GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

REPORT ON TESTING OF BIODIESEL AS AN ALTERNATE FUEL

(Test Bed Results & limited Field Trial On Jan Shatabdi)

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RESEARCH DESIGNS & STANDARDS ORGANISATION
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1.0 BACK GROUND INFORMATION

1.1 Preliminary Test Bed Evaluation

Preliminary testing of bio diesel on 3100 hp diesel engines as an alternate fuel was carried out in RDSO in November 2002. This testing was constrained owing to a limited availability of biodiesel. Bio diesel blends of 5, 10, and 20% were tested. It was observed that the engine was able to maintain full power out put with the bio diesel blends. The specific fuel consumption had deteriorated slightly.

1.2 Trial On Shatabdi Express

On 31st December 2002, a field trial was done on Delhi-Amritsar Shatabdi express using B5 biodiesel blend as fuel. It was noted that no problem was experienced in locomotive haulage, and acceleration while running the train. . The specific fuel consumption was also found comparable to the petro diesel.

2.0 INTENSIVE PERFORMANCE EVALUATION OF BIO DIESEL

2.1 Detailed Testing & Evaluation Of Bio Diesel

Detailed testing and evaluation of biodiesel has been conducted during April-May 2004 at RDSO on the 3100hp Diesel Engine Test Bed.

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.

2.2 Engine Configuration

The engine configuration used for the testing was a 16 cylinder, V type, water cooled, supercharged engine. Some more details of the engine are as follows:

1	Engine	16 cylinder Alco DLW fuel efficient
2	Rated HP	3100
3	Engine RPM	400-1050
4	Manifold	Stream lined – 3 entry
5	Cam shaft	140 degree valve overlap
6	Fuel injection pump	17 mm plunger diameter, 157 degree nozzle spray angle having 0.350 mm dia. holes.

Table 1: The engine configuration used for testing

2.3 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 power notches. The engine was run for a sufficiently long duration to ensure thermal

stabilization before conducting the specific fuel consumption and the emissions measurements.

2.4 Quality Assurance

To test the properties of bio diesel, which was of imported origin; the sample was sent to the IOC-R&D facility in Faridabad. The test results obtained for the various properties by carrying out the testing with the ASTM test method are as follows:

S. no.	Property	ASTM test method	Limits as per ASTM 6751	Test results of Bio-diesel
1	Flash point, ^{0}C	D-93	Min.130	163
2	Water and sediments, % vol.	D -2709	Max. 0.050	Nil
3	K. Viscosity at 40 ^{0}C	D-445	1.9 – 6.0	4.05
4	Sulphated ash, % wt.	D-874	Max. 0.020	0.001
5	Sulphur %mass	D-5453	Max. 0.05	0.0014
6	Copper strip corrosion at 100 3 hrs.	D-130	Max. 3	1
7	Cloud point, ^{0}C	D-2500	-	+2 ^{0}C
8	Cetane no.	D-613	Min. 47	Under process
9	TAN, mg KOH/gm	D-664	Max. 0.80	0.1
10	Carbon residue, % wt.	D-4530	Max. 0.05	0.02
11	Free glycerin, % wt.	D-6584	Max.0.020	Under process
12	Total glycerin, % wt.	D-6584	Max.0.240	Under process
13	Temp. at which 90 % recovery ^{0}C	D-1160	Max. 360	324
14	Phosphorus content, % wt.	D-4591	Max. 0.001	Under process

Table 2: Laboratory test results of Biodiesel

3.0 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 in 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, bio diesel blends of B10, B20, B50 and pure biodiesel B100 were used as fuel and the various parameters of the engine performance were noted.

3.1 Major Engine Performance Parameters:

	Regular diesel	Bio diesel blends with regular diesel			
		B10	**B20**	**B50**	**B100**
Horse power(HP)	3140	3116	3156	3153	3128
SFC,(gms/bhp-hr)	153.68	155.37	156.11	162.15	173.6
Exhaust gas temp.(^{0}C)	517	511	-	483	486
Firing pressure (psi)	1648	1650	1644	1631	1655

Table 3: A summary of results

As can be seen from the table above, the engine maintained full horse power with all the bio diesel blends including pure bio diesel i.e. B100.

