GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

REPORT ON TESTING OF INDIGENOUS WASTE FISHOIL BASED BIODIESEL AS AN ALTERNATIVE TRACTION FUEL ON ALCO DLW 16 V 3100 HP FE ENGINE
(Test Bed Results)

Report no. TR/ED/2008/196
(August 2008)

ENGINE DEVELOPMENT DIRECTORATE
RESEARCH DESIGNS & STANDARDS ORGANISATION
MANAK NAGAR, LUCKNOW – 226011

Synopsis

Utilisation of Biodiesel as Traction fuel is a mission area for Indian Railways. This is in harmony with the National Biofuel Mission of the Government of India. Use of Biodiesel as traction fuel is expected to provide energy security to country, reduce dependence on fossil based fuels and conserve the environment. Indian Railways is the single largest user of High Speed Diesel in the country with and annual consumption of 2.2 billion liters per year. Even if 20% of this fuel is replaced with biodiesel, a huge annual savings is expected in terms of foreign exchange since most of the petroleum products in India are imported. Government of India has identified about 50 million hectares of non-agricultural land which can be used for growing Tree Borne Oil crops. Use of biodiesel as traction fuel by IR will also help in providing employment in rural and industrial sectors for cultivation, collection, storage, production and transport of biodiesel in India. Arriva Railways in Europe is running all its Diesel Locomotives on 100% neat biodiesel. However, for IR to replicate this approach, it is essential that detailed engine characterisation with various native non-edible oils based biodiesel is done on the rail traction engines available with IR. There are more than fifteen such non-edible oils being wasted in the country to the tune of 5 million tones (equivalent to 1.5 billion liters of biodiesel).In addition Indian States and IR have also taken up cultivation of Tree Borne Oil crops in an aggressive manner. Thus certain representative native non-edible oils based biodiesel have been chosen for engine characterisation.

This report is about characterisation of ALCO DLW 16 V engine with Waste Fishoil based biodiesel and its blends. Engine has been tested with upto 100% biodiesel without any loss of power. Brake specific fuel consumption has however increased by about 11% but this is explained by the fact that biodiesel have approximately 10-12% lower heating value because of presence of an oxygen atom in their molecule. NOx emissions are seen to rise but the Total Hydrcarbons, Carbon Monooxide etc. have decreased siginificantly. Optimisation of the engine can be done to advance the injection timing so that bsfc can be decreased or to retard the timing to reduce NOx emissions. Detailed combustion simulation of the engine is planned to carry out this optimisation exercise. However even in the present scenario the engine can be run on 20% biodiesel made form Waste fishoil without any adverse effects. Quality control, handling, storage and transport need to be improved.

Table of Contents

Background Information

Detailed testing of Biodiesel on 3100 hp diesel engines as an alternate fuel was carried out in RDSO during April-May 2004 on the Engine Test bed at Engine Development Directorate.. Testing was done with B10, B20, B50 and B100 biodiesel blends. Five KL of pure bio diesel (B100) was arranged through Indian Oil Corporation. The objective of the detailed testing was to carry out the performance evaluation as well as some optimization of 10%, 20%, 50% and 100% blends of bio diesel on the 3100 hp engine on test bed. Biodiesel was produced from edible Soyabean oil, which is the standard raw material for production of biodiesel in USA. However, Government of India vide its Biofuels Policy and the Integrated Energy Policy has directed for use of only Non-Edible oils based biodiesel to be produced on Non-Agrarian lands, 50 million Hectares(Ha) of which has been identified by the Ministry of Agricultural and Rural Development. Government of India has linked the Biofuels Policy to production of biodiesel indigenously for the purpose of Energy Security of India and for generation of Rural and other employment. Planning Commission of the Government of India has declared use of Biofuels including biodiesel as a Mission Area for India. An Autonomous body, National Biofuels Development Board under the Ministry of New and Renewable Energy, Government of India has been announced of which the Ministry of Railways is a part.

Thus IR could not have continued with the use of Soyabean oil based biodiesel because it is edible and also because it is imported. In December 2005, Bureau of Indian Standards has brought out the B100 biodiesel specifications. On examination it is seen that these are prima-facie based on the European B100 biodiesel specifications EN 14214 and American B100 biodiesel specification ASTM 6751B.It is known from Literature survey that Engine performance and response to different types of biodiesel depends on the raw material from which the biodiesel has been produced although these biodiesels may meet the IS specifications or other International biodiesel specifications/ standards. Meanwhile the Railway Board has taken up Growing of Tree Borne Oil Seeds (TBOs) on the surplus land of IR as a Mission area and later formed an Indian Railways Organisation for Alternate Fuels (IROAF) for propagation of alternative fuels like CNG and Biodiesel on IR. Two Megaprojects, one on conversion of 100 DPCs to dual fuel CNG mode and the other on setting-up of four 50 tonnes per day (tpd) biodiesel production plants are being managed by IROAF to start with. Success of both of these projects depends on adequate research intervention(s) for which the detailed estimates of both of these projects provide funds for setting-up research facilities/pilot plants and establishment at RDSO.

It is therefore imperative for Engine Development Directorate of RDSO to carry out detailed engine characterization of ALCO and EMD engines with biodiesels produced from non-edible oils of Indian Origin produced indigenously. This is essential to ensure that as and when large-scale use of biodiesel as traction fuel is taken-up on IR, there are no or minor reliability and operational problems. It is also required to generate the actual field conditions in transportation and storage of biodiesel to see the performance on the rail traction engines. Main Objective is that the field problems should be reduced to a bare minimum and issues if any should be known before hand and corrective and preventive actions taken.

It is therefore decided to characterize the ALCO and EMD 16V engines of 3100 hp and 4000 hp ratings respectively with different indigenously produced biodiesels from Indian non-edible feedstocks. Following biodiesels have been chosen for Engine Characterisation: -

- WFFAME (Waste Fish fatty acids Methyl Esters)
- WCFAME (Waste Cottonseed fatty acids Methyl Esters)
- MFAME (Mahua fatty acids Methyl Esters)
- PFAME (Pongamia fatty acids Methyl Esters)
- JFAME (Jatropha fatty acids Methyl Esters)
- CPFAME (Crude Palm oil fatty acids Methyl Esters)

This report is about ALCO engine characterisation with WFFAME.

Availability of raw material for production of biodiesel

Doubts continue to be raised about availability of rawmaterial for production of biodiesel in India and world. After extensive literature survey, discussions with the National Botanical Research Institute, Lucknow, India and the IOC R&D, Faridabad, Ministry of New & Renewable Energy, Govt of India etc. it was learnt that with the present availability of non-edible oil-seeds itself a large part of traction diesel can be replaced by biodiesel. Accordingly, choice of various biodiesels has been made because these oils are representative of the native TBOs in India.

