to set up biodiesel esterification plants so that the seeds being generated due to Jatropha plantation by Indian Railways be utilized effectively.

Southern Railway, at their Locoworks, Perambur have set up a biodiesel production pilot plant with the base catalyzed esterification technology. The plant is capable of producing about 2000 liters of biodiesel per day through a batch-processing unit. This biodiesel is being utilized by Southern Railway to fuel two DMUs with B5 diesel blends successfully.

RDSO is a research wing of Indian Railways and has been doing research with biodiesel fuel and its blends for its use in Indian Railways. As per the directives received from the Railway Board, vide letter no. 2004/Fuel/282/4 dated 14th June 2006, RDSO is to provide guidance to the Zonal Railways in setting up the pilot biodiesel plants, advancement in technology and assist in maintaining consistency in quality of biodiesel being produced by these pilot plants.

In view of the above, RDSO has conducted audit of the biodiesel production facilities at Locoworks, Perambur, Southern Railway. A sample of biodiesel (B100) produced by the above pilot plant has been tested as per IS: 15607(2005) at IOC R&D Center, Faridabad. The results obtained have been discussed and the measures for improvement have been recommended.

1. Introduction

The world is presently confronted with the twin crisis of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground carbon-based resources. The need to exploit bio-origin-based alternative fuels to quench the world's energy thirst has long been realized.

Vegetable oil esters (Biodiesel) are receiving increasing attention as a non-toxic, biodegradable, 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. 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 process of utilizing biodiesel in the IC engines for transport as well as other applications, is gaining momentum. The international energy agency has recognized biodiesel as an alternative fuel for the transportation sector. The European Commission proposed a 12 percent market share for biofuels by the year 2020. Planning Commission of India in its report on biofuels has recognised biodiesel as an alternative fuel for diesel engines in India.

India is producing around 6.7 million tons of nonedible oils such as, linseed, castor, karanja, (Pongamia glabra,) neem,(Azadirachta indica), palash(Butea monospermal), and kusum (Schlelchera trijuga). Some of these oils produced even now are not being properly utilized, and it has been estimated that some other plant-based forest derived oils have a much higher production potential.

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 CO_2 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 is being considered by Indian Railways. For this purpose the Railway Board has already issued instructions to the Zonal Railways to take up the plantation of Jatropha Curcas plants on the surplus lands under possession of Indian Railways.

Vide letter no 2004/Fuel/282/4 dated 14th June 2006, Railway Board has instructed RDSO to acquire technology for production of biodiesel and set up a pilot plant for R&D work for carrying out esterification and engine performance studies on non-edible oils. Board in their above letter have stated that the above exercise by RDSO shall help in optimisation of the diesel locomotive engines of Indian Railways to multi-species oils based biodiesel as also standardization of the design of biodiesel pilot plants for Zonal railways.

2. Background

Engine oil dilution is a potential problem with biodiesel since it is more prone to oxidation and polymerization than diesel fuel. Engine oil formulations need to be studied to minimize the effect of dilution with biodiesel. It must be noted that the light duty diesel engines are sufficiently different from heavy-duty diesel engines in many aspects and one should not expect that the emission behavior of the two types of engines would be same. Thus it is considered essential to do engine related research with biodiesel produced from different feedstocks of oils to arrive at the most optimum design configuration before wide scale implementation on Indian Railways.

Southern Railway has set up a biodiesel production plant at their Perambur Loco works, Chennai with a production capacity of 2000 litres/day. The feedstock used for transesterification is Karanja oil, which is obtained from local market. Southern Railway have using B5 blend of this biodiesel on two DMU trains without any operational and performance problems. Engine Development Directorate have earlier carried out engine performance tests with various blends of imported soya oil based biodiesel on ALCO/Bombardier 16 cylinder engine. Engine tests with Indian non-edible oils based biodiesel could not be conducted due to their non-availability.

As per the Railway Board directives, it was decided to conduct an audit of the biodiesel production facilities available with Southern Railway at Chennai and also test the quality of the biodiesel obtained from their plant. This shall help in determining whether the biodiesel produced is able to meet the IS:15607(2005) standard before conducting engine tests on the engine testbeds at RDSO.