- The specific fuel consumption of the engine increased from 153.68 g/bhp-hr to 173.6 g/bhp-hr, an increase of 12.5%.
- The exhaust gas temperature in general showed a down ward trend.
- The firing pressure did not change significantly.

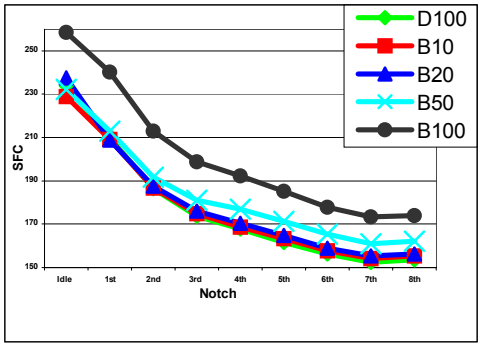
3.2 Specific Fuel Consumption

In general the specific fuel consumption increases with the increase in bio diesel 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 (gms/hphour) for all the power notches and various blends are tabulated below:

Power Notch	**Regular diesel**	**Bio diesel blends with regular diesel**			
		B10	**B20**	**B50**	**B100**
8th	153.68	155.37	156.11	162.15	174.00
7th	152.43	154.04	155.27	160.94	173.25
6th	156.34	157.62	158.98	165.24	177.71
5th	161.62	163.33	164.79	171.37	185.20
4th	167.86	168.58	170.31	176.93	192.37
3rd	173.64	174.71	176.14	181.18	198.76
2nd	186.29	186.79	187.60	191.73	213.00
1st	209.89	209.25	208.76	212.88	240.23
Idle	233.94	229.08	237.46	232.29	258.54

Table 4: The specific fuel consumption



Graph1 - SFC vs Notches for various blends

It can be seen that in general, SFC increases for higher blends of bio diesel. This is logically explained by the fact that the bio diesel has a lower calorific value when compared to petro diesel.
However, at lower notches (Idle, 1st, 2nd), SFC for bio diesel blends is comparable and even better than petro diesel.

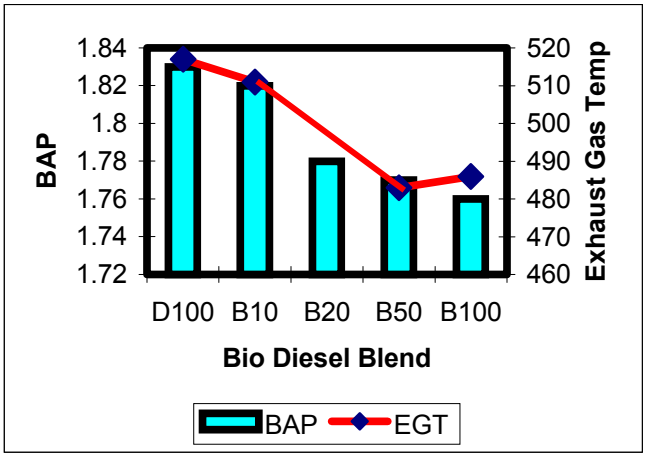
While testing the B10 bio diesel, it was seen that SFC at Idle was 229.08 as against 233.94 for regular diesel. Similarly in the1st notch with B10 bio diesel blends SFC obtained is 209.25 % as against 209.89 with regular diesel.

3.3 Exhaust Gas Temperature

Exhaust gas temperature in general has shown a downward trend. This has resulted in lowering booster air pressures. The results obtained in the following table:

	Regular diesel	Bio diesel blends with regular diesel			
		B10	B20	B50	B100
Ambient temp. (^{0}C)	36.96	32.05	34.62	37.86	35.75
BAP (bars) at 8th notch	1.83	1.82	1.78	1.77	1.76
Exhaust gas temp.(^{0}C)	517	511	-	483	486

Table 5: The correlation of BAP and exhaust gas temperature



Graph 2 - Correlation of BAP and Exhaust Gas Temp

The exhaust gas temperature is lower for higher blends of bio diesel because of the improved combustion provided by the bio diesel.