Tree-borne minor oilseeds (TBOs) have been accorded very high priority as a source material for biodiesel production in the country. India is endowed with a vast potential for oilseeds of tree origin, important being sal, mahua, neem, rubber, karanja, kusum, khakan (pilu), undi, dhupa, etc. (Table 1). These oilseed-bearing trees are found widely and distributed throughout the country. The present availability of oilseeds from them is estimated to be about 5 million tonnes annually. However, only 20% of the total availability is utilized for commercial applications (Kumar, 2003).

Table 1 : Available potential of tree-borne oilseeds in India

Sr. No.	TBOs	Seed yield [10] (lakh tonnes)	Oil content [36, 43] (%)	Oil yield (lakh tonnes)
1.	Sal (*Shorearobusta*)	62.0	12	7.44

2.	Mahua (*Madhucaindica*)	5.2	35	1.82
3.	Neem (*Azadirachtaindica*)	5.0	20	1.0
4.	Rubber (*Heveabrasiliensis*)	0.79	45	0.35
5.	Karanja (*Pongamiapinnata*)	1.11	27	0.30
6.	Kusum (*Schleicheraoleosa*)	0.45	33	0.15
7.	Khakan (*Salvadoraoleoides*)	0.44	33	0.14
8.	Undi (*Calophyllaminophyllum*)	0.11	60	0.07
9.	Dhupa (*Vateriaindica*)	0.13	19	0.02
10.	Other*	2.0		
	Total	77.34		

Source : Adapted from Damodaram and Hegde (2005).

* **Other** : Maroti (*Hydnocarpus wightiana*), Palash (*Butea monosperma*), Pisa (*Actinodaphne angustifolia*), Ratanjyot (*Jatropha curcas*), Tumba (*Citrullus colocynthis*), Teak (*Tectona grandis*)

Worldwide, oilseed crops occupy an area of 166.36 million hectares with a production of 295.6 million tonnes and productivity of 1777 kg/ha (FAO, 2003). In India, area under oilseeds is 23.7 million hectares with a production of about 25 million tonnes and a productivity of just about one ton/hectare. The oilseed production in the country presently meets only 60-70% of its total edible oil requirements and the rest is met through imports.

India also has a potential of collecting 5 million tonnes of tree-borne oilseeds (TBO) of which only 0.1-1 million tonnes are being collected presently (Kumar, 2003). In addition to the existing potential of TBO, there is about 60 million hectares of wasteland of which 30 million hectares can be suitably utilized for growing plantations of biofuel plants like Jatropha. It has been estimated that each hectare can produce about 2000 liters of biodiesel/year after the initial 3-year period of establishment of Jatropha in the field (Shukla, 2005; Ghaisas, 2005). This will result in the production of 60 billion liters of biofuel. Thus TBO from the wasteland can make a significant and important contribution to the energy requirement of the country in the days ahead.

The availability of TBO can be enhanced considerably without any extra land and inputs if proper network for procurement from seed collectors is established. There is a considerable scope to enhance the collection of seeds from the existing trees by developing infrastructure facilities such as seed/produce procurement centers equipped with facilities for drying, decorticating, cleaning/grading, depulping, storing and oil extraction near the areas of collection of TBO. Establishment of biodiesel processing units near the procurement centers will further help in reducing the cost of transportation of the raw oil to the biodiesel processing plant. This should result in reasonable remuneration to the primary seed collector and also help in getting a quality product by reducing losses caused due to delayed and improper handling of the material at different stages in the existing trade of TBO in India.

Apart from the existing trees in the country, there is 60 million hectares of wasteland, of which 50% can be suitably used for growing TBO plantations like those of Jatropha and karanja. With the recent central government drive to produce biodiesel from TBO, many state governments have given very high priority to plantations of Jatropha for biodiesel production. Information from various sources indicates that area under Jatropha plantations in the country has gone up to 20,000-30,000 hectares. Governments of states like Chhattisgarh, Gujarat and Madhya Pradesh have drawn up plans to take up Jatropha plantations on massive scale.

Biodiesel is a fast-developing alternative fuel in the U.S. and Europe. Pilot plants for power generation and encouraging adaptation by fleet operators have established biodiesel as a viable and sustainable alternate fuel. The biodiesel production from vegetable oils during 2004-05 was estimated to be 2.36 million tonnes globally. Of this EU countries accounted for 1.93 million tonnes, U.S. produced 0.14 million tonnes and rest of the world 0.29 million tonnes (Parikh, 2005). The EU usage of vegetable oil for biodiesel has been rising at about 30% annually in the last two years. In EU, rapeseed is the main source of oil for biodiesel, while in the U.S. soybean oil is used for manufacturing biodiesel. Malaysia - the largest producer of palm oil has set up three palm biodiesel plants with a combined annual capacity of 60,000 tonnes.

India consumes more than 250 million tonnes of fossil fuels every year. This comprises of approximately 40 million tonnes of diesel. India is ranked fifth in the world after China, Japan, Russia and the U.S. in terms of fossil fuel consumption. Recently in India the Planning Commission, Government of India launched “National Mission on Biodiesel” with a view to find a cheap and renewable liquid fuel based on vegetable oils (Shukla, 2005). The rural development ministry has been appointed as the nodal ministry for implementing the programme. This mission is being carried out in two phases – the first phase involving a demonstration stage for plantation of Jatropha on four lakh hectares and associated research activities for establishing the commercial viability of the fuel, and phase two for carrying out a self-sustaining expansion of the biodiesel programme.

Indian Railways total consumption of HSD is about 2.2 billion liters per year, even with the present availability of TBOs (5.5 million tones) entire traction fuel requirement of IR can be met by replacing diesel with biodiesel. It is with this background that rail traction engines characterization has been done with upto B100 biodiesel.

Quality Assurance

In the last engine bed trials done with Imported Soyabean based biodiesel, all biodiesel properties could not be evaluated. For example Oxidation Stability and the Cetane no. were not established before the test. However engine tests were done to see whether the biodiesel is able to produce the required horsepower and to see the effect on other critical engine performance parameters. In a way, this is similar to simulating the field conditions because in field, it is seldom that all the qualities like water, sediments, contamination are rarely met. In this case however more tests could be done in time and these are as given below. However because of limited biodiesel testing facilities in India, the firm could test only few parameters which were found to be within limits as per IS: 15607, 2005. Only IOC R&D Center is having complete facilities for testing of biodiesel properties as per IS:15607,2005 so after keeping the biodiesel for more than two months, the biodiesel was again tested at IOC R&D Centre to study the deterioration in properties before the engine tests were carried out.