3. BIS specification

Bureau of Indian Standards has adopted a Standard for Biodiesel (B100) blend stock for diesel fuel specification IS 15607:2005 in December 2005.The standard has been prepared keeping in view of the end use application, production and feed stock availability. Considerable assistance has been drawn from ASTM D 6751-02 and EN 14214 while preparing this standard. The requirements to be met by a sample of biodiesel as per IS: 15607 (2005)is given below.

Table 1: Biodiesel specifications as per IS:15607(2005)

Sl No.	Characteristic	Requirement	Method of Test, Ref to	
			ISO/ASTM D/En	[P:] of IS 1448
i)	Density at 15°C, kg/m^3	860-900	ISO 3675 ISO 12185 D 4052	P: 16/P:32
ii)	Kinematic Viscocity at 40°C, cSt	2.5-6.0	ISO 3104	P: 25
iii)	Flash point(PMCC) °C, Min	120	-	P:21
iv)	Sulphur, mg/kg, Max	50.0	D 5453	P:83
v)	Carbon residue (Ramsbottom), percent by mass, Max [to be run on 100% sample.]	0.05	D 4530 ISO 10370	-
vi)	Sulphated ash, percent by mass, Max	0.02	ISO 6245	P:4
vii)	Water content, mg/kg, Max	500	D 2709 ISO 3733 ISO 6296	P:40
viii)	Total contamination, mg/kg, Max	24	EN12662	-
ix)	Copper corrosion, 3H at 50^0 C, Max.	1	ISO 2160	P:15
x)	Cetane No., Min.	51	ISO 5156	P:9
xi)	Acid value mg KOH/gm max.	0.50	-	P:1/Sec.
xii)	Methanol, % by mass, Max. (applicable for fatty acid metyl ester)	0.20	EN 14110	-
xiii)	Ethanol % by mass (applicable for fatty acid ethyl ester)	0.20	-	-
xiv)	Ester content, % by mass Min.	96.5	EN 14103	-
xv)	Free Glycerol, % by mass Max.	0.02	D6584	-
xvi)	Total Glycerol, % by mass Max.	0.25	D6584	-
xvii)	Phosphorous, mg/kg, Max.	10.0	D4951	-
xviii)	Sodium and Potassium, mg/kg Max.	To report	EN14108 & EN14109	-

xix)	Calicum and magnesium, mg/kg Max.	To report	European method is under development	-
xx)	Iodine value	To report	EN14104	-
xxi)	Oxidation stability at 110^0 C, h, Min.	6	EN14112	-

The test equipments for carrying out these test are not available with RDSO and some of these testing facilities are available at IOC R&D only. The Railway Board (AMME) vide Minutes of the 38th Meeting of Central Board of Railway Research at article no 11.6 have given instructions to the M&C Directorate of RDSO to set up a cell for biodiesel for collecting information as well as for testing of biodiesel.

4. Facilities available

The biodiesel plant at the Southern Railway Loco Works Perambur was audited by Engine Development Directorate of RDSO. Following equipments are available at their biodiesel plant.

Table 2: List of Equipments of the biodiesel plant at Locoworks, Perambur

Sno	Equipment
1.	300 l capacity stainless steel reaction vessel
2.	300 l capacity stainless steel water tank with electric heater
3.	300 l capacity stainless steel biodiesel storage tank with heater
4.	300 l capacity stainless steel water collection tank
5.	100 l stainless steel methanol collection tank
6.	100 l capacity methoxide tank
7.	20 l stainless steel capacity concentrated suphuric acid tank
8.	500 l translucent HDPE settling tank
9.	100 l translucent HDPE glycerine tank
10.	300 l stainless steel raw oil tank
11.	300 l stainless steel filtered oil tank
12.	Stirrer electric motor for reaction vessel
13.	Stainless stirrer for reaction vessel
14.	Stirrer electric motor for methoxide tank
15.	Stainless steel stirrer for methoxide tank
16.	Electrically driven oil pump
17.	Stainless steel water showers of appropriate numbers
18.	Stainless steel ball valves with compatible seals
19.	Two kW electric heaters, 2 nos.