This however leads to a lower booster pressure because of the reduced energy content in the exhaust gases.

The reduction in booster air pressure is not a cause for concern. On the contrary, it signifies that the BAP has moved towards a more ideal value with the improved combustion in the combustion chamber of the engine.

3.4 Emission Results

AVL make Digas analyzer model AVL DiGas 4000 was used for measuring emissions such as CO, CO2, Nox, and O2.

The emission results obtained during the testing with various blends are tabulated below:

	Regular Diesel	**Bio diesel blends with regular diesel**			
		B10	**B20**	**B50**	**B100**
Nox at 8 th notch in ppm	1422	1266	1480	1553	1491
Hydro carbon (HC Hexane) in ppm	13	12	9	11	6
Residual oxygen (% vol.)	12.2	12.3	12.2	12.1	12.2
CO (% vol.)	0.01	0.01	0.01	0.01	0.00
CO_2 (% vol.)	6.2	5.9	5.8	6.0	6.1

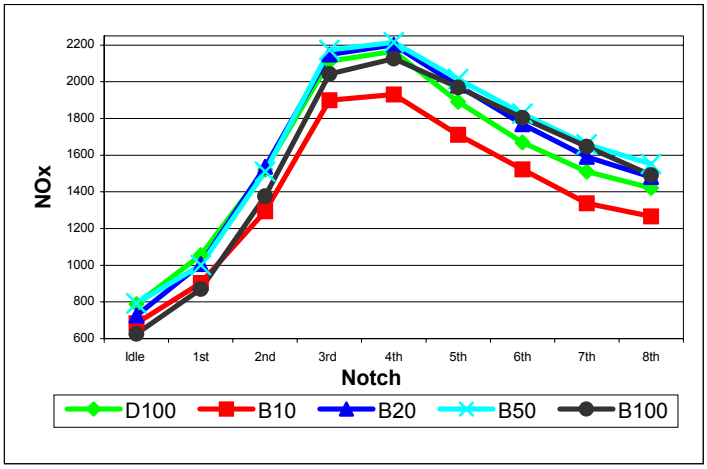
Table 6: The data on emissions

3.4.1 NOx Emissions

As can be seen from the table, the NOx values increased in higher blends except for B10 bio diesel in which the NOx percent has decreased. A similar decrease in the NOx level was observed for all the notches while testing the B10 fuel.

Notch	**Regular diesel**	**Bio diesel blends with regular diesel**			
		B10	**B20**	**B50**	**B100**
8^{th}	1422	1266	1480	1553	1491
7^{th}	1511	1337	1590	1658	1647
6^{th}	1669	1522	1769	1826	1804
5^{th}	1891	1711	1980	2015	1970
4^{th}	2166	1931	2201	2215	2127
3^{rd}	2133	1900	2148	2173	2043
2^{nd}	1521	1295	1537	1511	1376
1^{st}	1056	904	1007	1001	870
Idle	789	683	726	791	627