Table 2 : Test of WFFAME after more than two months storage without any Nitrogen Cover

Sn	**Characteristic**	**Unit**	**Method of test as per BIS 15607-2005**	**Limit**	**Waste Fishoil Ester as tested by IOC(figures in brackets are as reported by the firm)**
1	Density at 15°C	Kg/m^3	ISO 3675, ISO 12185	860-900	889
2	Kinematic Viscosity at 40°C	cSt	ISO 3104	2.5-6.0	**6.05 (4.25)**
3	Flash Point (PMCC)	°C, min	IS 1448 P:21	120	**76.6 (> 120)**
4	Sulphur	mg/Kg max.	ASTM D-5453	50	**96 (15.3)**
5	Carbon residue (Ramsbottom)	% by mass, max	ASTM D-4530/ISO 10370	0.05	**0.36 (not tested by firm)**
6	Sulphated Ash	% by mass, max	ISO 6245	0.02	0.009
7	Water/ Water & sediment	ppm	ASTM D-2709, ISO 3733, ISO 6296	500	Nil
8	Total Contamination	mg/Kg max.	EN 12662	24	**36.4 (not detected)**
9	Cu corrosion	3 hrs at 50°C, max	ISO 2160	1	1
10	Cetane No	Min.	IS 5156	51	54.1

11	Acid Value	mg KOH/gm, max	IS-1448, P:1/Sec 1	0.5	0.47
12	Methanol	% by mass, max	EN 14110	0.2	0.003
13	Free Glycerol	% by mass, max	ASTM D-6584	0.02	0.00063
14	Total Glycerol	% by mass, max	ASTM D-6584	0.25	0.0037
15	Phosphorous	mg/Kg max.	ASTM D-4951	10	<1
16	Oxidation Stability, at 110°C	hrs, min	EN 14112	6	**1.54 (4.5 by American Oil Method)**
17	Sodium & Potassium	mg/Kg max.	EN 14108 & EN 14109	To report	< 1 & < 1
18	Calcium & Magnesium	mg/Kg max.	EN 14108 & EN 14109	To report	< 1 & < 1
19	Iodine Value		NMR method	To report	101.7
20	CFPP	° C, max.	ASTM D 6371	Winter 6°C Summer 18°C	2°C
21	Pour Point	° C, max.	ASTM D 97	Winter 3°C Summer 15°C	0°C
22	Monoglyceride content	%, mass,max	ASTM D 6584	0.8(as per EN 14105)	0.0286
23	Diglyceride content	%, mass, max	ASTM D 6584	0.2(as per EN 14105)	Nil
24	Triglyceride content	%, mass, max	ASTM D 6584	0.2(as per EN 14105)	Nil

It can be see from Table above that after storage for more than two months, there has been deterioration in properties of biodiesel. These are discussed below: -

Kinematic Viscosity has increased slightly due to oxidation of the biodiesel but this is only marginal. Flash point has decreased appreciably and cause for this could not be established. This is probably due to breakdown of fatty acids since the base oil is from animal origin. Another reason can be contamination of the samples during transport from ED Dte. to IOC R&D. Sulphur content, Carbon residue and Total Contamination has also increased and is attributed to unclean tanks. This can also be attributed to use of buckets to empty the biodiesel tanker for the last few liters. Oxidation stability has decreased due to non-availability of any nitrogen cover during storage and no anti-oxidation additive added to the biodiesel. All these aspects have been noted for large-scale implementation.

Engine Configuration

The engine configuration used for the testing is as given below: -

Table 3: Engine Configuration used for testing biodiesel

1	Engine	16 cylinder ALCO V engine with SUCS
2	Rated HP	3100
3	Engine RPM	400 – 1050
4	Manifold	Stream lined – 3 entry
5	Camshaft	Stiffer Unit Camshaft
6	Fuel Injection Equipment	17 mm plunger diameter Fuel Injection Pump, 157 degree nozzle spray angle having 0.350 mm dia nozzle holes
7	Turbocharger	ABB TPR-61A
8	Piston	11.75 CR of M/s FMGIL Make Steel Cap composite
9	Ring Pack	M/s Kaydon FE
10	Lube oil Cooler	3100 HP
11	Exhaust Manifold	3 entry stream line
12	Cylinder head	251 Plus
13	Engine Lubricating Oil	RR 606 MG of Indian Oil Corporation
14	After Cooler	Large Aftercooler 16 rows

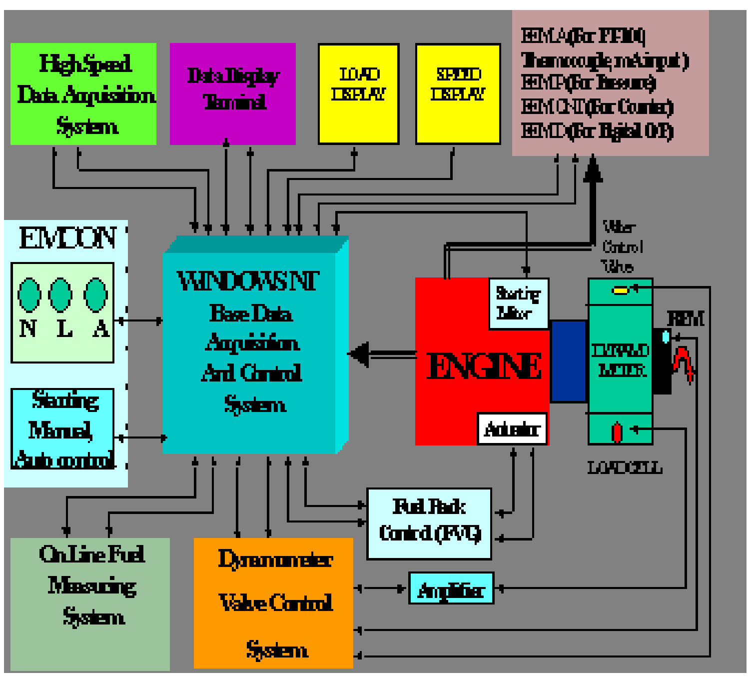

Figure 1: Schematic of the Engine Test and Control Configuration

Test Procedure

Necessary instrumentation was provided 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. Fuel consumption and power was measured for each of the engine operating notch. The engine was run for a sufficiently long duration to ensure thermal stabilization before taking the specific fuel consumption and the emission measurements.