20.	50 micron oil filtering system – Filter press
21.	Control Panel
22.	Oil mill for expelling oil from seeds

The construction of reaction vessels are designed to withstand hot water / steam upto 100^0 C and a maximum pressure of 5 kg/cm^2. The reactor is compatible to concentrated sulphuric acid, multifeed stock, methoxide etc. Similarily various other containers are compatible with different types of fluids required for the process. The pump and the electric motors are protected against the flame and corrosive liquids being handled. The flow of fluids from one vessel to another is by siphoning process.

Layout diagram of the biodiesel production plant is given in Figure 1.

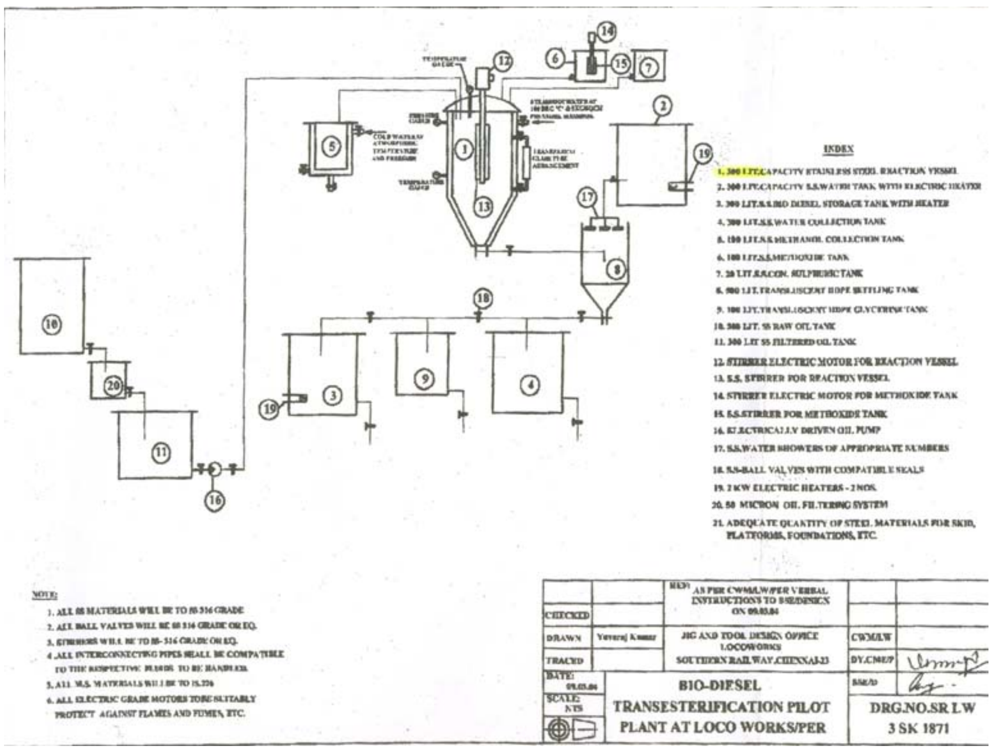

Figure 1: Biodiesel transesterification pilot plant at Loco Works Perambur

5. Details about the equipments

Decorticator – Has provision for shelling groundnut for seed purpose without breakage. It has a capacity of 300 Kg/hr and operates on a 2 hp motor.

Oil expeller - Consists of a screw press type oil expeller 22” x 3.5” chamber size with a capacity of 60 to 70 kg/hr. The press is capable of crushing all types of oilseeds whether edible or non-edible.

Filter Press – With a size of 12”x 12” – 14 plates , there are two such filter presses. The filtered oil coming out was of transparent type and majority of the impurities and gums were seen to be removed.

Reaction vessel – The reaction vessel is made of stainless steel, non-pressurised and TIG welded. Transparent inspection glass on top of the reactor vessel which incorporates temperature gauge and pressure monitoring is provided with sensors for tripping the alarm system. The reactor is thermally insulated and all the instrumentations are with barriers/ protective covers. The reaction vessel is also fitted with a motorized stirrer.

Methanol tank – is jacketed for water circulation to save the methanol from absorbing water or leaking into the atmosphere.