Table 7: Nox values obtained for different notches and blends



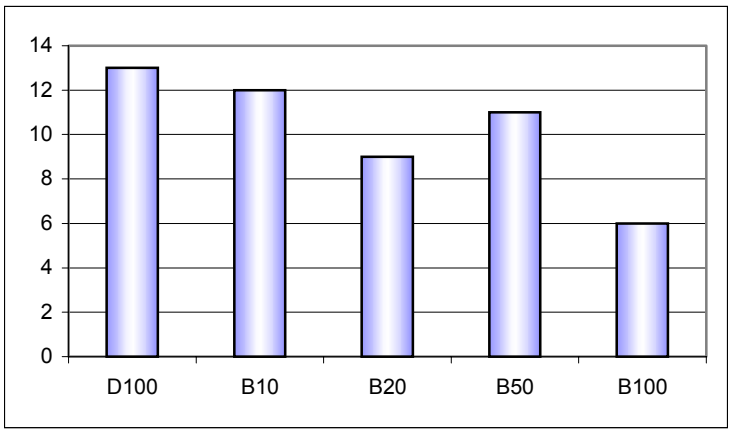
Graph3 - NOx versus Notches

It may be seen that the NOx emissions increased with the increase in notch or speed of the engine. The maximum NOx value was obtained for the 4th notch when the engine RPM was 650. For further increase in the notches upto 8th notch (RPM 1050), the NOx emissions tended to decrease. This may be due to the lower energy content associated with bio diesel fuel, which may result in lower peak temperature than the petro diesel.

Another important observation is the lower Nox values obtained for bio diesel blends at lower notches viz. idle, 1st,2nd and 3rd when compared to petro diesel. Normally an increase in NOx is expected and is mainly attributed to the oxygen content of bio diesel. At elevated temperature this oxygen reacts with Nitrogen and tended to form NOx. However the reduced Nox formation at lower notches is probably due to the reduced temperatures and pressures, which occur due to the improved combustion and which inhibit the combining of nitrogen and oxygen.

The effect of advancing and retarding the fuel injection timing on NOx emissions is also proposed to be studied.

3.4.2 Hydro Carbon Emissions



Graph4 - Hydro Carbon emissions in ppm

The hydrocarbon content in emission has shown an over all down ward trend. For B100, there is reduction of 54% in hydrocarbon emission as compared to petro diesel

3.5 Fuel Injection Pump – High Pressure (HP) Line Pressure

It was seen that the fuel injection pump HP line pressure increased significantly and even crossed the permissible limit of 1000 bar during the testing of B100. This is due to the higher viscosity of biodiesel. Hence higher the blending percentage of biodiesel more the rise in the HP line pressure.

The viscosities of various blends of bio diesel and the corresponding HP line pressures obtained during testing with those blends are tabulated below:

	Regular diesel	**Bio diesel blends with regular diesel**			
		B10	**B20**	**B50**	**B100**
K.Viscosity (cSt)	3.026	3.07	3.25	3.44	4.05
HP line pressure	927	936	949	971	1015

Table 8: The correlation of viscosity and HP line pressure

Since it is quite clear that the injection pressure in the HP tube are increasing significantly with viscosity, therefore, it is essential that the viscosity limit should be further controlled while producing bio diesel. As per the ASTM limit the kinematic viscosity at 40º C can vary between 1.9 to 6 cst. In this case the viscosity of B-100 is found to be 4.05 cst. It is clear that even this level of viscosity is creating a very high level of pressure in the HP tube. Hence stipulating a more stringent control on viscosity may be essential.

4.0 OPTIMIZATION OF THE ENGINE PERFORMANCE:

At present with petro diesel fuel injection point is 25.5 degrees before the top dead center (BTDC). As per the literature, advancing the fuel injection timing results in improvement of the specific fuel consumption. However, firing pressure generally tend to increase. On the engine, injection timing was advanced by 2º from 25.5 BTDC to 27.5 BTDC. 10% and 20% blends of bio diesel were subsequently tested with advanced injection timing to ascertain engine performance. The performance parameters of SFC, HP and firing pressure are tabulated below:

	Regular diesel	**B10 Bio diesel blends with regular diesel**		**B20 Bio diesel blends with regular diesel**	
		Point of injection			
		25.5º BTDC	**27.5º BTDC**	**25.5º BTDC**	**27.5º BTDC**
Horse power(HP)	3140	3127.8	3110	3137.6	3121.86
SFC,(gms/bhp-hr)	153.68	155.37	154.16	156.11	156.22
Firing pressure (psi)	1648	1650.25	1763	1644.34	1741.34

Table 9: The results obtained with engine optimization

As can be seen from the table above for B10 blends of bio diesel used with the advanced injection timing, the SFC improved 155.37 to 154.16. As compared to regular diesel, the SFC remains only marginally higher.
The firing pressure increased from 1650 psi to 1753 psi as a result of advancing the injection timing. The exhaust gas temperature reduced from 511ºC to 480ºC as a result of optimization. This is indicative of more complete combustion in the combustion chamber with minimal afterburning thus resulting in lower exhaust gas temperatures.