Engine Test points

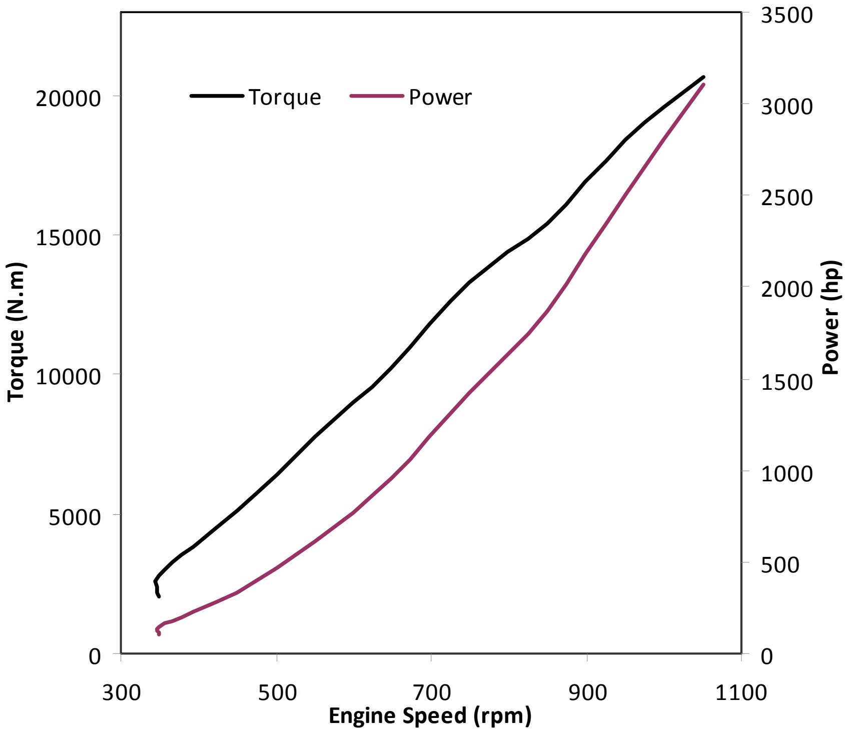

Figure 2: Engine operating points for this test

Figure above shows the Engine Operating line which has been used for Engine Characterisation.

Test Result Analysis

Results obtained in this study with petro diesel, neat biodiesel and different biodiesel blends are deliberated upon with respect to engine performance and emissions.

The testing was carried out on the 16-cylinder test bed. A test matrix was designed with petro-diesel and biodiesel in various volume proportions. Initially, the base line data was generated by testing with petro diesel and carrying out the measurement of all the requisite parameters. Subsequently, biodiesel blends of B10, B20, B50 and neat biodiesel B100 were used as fuel and the various parameters of the engine performance were noted.

Major Engine Performance Parameters

Table 4 : Summary of results for critical parameters at 8th Engine Notch

		Biodiesel blends with Normal HSD			
PARAMETERS	**Normal High Speed Diesel**	**B10**	**B20**	**B50**	**B100**
Horsepower(HP)	3105	3114	3117	3104	3109
BSFC(gm/bhp-hr)	153.48	155.49	157.62	162.04	170.43
Exhaust gas temperature (°C)	409.45	402.22	418.16	405.28	406.01
Firing pressure (bar)	112.99	111.71	111.59	113.36	107.52

As can be seen from the table above, the engine maintained full horsepower with all the biodiesel blends including pure biodiesel, i.e. B100.

- The specific fuel consumption increased from 153.48 gm/bhp-hr to 170.43 gm/bhp-hr, an increase of 11 %. This is in agreement with the lower heating value of biodiesel, about 10-11%.
- The exhaust gas temperature in general showed a downward trend. This will be discussed graphically also.
- The firing pressure did not change significantly and are therefore not discussed.
- Since testing was carried out at different ambient temperatures, this may have affected the test results to some extent. These are shown below.

Ambient Air Temperature

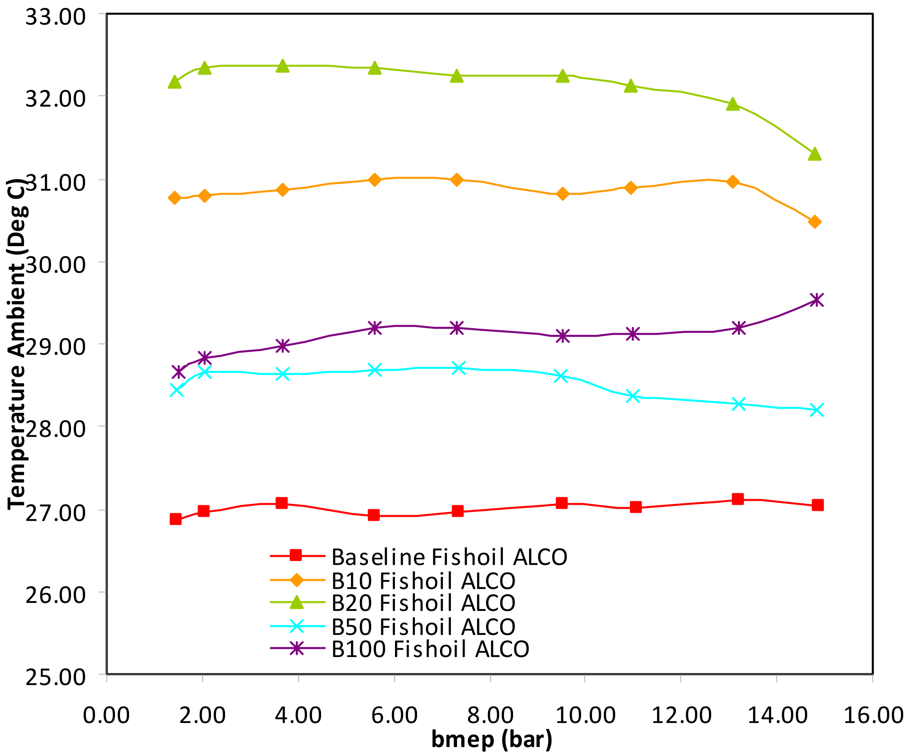

Figure 3: Variation of Ambient air temperatures

Figure shows the variation in ambient air temperatures as recorded during different days when these tests were conducted. Test for each blend was repeated three times and the values shown are average of the three days. There is a variation in the recorded ambient temperatures.

Specific Fuel Consumption

In general the specific fuel consumption increases with the increase in biodiesel percentage as has been shown in the summary table before. However a more detailed analysis of the data is also recorded and deliberated upon to observe the effect of engine rpm on the specific fuel consumption.
The observations of the specific fuel consumption (gm/bhp-hr) for all the power notches and various blends are tabulated below:

Table 5: Comparison of brake specific fuel consumption

		Biodiesel blends with Normal HSD			
Engine Notch	Normal HSD	B10	B20	B50	B100

8th	153.48	155.49	157.62	162.04	170.43
7th	154.37	156.06	159.29	163.15	171.50
6th	160.62	162.49	166.66	170.15	179.36
5th	169.08	170.96	175.43	179.13	189.57
4th	178.76	180.42	187.11	189.96	202.16
3rd	186.77	188.52	196.17	198.84	212.77
2nd	197.99	201.13	210.17	210.65	225.88
1st	224.17	230.45	245.30	236.07	255.36
Idle	246.03	257.87	273.80	258.81	274.57

It can be seen that in general, BSFC increases for higher blends of biodiesel. This is logically explained by the fact that the biodiesel has a lower calorific value when compared to petrodiesel.