Methoxide tank – is fitted with flame proof motor and stirrer arrangement to mix the salt with methanol safely.

6. Production process

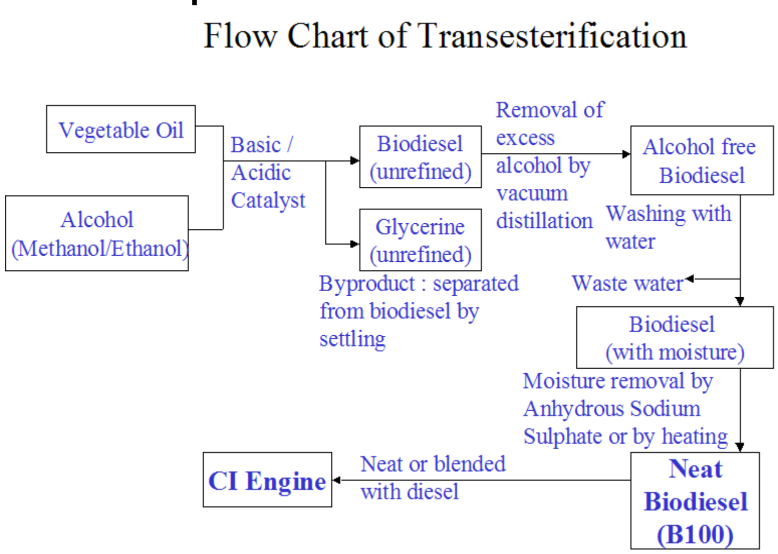

Figure 2: Flow chart for production of biodiesel

1. The Loco works are getting the Karanja seeds locally and doing the deshelling and crushing of the seeds in-house. The oil extracted from the screw press is then filtered in the 50 micron filter press and the refined oil thus obtained is used for transesterification.
2. In addition, waste frying oils from restaurants is also obtained for conversion. Waste frying oil is added when the FFA content of the oils is high. High FFA interferes with the yield of the biodiesel conversion process.
3. Methanol and sodium methoxide catalyst are obtained from suppliers.
4. A mixture of sodium methoxide with methanol is made in the required ratio.

5. Refined oil is filled in the conversion reactor and heated to about 70°C and the mixture of catalyst and methanol is then pumped into the reactor vessel. The reactor vessel is then stirred for carrying out the reaction and the extent of reaction can be observed through the glass gauge.
6. After conversion, the glycerol is allowed to settle to the bottom of the reaction vessel and the glycerol is separated out by gravity. This is crude glycerol and is contaminated with methanol, triglycerides and catalyst and is washed to remove these components.
7. Biodiesel is then taken out from the reaction vessel and washed to remove the catalyst etc.
8. Excess methanol in the reaction vessel is then recovered by heating and distillation. This can be recycled. The catalyst recovered during the washing process is also recycled.
9. The biodiesel is then stored in the storage tanks.

Photographs of different equipments are shown below.

Figure 3: Biodiesel production center

Figure 4 : Control Panel

Figure 5: Biodiesel reactor

Figure 6: Methanol recovery

Figure 7: Acid treatment

Figure 8 : Settling & washing tank

Figure 9 : Filter press

Figure 10 : Methoxide mixer

Figure 11: Mixing arrangement

7. Discussion on test results

A five litre sample of biodiesel has been obtained from Loco works Perambur and this sample was sent to IOC R&D Center Faridabad for testing as per IS:15607(2005). The results obtained are shown in Table 3.