5.0 FILTER CONDITION

The fuel filters fitted on the engine test bed were instrumented by naustran pressure gauge before and after the filter. The differential pressure developed across the filter were carefully monitored and it was seen that there were no unusual increase in the differential pressure during the test.

6.0 CONCLUSIONS

The performance studies on different blends of bio diesel carried out on the 3100 HP Alco DLW engine reveal the following:

1. There is no change in power for various blends of bio diesel. Even B-100 i.e. pure bio diesel is capable of developing full horsepower on the Alco DLW engine.
2. In general the SFC showed an increased trends with higher blends of bio diesel. However, the combination of B10 with the optimized injection timing was quite comparable to petro diesel. At lower notches (lower engine speeds) the SFC was even better than petro diesel).
3. The NOx emissions in general increase with higher blends of bio diesel. However, at lower notches (1^{st}, 2^{nd} & 3^{rd}), bio diesel blends showed lower NOx readings compared to petro diesel.
4. The hydrocarbon emission also revealed a decreasing trend with high blends of bio diesel with as much as 54% reduction with B-100 as compared to regular diesel.
5. The exhaust gas temperature showed the decreasing trend for increasing blends of bio diesel. This also resulted in lower booster air pressure. The exhaust gas temperature was further reduced on optimizing the injection timing.
6. Based on above results, it is concluded that the bio diesel blends and even neat bio diesel can be used as a fuel on Alco DLW diesel engines. For the present, an optimized blending ratio of bio diesel i.e. B-10 would be ideal.

Bio diesel has got tremendous potential as a fuel. It is an indigenously produced and environment friendly source of energy. The testing done so far clearly indicates that there is a considerable scope for further improvement in specific fuel consumption, emissions and other performance parameters. Towards this end sustained optimisation trials and studies on state of the art high horse power test bed facility as available at RDSO is considered vital.

7.0 FOLLOW-UP SERVICE FIELD TRIAL

After the lab testing, it was decided to carry out service trials with B10 biodiesel blends. The trials were carried out on a locomotive hauling Jan-Shatabdi Express between Lucknow and Allahabad. In all 3 round trips were done using B10 blend of biodiesel as a fuel. It was seen that there was no problem experienced during these runs. The locomotive did not lose any time and maintained full horsepower during the run. These trial runs were a significant step forward compared to the singe trial run done on the Delhi-Amritsar Shatabdi in December, 2002 with a 5% blend of biodiesel.

Despite the successful trial runs, it would be necessary to carry out an extended trial on 5 locomotives for a period of 6 months. This will enable us to analyze the long term effect of the fuel on various engine components and the lubricating oil. Using 10% blend of biodiesel will serve to substitute 144 Kl of petrodiesel.

8.0 TECHNICAL TASKS AHEAD

The observations made after detailed testing indicate a very encouraging potential for possible usage of high blends of bio diesel in the range of B20 to B50 depending on indigenous availability of bio diesel. This would however have to be ratified through extended field runs for a reasonable period.

The tests have also shown the potential for use of B100, which of course will require detailed study, optimization and certain design and logistic modifications.