Graph of Engine Notch vs BSFC

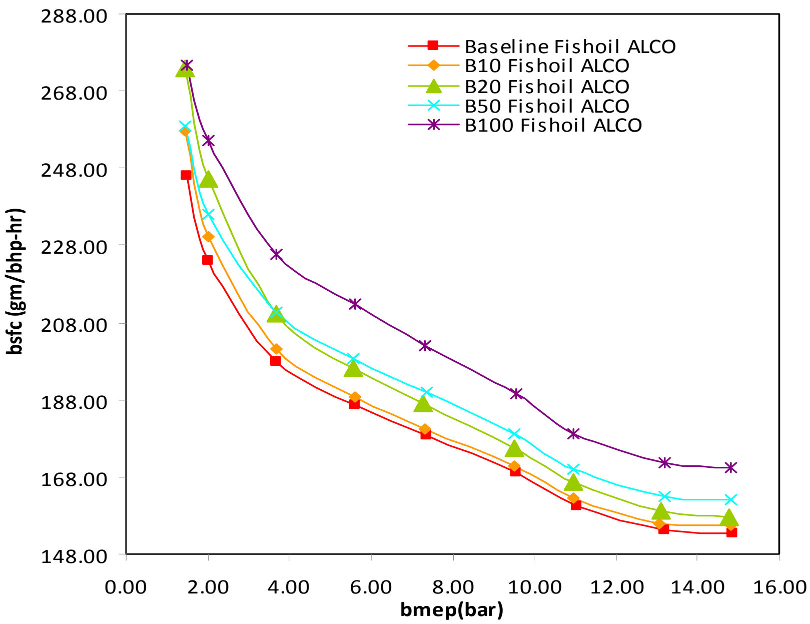

Figure 4: Comparison of bsfc

Figure above shows the graph of engine brake specific fuel consumption plotted against bmep. Graph of engine bmep vs speed is already shown in figure 4 above. It can be seen from the figure that the bsfc increases with higher blends of biodiesel. There is marginal difference in the bsfc of plain diesel and B10 biodiesel.

Exhaust Gas Temperature

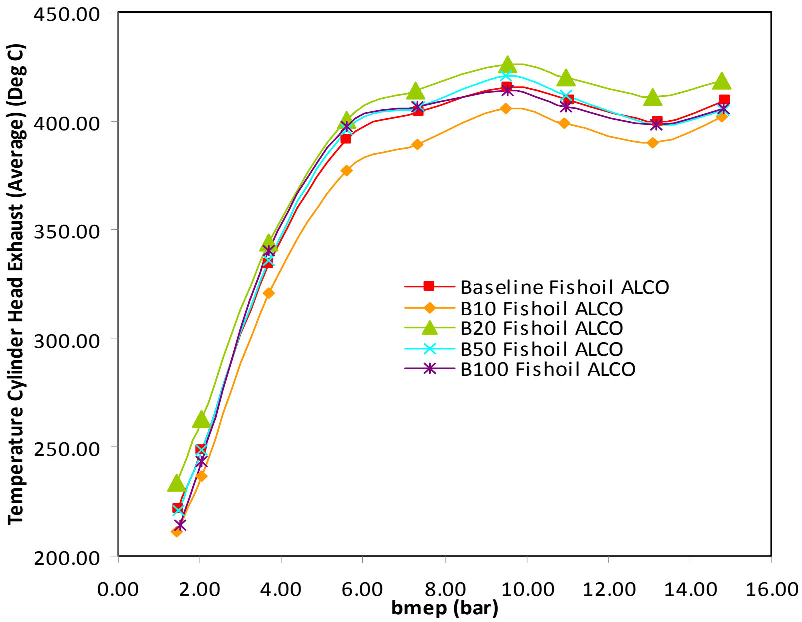

Figure 5: Comparison of exhaust gas temperatures

Figure shows the variation of Exhaust gas temperatures at cylinder head. These temperatures are lesser than Normal HSD for B10 blend and highest for B20 blends. However all the temperatures are below the upper limit of 450°C. Exhaust gas temperatures for B100 blend are very close to the plain diesel. The Band over which the Exhaust gas temperatures vary is narrow, but show the highest values at 5th engine notch as has been the experience from past. This was an unusual pattern as compared to the last report so this was corroborated with the Turbine Gas Inlet temperatures. Effect of higher ambient temperatures on the B20 blend can be seen.

Table 6: Comparison of exhaust gas temperatures

		Biodiesel blends with Normal HSD			
Engine Notch	Normal HSD	B10	B20	B50	B100
8th	409.45	402.22	418.16	405.28	406.01
7th	399.81	390.30	410.87	397.84	398.00
6th	409.79	398.86	420.01	411.58	406.37
5th	415.81	406.00	425.60	420.57	413.75
4th	404.23	388.97	413.71	406.67	406.62
3rd	391.34	377.39	400.41	396.13	397.80
2nd	334.31	320.97	344.49	335.93	340.06
1st	249.17	236.86	262.97	248.72	243.69
Idle	221.41	211.19	233.90	220.71	214.09

