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**REPORT ON**  
**INVESTIGATIONS OF DIESEL ENGINE PERFORMANCE**  
**ON STRAIGHT VEGETABLE OIL**

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## Abstract

*The experiment sought to examine the feasibility of using straight vegetable oil (SVO) as a fuel for Kirloskar Oil Engines genset applications. A fresh 4R1040NA engine was tested using both diesel and SVO at Corporate Research and Engineering, Kirloskar Oil Engines Ltd., Pune, and a comparison of the two fuels was done. Based on the initial test, some settings were readjusted and the engine was subsequently tested with these changes. A brief introduction to the need for alternatives fuels and to SVO is followed by the experimental procedure and results. The results are then discussed and conclusions and recommendations given.*

*Performance on SVO was satisfactory, with small drops in power and efficiency, but a large reduction in smoke. While the use of SVO for commercial purposes is some way off, the results were encouraging. A maximum efficiency of 38.5% was recorded for SVO, as against 44.5% for diesel. A measurement of smoke showed smoke to be significantly lower for SVO, while the engine generally performed slightly better on diesel.*

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## 1. Introduction

India currently imports 73 percent of its crude oil requirement to meet energy demands and its crude oil import bill rose by 45 per cent to 29.322 billion US dollars in April-October this fiscal from \$ 21.165 billion in the same period last year, as international crude prices touched a record 76 dollars a barrel<sup>(1)</sup>.

Jeffrey Rubin, chief economist, Imperial Bank of Commerce predicts that oil prices will reach \$100 a barrel by late 2007. India's Finance Minister, P. Chidambaram, reacted angrily to the recent increases, saying oil producers were exploiting already impoverished nations, and that India was being robbed of at least 1 percent GDP as oil prices soared.

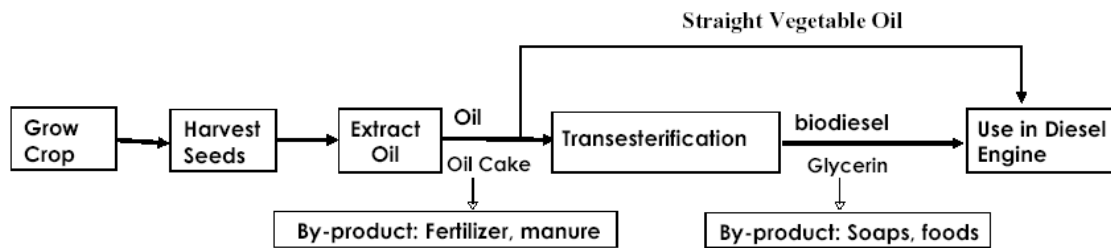
Many industrialised countries, particularly Germany and Australia have invested heavily in the use of vegetable oils as an alternative to diesel. The Australian biodiesel industry has grown in just six years to a capacity of over 100 million litres per annum<sup>(2)</sup>. Similar work has been initiated in India, but the local industry has a long way to go before alternative fuels are available in commercial quantities.

Environmental concerns are also a large driving force behind the push for alternative fuels. Recent emphasis on cutting emissions has forced engine manufacturers to explore cleaner, greener fuels. The concept of carbon credits is seen as an incentive to develop environmentally friendly fuels. India is considered as the largest beneficiary, claiming about 31% of the total world carbon trade through the Clean Development Mechanism (CDM), which is expected to rake in at least \$5-10bn over a period of time<sup>(3)</sup>.

Some renewable fuels are "carbon neutral" – a term that means the net amount of carbon released to the atmosphere is zero, taking into account both engine emissions and carbon absorbed from the atmosphere for photosynthesis. Although SVO's emissions have not had as much study as biodiesel's, it is believed SVO will have similar emission characteristics: no sulphur, much lower unburnt hydrocarbons, lower carbon monoxide and particulates, and slightly elevated nitrogen oxides<sup>(4)</sup>. Additionally, today's emissions are consumed by tomorrow's vegetable crop plants, leading to "Zero CO<sub>2</sub>" vehicles.

The major disadvantage of SVO is its high viscosity. Sometimes, the hot oil flows into a cooler injection pump (which is often mounted away from the engine, and thus thermally isolated), where it cools down and gels, causing damage. Injectors and piston rings can collect carbon deposits (coke)<sup>(5)</sup>. Heating the fuel solves the problem, and at approximately 80°C, its viscosity is only slightly above that of diesel.