In this regard; the following course of action of further technical studies is proposed:

i. During the testing considerable data was collected of the emissions at various notches (engine power and speeds) and for various blends. However a more detailed study is required which includes sensitivity analysis. For instance, it was seen that the Nox emissions varied with respect to the ambient temperature. The ambient temperature essentially governs the temperature of the inlet air to the turbo super charger. Variations in temperature of the inlet air effects the turbo charger performance and consequently plays a role in determining the extent of Nox emissions. A more elaborate study is required to determine the exact influence of ambient temperature using the inlet air temperature as a control parameter.

ii. The Nox emissions generally tend to increase with the use of bio diesel because the Nitrogen present in the inlet air combines with the inherent Oxygen in the bio diesel. Bio diesel contains nearly 10% Oxygen in its molecular composition and this Oxygen while combining with the Nitrogen in the inlet air results in higher Nox emissions. To optimize the combustion process and minimize the Nox emissions it is considered appropriate to develop the technique by which the oxygen present in biodiesel can be inhibited from combining with Nitrogen and instead be made to react with the fuel hydrocarbons for superior combustion.

iii. Since the exhaust gas temperature reduces with the use of biodiesel, there is a scope available to reduce the SFC by reducing the throat area of the nozzle ring of the turbocharger. Optimization of the nozzle ring throat area is to be undertaken.

ANNEXURE -1

Trial Scheme

LAB TESTING

In order to establish the parameters of bio diesel that has been received from M/s Pure Energy Corporation/USA, two litres each of B100 would be provided to the R&D Labs of IOC, BP as well as M&C Lab in RDSO to carry out the testing as per ASTM 6751. The testing would be done as per the prescribed tests specified in the standard and the critical properties of the fuel would be assessed against the specified limits.

2.0 TEST BED TESTING SCHEME FOR BIODIESEL

2.1 Objective

Performance evaluation of 10%, 20%, 50%, 100% blends of bio diesel in HSD oil on the 3100 hp engine test bed.

2.2 Parameters to be measured

i) Specific fuel consumption g/BHP-hr.
ii) Horse power.
iii) Exhaust gas temperature at cylinder heads and turbine inlet.
iv) Firing pressures.
v) P- θ curve plotting
vi) Exhaust emission (NO_x, CO, HC, PM)

2.3 Engine configuration

The engine configuration that shall be used during the testing is as follows:

1.	Engine	16 cylinder DLW fuel efficient
2.	Turbo	ABB VTC-(3100 hp)
3.	Pistons	M/s Mahle Germany (11.75 CR)
4.	Ring pack	M/s Kaydon's F.E. ring pack
5.	Manifold	Stream line – 3 entry
6.	After cooler	Large After cooler
7.	Camshaft	140^o valve overlap
8.	Fuel injection pump	17 mm plunger diameter, 157^o nozzle spray angle having 0.350 mm dia holes
9.	Lube oil cooler	Flemrings – 3100 HP

2.4 Methodology

Stage 1: A base line test data would be generated with regular petro diesel.

Stage 2: A 10% blend of biodiesel with petro diesel would be used on the engine and data as per the above mentioned parameters would be generated.

Stage 3: A 20% blend of biodiesel with petro diesel would be used on the engine and data as per the above mentioned parameters would be generated.

Stage 4: A 50% blend of biodiesel with petro diesel would be used on the engine and data as per the above mentioned parameters would be generated.

Stage 5: 100% Biodiesel would be used on the engine and data as per the above mentioned parameters would be generated.

Stage 6: Optimisation studies – by advancing the injection timing 1 degree at a time to ascertain impact on firing pressures and SFC.

Stage 7: The base line test would be repeated with regular petro diesel

2.5 Duration of testing

Each blend shall be tested for a duration of 5 hours. The readings shall be taken at each notch once the control parameters viz. rpm and load have stabilized. The whole cycle normally takes approx. 4 – 5 hours.

The measurable parameters viz. sfc, hp etc as mentioned in 2.2 shall be measured at the following speed (rpm) and loads:

	Control Parameters	
NOTCH	**RPM**	**LOAD (N)**
8th.	1050 ± 3	21600 ± 50
7th.	950 ± 3	19082 ± 50
6th.	850 ± 3	16018 ± 50
5th.	750 ± 3	13826 ± 50
4th.	650 ± 3	10616 ± 50
3rd.	550 ± 3	8138 ± 50
2nd.	450 ± 3	5471 ± 50
1st	350 ± 3	2984 ± 50
IDLE	350 ± 3	2131 ± 50