Turbine Gas Inlet Temperatures

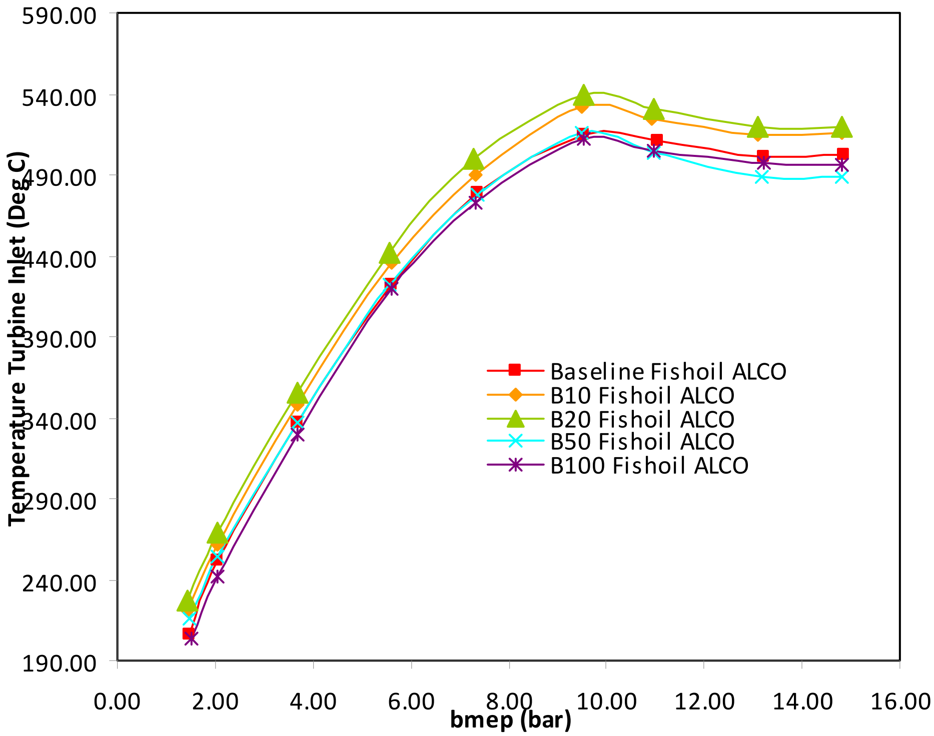

Figure 6: Comparison of turbine inlet gas temperatures

Figure above shows the Turbine inlet gas temperatures and in this case also we find that the B20 blend is showing the highest temperatures. The lowest temperatures are however shown by the B50 and the B100 blends. Reason for this unusual phenomenon needs to be studied further in conjunction with the fatty acid composition of the biodiesel.

Table 7: Comparison of turbine inlet gas temperatures ºC

		Biodiesel blends with Normal HSD			
Engine Notch	Normal HSD	B10	B20	B50	B100
8th	502.84	516.20	519.56	488.91	496.61
7th	501.62	514.88	520.24	489.31	497.01
6th	510.94	525.02	530.54	503.81	504.87
5th	515.06	531.98	539.03	516.05	511.96
4th	478.28	490.04	499.39	477.74	472.36
3rd	422.35	435.39	441.77	421.75	419.33
2nd	336.85	347.84	355.90	336.74	329.67
1st	251.98	261.38	268.41	253.79	242.02
Idle	205.96	220.49	226.45	215.41	203.22

Boost Pressures

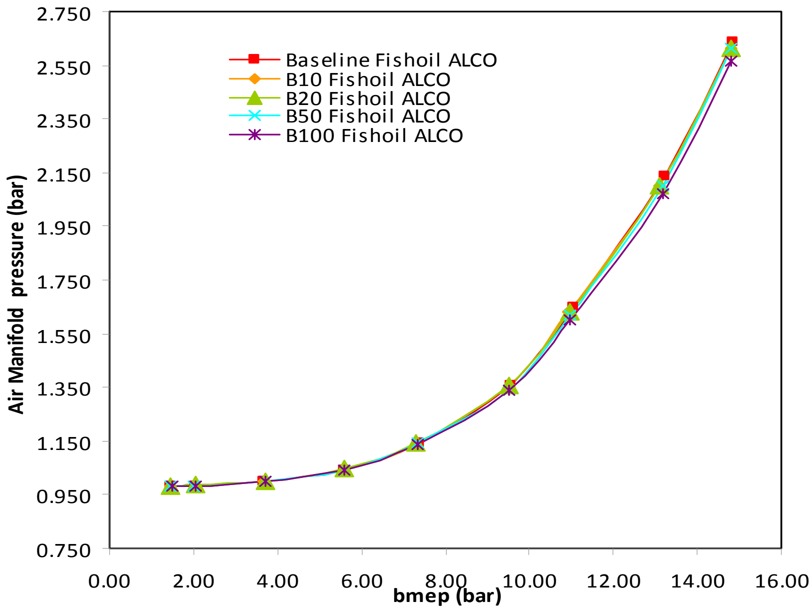

Figure 7: Comparison of Boost Pressures

Figure shows the variation of boost pressures with various blends of biodiesel plotted against the engine notch. There is almost no variation as far as the boost pressures are concerned. Thus the biodiesel and its blends do not adversely affect the performance of the turbocharger.

Table 8: Comparison of boost pressures (bar)

		Biodiesel blends with Normal HSD			
Engine Notch	Normal HSD	B10	B20	B50	B100
8th	2.638	2.611	2.611	2.611	2.566
7th	2.135	2.102	2.100	2.102	2.071
6th	1.647	1.631	1.630	1.617	1.599
5th	1.356	1.355	1.355	1.341	1.337
4th	1.140	1.138	1.140	1.140	1.137
3rd	1.040	1.040	1.046	1.040	1.041
2nd	0.999	1.000	1.000	1.000	1.000
1st	0.980	0.981	0.990	0.984	0.984
Idle	0.980	0.980	0.980	0.980	0.980