Bio-fuels in India may be obtained from crushing the seeds of both *Pongamia Pinnata* (Karanja or Honge) and *Jatropha Curcas*. Debate exists as to which is more suitable for the purpose of getting SVO, but this report focuses entirely on Karanja oil. *Pongamia Pinnata* is a fast growing deciduous tree that grows up to 25m tall and has a trunk diameter of 0.6m<sup>(6)</sup>. A flowchart for the production of SVO is shown in Figure 1.1.



**Figure 1.1 Biodiesel and SVO production and use.**

**(from: “India’s Unique Sources of Fuel for Electricity and Transportation”, Deepak Rajagopal, Ayesha Khan and KJ Yoo, RAEL Lunch Talk, 2005)**

The advantage of SVO over bio-diesel is that SVO does not need the chemical process of transesterification nor the removal of glycerin, which are both expensive. The methanol that is used in bio-diesels comes from fossil fuels, which is why today’s bio-diesel is not completely sustainable. Ethanol may be used instead, but it complicates the process.

## 2. Methodology

A fresh KOEL 4R1040NA (56hp) engine was obtained from the production line and installed on the test dynamometer ( Figure 2.1). Initial running in was completed, followed by comprehensive base line mapping on high speed diesel to establish a yardstick.



Figure 2.1 KOEL 4R1040NA on dynamometer

Once base line testing on diesel was completed, testing on SVO commenced. Testing was carried out on room temperature SVO, but provisions were made for heating the fuel should it be required. The heater used was a KIM HotStart TPS152GT12-000 Tank Heater (Figure 2.2), which operated between the temperatures of 48°C and 60°C. Although the heater was designed to be an engine coolant heater, it was sufficient for our purpose.

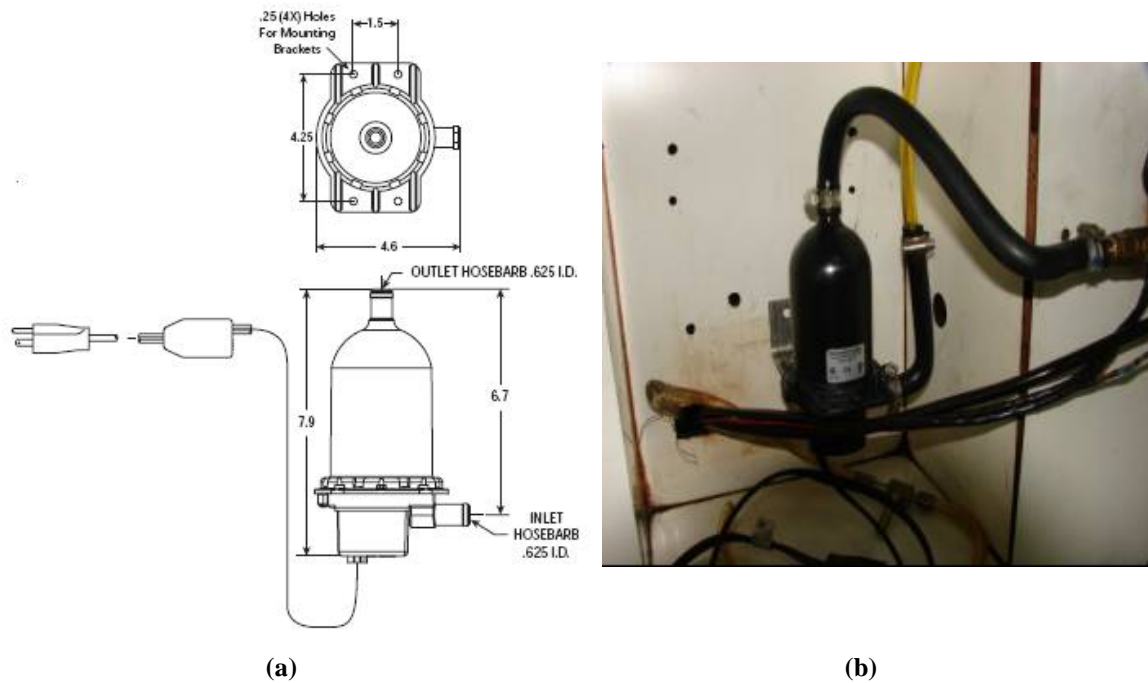
After this initial test on SVO, the rack setting was changed to set the RPM at 1500 for full load. The engine was then retested on this new setting.