Table 3: Test results of the biodiesel sample from Locoworks Perambur

Sl No.	***Characteristic***	***Requirement***	***Test results***
i)	**Density at 15°C, kg/m^3**	**860-900**	**906.3**
ii)	**Kinematic Viscocity at 40°C, cSt**	**2.5-6.0**	**7.00**
iii)	Flash point(PMCC) °C, Min	120	188
iv)	Sulphur, mg/kg, Max	50.0	<10
v)	**Carbon residue (Ramsbottom) percent by mass, Max [to be run on 100% sample.]**	**0.05**	**0.74**
vi)	Sulphated ash, percent by mass, Max	0.02	0.0025
vii)	Water content, mg/kg, Max	500	<500
viii)	**Total contamination, mg/kg, Max**	**24**	**40**
ix)	Copper corrosion, 3H at 50^0 C, Max.	1	1
x)	Cetane No., Min.	51	58.7
xi)	**Acid value mg KOH/gm max.**	**0.50**	**1.64**
xii)	Methanol, % by mass, Max. (applicable for fatty acid metyl ester)	0.20	
xiii)	Ethanol % by mass (applicable for fatty acid ethyl ester)	0.20	
xiv)	Ester content, % by mass Min.	96.5	
xv)	Free Glycerol, % by mass Max.	0.02	0.0095
xvi)	**Total Glycerol, % by mass Max.**	**0.25**	**0.3719**
xvii)	Phosphorous, mg/kg, Max.	10.0	<10
xviii)	Sodium and Potassium, mg/kg Max.	To report	
xix)	Calicum and magnesium, mg/kg Max.	To report	
xx)	Iodine value	To report	
xxi)	**Oxidation stability at 1100 C, h, Min.**	**6**	**0.80**

Out of twenty one tests stipulated by the IS:15607(2005) standard, M/s IOC could test only fifteen parameters. For the other parameters M/s IOC do not have the test facilities at present. Out of the fifteen parameters tested, seven characteristics are outside the range of the IS:15607(2005) specifications. Implication of these non-compliances is discussed below: -

Density

Density of the biodiesel sample is observed to cross the upper limit of specification. Changes in fuel density affect the energy content of the fuel brought into the engine at a given injector setting. European studies indicate that reducing fuel density tends to decrease NOx emissions in older technology engines that cannot compensate for this change. Emissions from modern engines with electronic injection and computer control appear to be independent of density.

Kinematic viscosity

The kinematic viscosity of biodiesel sample has been found to be higher than the one stipulated in the IS:15607(2005) standard. This shall lead to increase in fuel injection pressures and exceed the design pressure limits of the fuel injection equipment. Also, a higher viscosity of fuel results in higher duty for the fuel pump. Higher kinematic viscosity also affects the atomization capability of the fuel and may lead to inadequate combustion and coking of the injector nozzles. Diesel fuels with high viscosity tend to form larger droplets on injection which can cause poor combustion and increased exhaust smoke and emissions.

Carbon residue

The Ramsbottom Carbon residue test is intended to provide some indication of the extent of carbon residue that results from the combustion of a fuel. The limit is a maximum percentage of deposits by weight. A higher carbon residue shall indicate more build-up of carbon residue in the combustion chamber with adverse effect on combustion and more HC and PM emissions. The biodiesel sample obtained from Loco works Perambur has shown much higher carbon residue than specified.

Total Contamination

Fuel contaminants are foreign materials that make fuel less suitable or unsuitable for the intended use. Fuel contaminants include materials introduced subsequent to the manufacture of fuel and fuel degradation products. The total contamination of a fuel indicates the extent to which the fuel is free of undesirable matter. This is an indication of the purity of the raw material as well as the handling process in the production sequence. The total contaminants in the biodiesel sample from Loco works Perambur have shown about 70% more contaminants than specified in the IS: 15607 standard. Some of the effects of fuel quality including total contamination of fuel on engine components are illustrated in Figure below.