Fuel Injection Pump – High Pressure Line Pressure

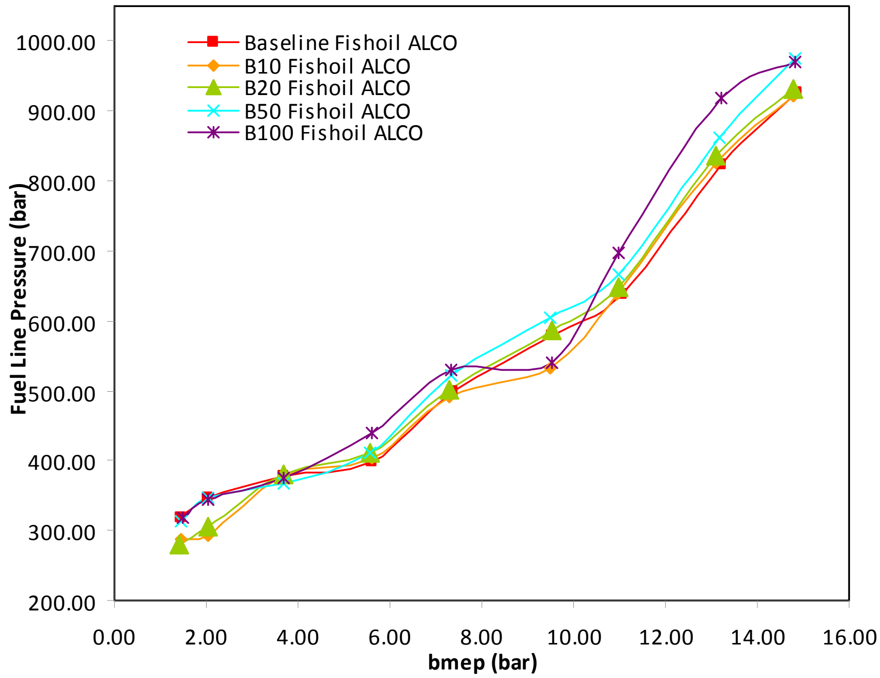

Figure 8: Comparison of Fuel Line pressures

Table 9: Comparison of Fuel High Pressure Line Pressure

		Biodiesel blends with Normal HSD			
Engine Notch	Normal HSD	B10	B20	B50	B100
8th	927.28	920.79	931.10	976.53	970.42
7th	824.09	826.23	835.57	861.62	918.80
6th	637.70	636.70	647.12	666.92	697.38
5th	577.79	533.33	585.15	605.62	539.72
4th	499.04	490.82	501.19	522.65	530.46
3rd	399.40	403.89	410.70	411.46	438.76
2nd	378.11	378.35	379.71	367.69	375.10
1st	348.02	293.98	304.66	346.85	344.02
Idle	319.70	288.73	281.08	313.28	319.46

It can be seen from Figure and Table above that the Fuel line Pressures increase with increasing blends of biodiesel, however, fuel injection pressures have not crossed the 1000 bar mark even with B100 Biodiesel. Fuel injection pressures have increased due to higher viscosity of biodiesel.

NOx emissions

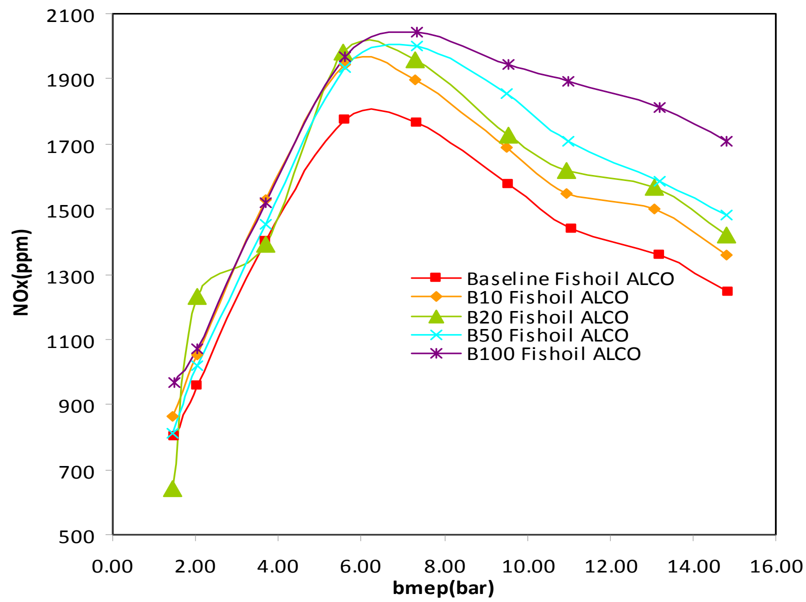

Figure 9: Comparison of NOx emissions

Figure shows the variation of NOx emissions with various blends of biodiesel at different engine notches. As is expected the NOx emissions increase with higher blends of biodiesel. This is due to the higher viscosity of biodiesel leading to earlier injection, earlier combustion and also because biodiesel is an oxygenated fuel. There are non-thermal reasons also for increase of NOx. NOx can be reduced by suitably adjusting the fuel injection timing and also by EGR. Particular of ALCO engine is the highest NOx levels at the 4th engine notch because of highest volumetric efficiency of the engine at this operating point.

Table 10: Comparison of NOx emissions (ppm)

		Biodiesel blends with Normal HSD			
Engine Notch	Normal HSD	B10	B20	B50	B100
8th	1246	1358	1422	1481	1706
7th	1357	1499	1568	1585	1810
6th	1440	1548	1619	1710	1894
5th	1576	1690	1727	1855	1946
4th	1767	1895	1957	2000	2045
3rd	1773	1943	1984	1935	1970
2nd	1402	1528	1394	1454	1520
1st	958	1052	1233	1019	1072
Idle	803	862	643	812	966

THC emissions

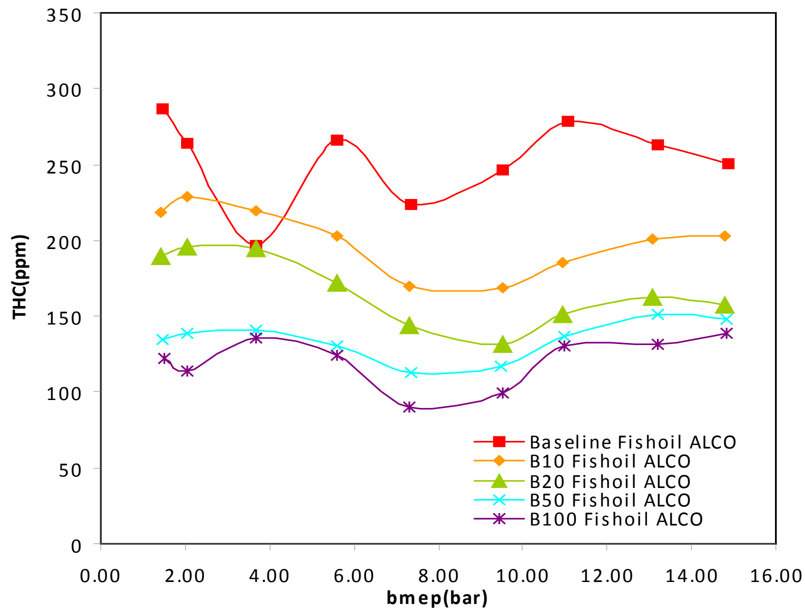

Figure 10: Comparison of Total Hydrocarbon emissions

Table 11: Comparison of THC emissions (ppm)

		Biodiesel blends with Normal HSD			
Engine Notch	Normal HSD	B10	B20	B50	B100
8th	250	203	157	148	139
7th	263	201	162	151	132
6th	279	185	151	137	130
5th	247	169	131	117	99
4th	224	170	144	113	90
3rd	266	203	172	130	124
2nd	197	220	195	141	136
1st	264	229	196	139	114
Idle	286	219	190	134	122

As can be seen from Figure and Table above, THCs have reduced with the use of biodiesel and its blends. This is because biodiesel is an oxygenated fuel and combustion is better with biodiesel, however biodiesel has a lower calorific value because of presence of an oxygen atom.