2.6 Quantity of fuel required

TEST (5 hrs. Run)	**Blends**	**QUANTITES REQUIRED (Litre)**		
		HSD OIL (Plain)	**BIO DIESEL**	**TOTAL**
Base Line	-	1700	-	1700
Test 1 (2 days)	10 %	1530 x 2	170 x 2	3400
Test 2 (2 days)	20%	1360 x 2	340x 2	3400
Test 3 (2 day)	50%	850 x 2	850 x 2	3400
Test 4 (1day)	100%	-	1700	1700
Optimisation test (1 day – 2 times)	20%	660 x 2	190 x 2	1700
Base Line	-	1700	-	1700
Additional bio diesel for contingency			200	
Total Bio diesel requirement			**5000**	

Note: the optimization study shall only be done on the 8th notch by advancing the injection timing to 26.5 degree and 27.5 degrees before TDC respectively.

Optimisation studies

During the initial testing in RDSO, it was seen that the firing pressures with a 20% blend of bio diesel reduced by as much as 100 psi. This was coupled with an increase in Specific Fuel Consumption of 1 to 1.5%.

Hence engine thermodynamics dictates that for optimising the performance, the timing should be advanced. At present the timing for fuel injection is 25.5 degree before TDC. Now the timing would be advanced 1 degree at a time to 26.5 and 27.5 degrees before TDC.

2.7 Blending Procedure

The blending of bio diesel shall be done in the overhead tanks of engine development directorate. For this purpose 2 tanks of 5 Kl have already been cleaned and kept in readiness. These shall first be filled with petro diesel. Then the required amount of bio diesel shall be pumped into the tanks to create the blend.
e.g. for creating a blend of 5% bio diesel, initially 2850 litres of petro diesel shall be pumped into the tank. Subsequently the 150 litres of bio diesel shall be pumped into the tank. This procedure is as per the norms and will make a homogenous blend of 5 % bio diesel in petro diesel.

ANNEXURE-2

A Summary of EngineTest Bed Results
(as reported by ED Directorate, RDSO)

Notch	% Blend	Corrected HP/RPM	Ambient Temp	Corrected BSFC (gm/bhp-hr)	Fuel Line Pressure (bar)	Firing Pressure (psi)	NOx	Exh.gas Temp°C
8th	0	3100/1050	36.96	153.68	927.12	1648.31	1422	516.9
	10		32.05	155.37	936.80	1650.25	1266	510.7
	20		34.62	156.11	948.72	1644.34	1480	--
	50		37.86	162.15	971.05	1631.47	1553	483
	100		35.75	174.00	1015.43	1652.20	1491	486.6
	100*		29.88	172.95	1025.85	1690.25	1496	483.27
	0*		29.46	153.02	953.93	1685.50	1276	492.09
	50*		32.74	161.77	970.61	1681.40	--	494.95
	10**		30.2	154.16	955.42	1762.90	--	480
	20**		33.2	156.22	964.79	1741.34	--	493.18
	10***		36.42	157.24	1113.26	1637.59	--	526.7
	10****		38.5	155.42	948.7	1712.96	--	509.5
	10*****		32.89	153.65	898.6	1810.4	1389	489.13
7th	0	2500/950	--	152.43	725.35	--	1511	--
	10		--	154.04	722.44	--	1367	--
	20		--	155.27	736.97	--	1590	--
	50		--	160.94	767.20	--	1658	--
	100		--	173.25	812.61	--	1647	--
	10*****		--	152.16	693.0	--	1490	--
6th	0	1870/850	--	156.34	638.84	--	1669	--
	10		--	157.62	637.53	--	1537	--
	20		--	158.98	649.56	--	1769	--
	50		--	165.24	640.33	--	1826	--
	100		--	177.71	710.46	--	1804	--
	10*****		--	155.37	624.0	--	1622	--
5th	0	1430/750	--	161.62	585.97	--	1891	--
	10		--	163.33	580.02	--	1760	--
	20		--	164.79	548.89	--	1980	--
	50		--	171.37	627.97	--	2015	--
	100		--	185.20	635.26	--	1970	--
	10*****		--	161.75	549.3	--	1853	--
4th	0	950/650	--	167.86	482.93	--	2166	--
	10		--	168.58	500.80	--	2004	--
	20		--	170.31	509.28	--	2201	--
	50		--	176.93	477.42	--	2215	--
	100		--	192.37	492.01	--	2127	--
	10*****		--	168.91	450.5	--	2075	--
3rd	0	615/550	--	173.64	439.15	--	2113	--
	10		--	174.71	438.11	--	1919	--
	20		--	176.14	426.34	--	2148	--
	50		--	181.18	460.74	--	2173	--
	100		--	198.75	503.77		2043	
	10*****		--	177.47	424.8		1990	