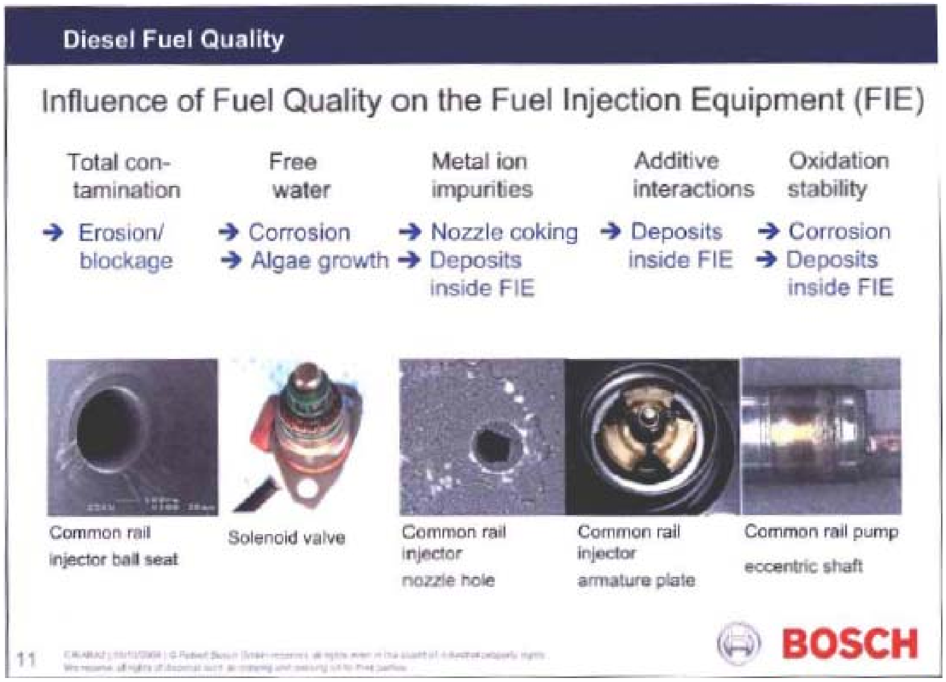

Figure 12 :Influence of fuel quality on the fuel injection equipment

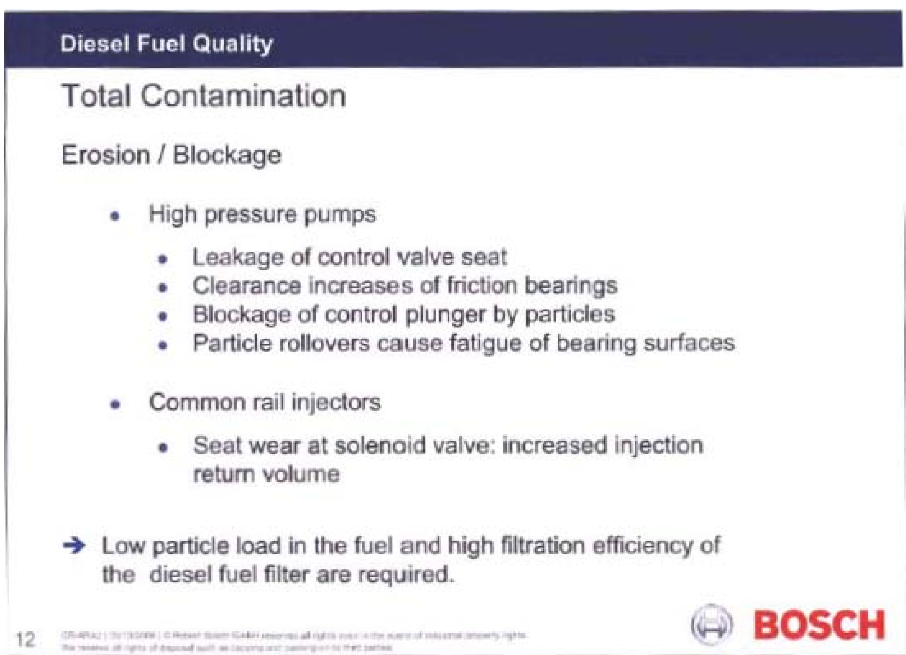

Figure 13: Effect of total contamination of fuel on engine components

Acid Value

Acid number is a measure of acids in the fuel. These acids emanate from two sources: (i) acids utilized in the production of the biodiesel that are not completely removed in the production process; and (ii) degradation by oxidation. For biodiesel blends, the acid number will change as a result of the normal oxidation process over time. High acid number obtained with the biodiesel sample indicates that the washing of the biodiesel to remove the acids etc. has not been done. Also, it may indicate the biodiesel kept for long period has degraded.

Total Glycerol(Glycerin)

Glycerin is a byproduct of the production of biodiesel. If glycerin remains in the finished biodiesel, or biodiesel fuel blend, it can result in fuel separation, material incompatibility, engine deposits and engine durability concerns. Higher total glycerin in the biodiesel sample indicates that separation of biodiesel from glycerin has not been complete.