CO emissions

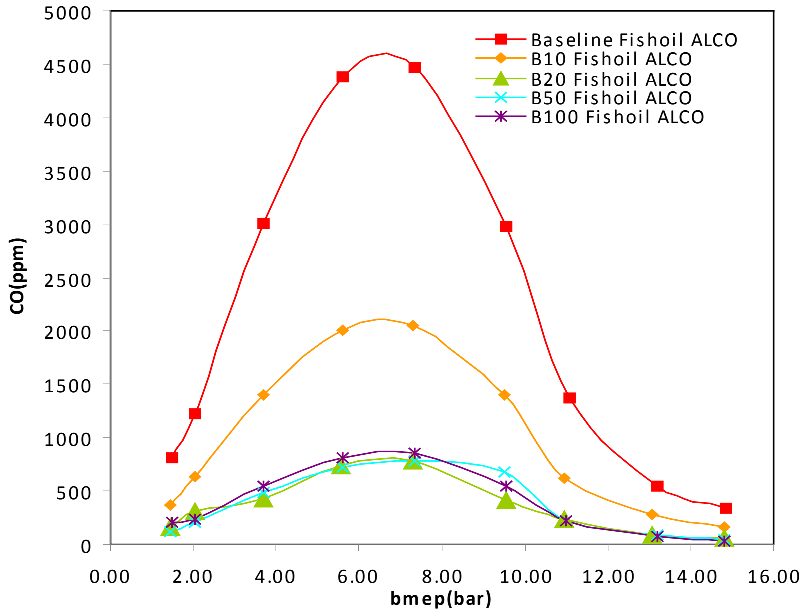

Figure 11:Comparison of CO emissions

Table 12: Comparison of CO emissions (ppm)

		Biodiesel blends with Normal HSD			
Engine Notch	Normal HSD	B10	B20	B50	B100
8th	343	162	55	44	36.7
7th	548	281	92	89	72.9
6th	1377	618	239	220	228
5th	2973	1398	416	683	541
4th	4463	2043	778	786	851
3rd	4385	2012	735	729	818
2nd	3015	1405	428	486	540
1st	1217	641	307	210	239
Idle	807	370	156	122	206

As can be seen from Figure and Table above, the CO emissions show a downward trend when biodiesel and its blends are used as fuel. Presence of Oxygen atom in the Ester helps in better combustion. One characteristic feature is the highest CO emission at 4th and 5th engine notches. This combined with the NOx emissions shows that combustion optimisation of the ALCO engine is immediately required for lower notches, not only for better fuel consumption but also for better emissions and noise.

Smoke Opacity

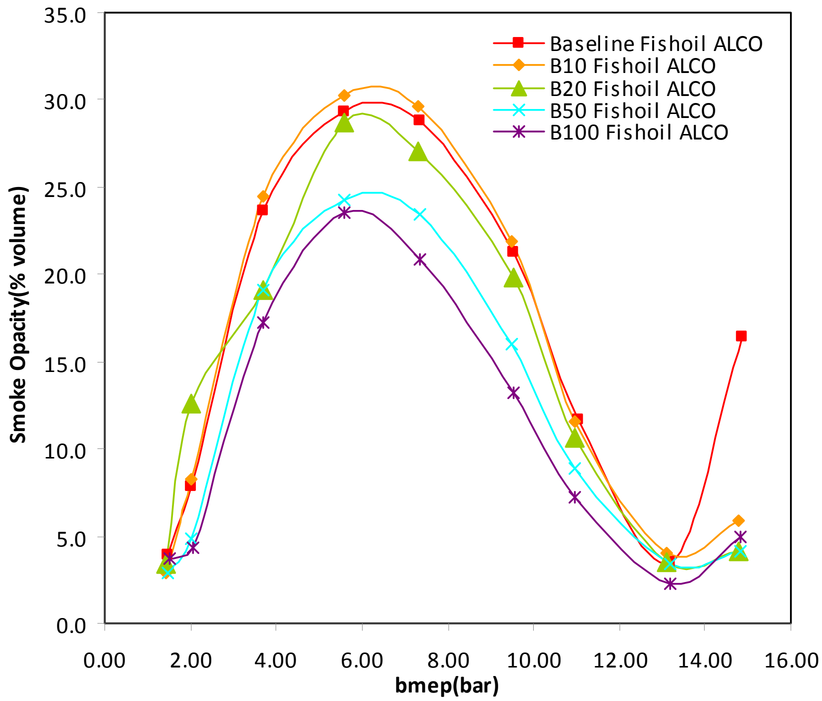

Figure 12: Comparison of Smoke Opacity

Figure above shows the Smoke opacity values obtained with different blends of biodiesel. It can be clearly seen that the smoke opacity decreases with higher blends of biodiesel which corroborates well with the fact that esters are oxygenated fuels.

Filter Condition

No abnormal deposits were observed nor the filters changed. Differential pressure across filter did not increase more than the stipulated value.

Conclusions

The performance studies on different blends of biodiesel carried out on the 3100 hp ALCO DLW engine reveal the following:

1. There is no change in power for various blends of biodiesel. Even B100 i.e. pure biodiesel is capable of developing full horsepower on the ALCO DLW engine.
2. In general the bsfc showed an increased trend with higher blends of biodiesel. No optimisation of injection timing was carried out, but from

previous experience it can be said that the bsfc can be reduced with optimised timing.
3. The NOx emissions in general increase with higher blends of biodiesel.
4. The hydrocarbon emissions also revealed a decreasing trend with higher blends of biodiesel with as much as 44 % reduction with B100 as compared to Normal HSD.
5. The CO emissions also showed a decreasing trend with higher blends of biodiesel with as much as 89.3 % reduction with B100 as compared to Normal HSD.
6. The Smoke Opacity of the exhaust also showed a decreasing trend with higher blends of biodiesel with as much as 20 % reduction with B100 as compared to Normal HSD.
7. Average Cylinder head exhaust temperatures are lesser than Normal HSD for B10 blend and highest for B20 blends. B20 tests were carried out at the highest ambient temperatures. However all the temperatures are below the upper limit of 450°C. Exhaust gas temperatures for B100 blend are very close to the plain diesel.
8. Based on above results, it is concluded that WFFAME and its blends upto B100 can be used as a fuel on ALCO DLW diesel engines. Some adjustments to the injection timings and change of natural rubber component parts to synthetic rubber and bronze parts to stainless steel parts may be required.

Recommendations

1. Because of shortage of biodiesel testing facilities in the country (only IOC R&D Centre, Faridabad has these facilities at the time of issuing this report), RDSO should develop these facilities in-house for which a Sanctioned Work already exists.
2. IR should consider management of collection of the already available non-edible seeds in the country for biodiesel production.
3. To carry out detailed compatibility studies with biodiesel and rubbers, bronzes etc. in future.
4. To carry out detailed flame visualization studies and combustion optimisation using simulation software with biodiesel and its various blends.