(Contd)

Notch	% Blend	Corrected HP/RPM	Ambient Temp	Corrected BSFC (gm/bhp-hr)	Fuel Line Pressure (bar)	Firing Pressure (psi)	NOx	Exh.gas Temp°C
2nd	0	330/450	--	186.29	383.46		1521	
	10		--	186.79	365.44		1304	
	20		--	187.60	358.74		1537	
	50		--	191.73	388.07		1511	
	100		--	213	364.24		1376	
	10*****		--	192.14	351		1295	
1st	0	145/350	--	209.89	353.82		1056	
	10		--	209.25	350.99		902	
	20		--	208.76	331.92		1007	
	50		--	212.88	354.42		1001	
	100		--	240.22	366.85		870	
	10*****		--	218.27	331.5		923	
Idle	0	105/350	--	233.94	283.39		789	
	10		--	229.08	272.07		664	
	20		--	237.46	290.83		726	
	50		--	232.29	292.62		791	
	100		--	258.54	315.85		627	
	10*****		--	240.90	272.1		732	

* - with 2°retarded injection timing
** - with 2°advanced injection timing
*** - with 0.32 mm nozzle
**** -with 0.34 mm nozzle
***** -with 139 mm nozzle ring of turbo

As can be seen from the table above, the engine maintained full horse power with all the bio diesel blends including pure bio diesel i.e. B100.
The specific fuel consumption of the engine increased from 153.68 g/bhp-hr to 174 g/bhp-hr, an increase of 13.2%.
The exhaust gas temperature in general showed a down ward trend.
The firing pressure did not change significantly.

ANNEXURE-3

SUMMARY OF FIELD TRIAL OF BIO DIESEL

Train N0 2054- LKO-ALD, 2053-ALD-LKO Jan Shatabdi Express

Loco No 18647 / WDM2/AMV Diesel Shed / N.Rly.

Date	Train No.	Departure	Arrival	Type of fuel	HSD consumption in litre
13.05.04	2054	LKO-6.00	ALD-10.20	Normal HSD	550
13.05.04	2053	ALD-15.20	LKO-19.30	Normal HSD	600
14.05.04	2054	LKO-6.00	ALD-10.20	10% BIO	750
14.05.04	2053	ALD-15.20	LKO-19.30	10% BIO	770
15.05.04	2054	LKO-6.00	ALD-10.20	10% BIO	700
15.05.04	2053	ALD-15.20	LKO-19.30	10% BIO	700
	2054	LKO-6.00	ALD-10.20	10% BIO	700
17.05.04	2053	ALD-15.20	LKO-19.30	10% BIO	700
21.05.04	2054	LKO-6.00	ALD-10.20	Normal HSD	550
21.05.04	2053	ALD-15.20	LKO-19.30	Normal HSD	600
22.05.04	2054	LKO-6.00	ALD-10.20	Normal HSD	600
22.05.04	2053	ALD-15.20	LKO-19.30	Normal HSD	700

- Total route is 202 KM from Lucknow to Allahabad.
- GTKM per trip is 110550.
- Nothing unusual was noticed during the above trial trips on the engine or locomotive.
- No external leakage of fuel oil was observed from the engine during above trial trips.