Oxidation stability

Diesel fuel should be stable under normal storage and use conditions. Unstable fuel will darken and form black particulate materials, which will cloud fuels and create gum residues in the fuel system. Although the accelerated stability test is intended to predict primarily storage stability, it can provide indication of overall fuel stability.

From the time of production, biodiesel fuels are unstable due to the natural oxidation process. The process involves a free radical chain reaction that continues until the reactive molecular links or available oxygen is depleted. Peroxides (hydro peroxides) are reactive oxidizing agents formed during the first steps of fuel oxidation. At high concentration, peroxides or the free radicals formed can damage or degrade certain plastics and elastomers, particularly at higher temperatures. Subsequent steps in the oxidation process produce acids, gums, polymers, and other insolubles.

Historically, petroleum diesel fuels have exhibited extremely long storage stability periods. In some cases, the processing required to produce very low sulfur level petroleum diesel fuels has significantly reduced the stability of the petroleum fuel component in biodiesel blends. The test method utilized predicts the amount of time that fuel can be stored before the production of acids indicates that the fuel is becoming unstable. Fuel that meets the specified limit is expected to provide six months of storage capability, depending on the storage conditions, before degradation occurs.

The biodiesel sample from Loco works has exhibited extremely low oxidation stability when compared to that stipulated in the IS:15607(2005) specification.

8. Conclusion

The biodiesel obtained from Loco works Perambur is not meeting the IS:15607(2005) specification. If used at low blending ratios like B5, this may not affect the performance and durability of the engine. However with higher blends B10 and above, the engine performance and reliability may be adversely affected.

Reason for non-compliance of the biodiesel sample to IS:15607(2005) specification might be:-

1. Incomplete transesterification.
2. Incomplete separation of biodiesel from glycerine.
3. Incomplete washing of biodiesel to remove other fluids.
4. Non-addition of additives to enhance the oxidation stability.

The above non-conformities also indicate inadequate process controls.

9. Recommendations

a) Audit of the biodiesel production process at Locoworks, Perambur

Test results of the biodiesel sample from the Perambur biodiesel pilot plant indicate deficiency in the production process and its controls. This may be attributable to methods, materials or human error. An in-depth audit of the production process needs to be carried out by Locoworks Perambur in association with a consultant with necessary wherewithal. The outcome of the audit should be in form of recommendations for corrective and preventive action. After process correction, another sample of biodiesel shall require to be tested to find out conformance to IS:15607(2005).

b) Carrying out an Advanced Product Quality planning for the biodiesel production process

Advanced Product Quality Planning(APQP) is a technique developed to ensure process quality. This is turn ensures that the product is able to meet the specification limits. In APQP, the process flow chart is made which shows all the steps of the process. The process flow chart is then used for carrying out the Process Failure Modes and Effects Analysis(PFMEA). In PFMEA, each step of the process is analysed for possible failure modes and the probability of such a failure, this requires experience as well as historical data. During this step, the weak links in the process are identified. In the third step, the Process Control Plan is made. The weak links identified during the PFMEA are then controlled to avoid failures. The controls are of three types, a) To detect the defect, b) To detect the cause of defect, c) To prevent the cause of defect. This methodology has been successfully implemented by all types of Industries including the chemical industry to reduce the rejection rates.

c) Selection of a suitable additive to enhance the oxidation stability of the biodiesel

The oxidation stability of the biodiesel sample is found to be abnormally low compared to that stipulated in the IS:15607(2005 standard. As per the discussions held with M/s IOC, addition of suitable additive is required to be done to enhance the oxidation stability of the biodiesel being produced. This shall become standard part of the biodiesel production process.

d) Setting up of biodiesel testing facilities as per IS: 15607(2005) at RDSO in the M&C directorate of RDSO

No laboratory in India, including IOC R&D Centre, Faridabad have complete facilities to test biodiesel as per IS:15607(2005). Indian Railways with its projected annual requirement of biodiesel to be in excess of 400 MT(with B20) shall require a centralized laboratory to test the quality of biodiesel and its blends to ensure quality in for use in Traction and other purposes.