Karanja oil is a very viscous fluid at room temperatures. Therefore, engines running on SVO should be started on diesel, switched to SVO once steady state operating conditions have been reached, and then run for a short time on diesel before stopping to remove any SVO remaining in the system. One particular area of concern was the injectors, which were potentially parts that could suffer clogging.

The following values were measured and recorded:

- 1) Engine RPM
- 2) Dynamometer Load
- 3) Fuel Temperature
- 4) Engine Coolant temperature
- 5) Exhaust Gas Temperature
- 6) Ambient Temperature
- 7) Exhaust Gas Opacity
- 8) Engine oil temperature

Thermocouples were used to measure all temperatures. A Bosch smoke gun was used to measure the smoke in Bosch Smoke Units (BSU). More advanced emission testing was not possible as the CRE Emissions Laboratory was not equipped to test for alternative fuels.



**Figure 2.2** TPS152GT12-000 Tank Heater (a) diagram and (b) installed.

(Figure 2.2a from Kim Hotstart, [http://www.kimhotstart.com/kimhotstart/uploads/documents/products/tps\\_models.pdf](http://www.kimhotstart.com/kimhotstart/uploads/documents/products/tps_models.pdf))



Figure 2.3 Instrumentation board



Figure 2.4 Thermocouple electrical connections

Specific fuel consumption was measured using an electromechanical device that digitally measured the exact amount of fuel consumed (Figure 2.5). Measuring was problematic at high engine loads because of the SVO, but manipulation of the load setting solved the problem.



Figure 2.5 Measuring fuel consumption



### 3. Results and Discussion

#### Specific Fuel Consumption

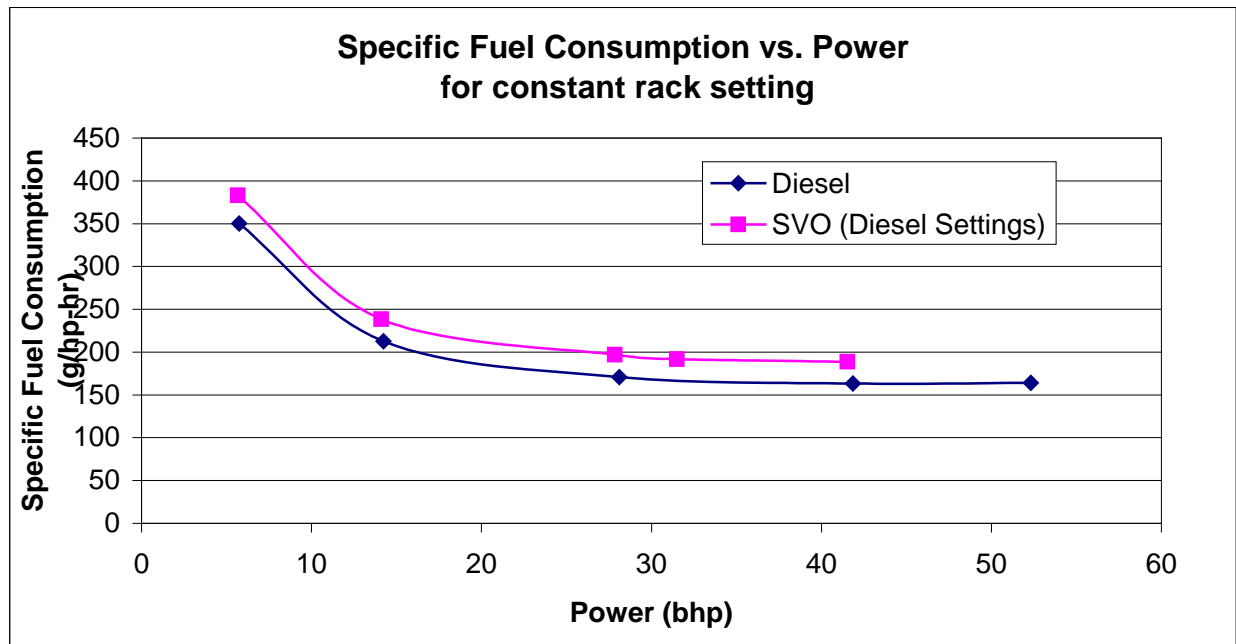
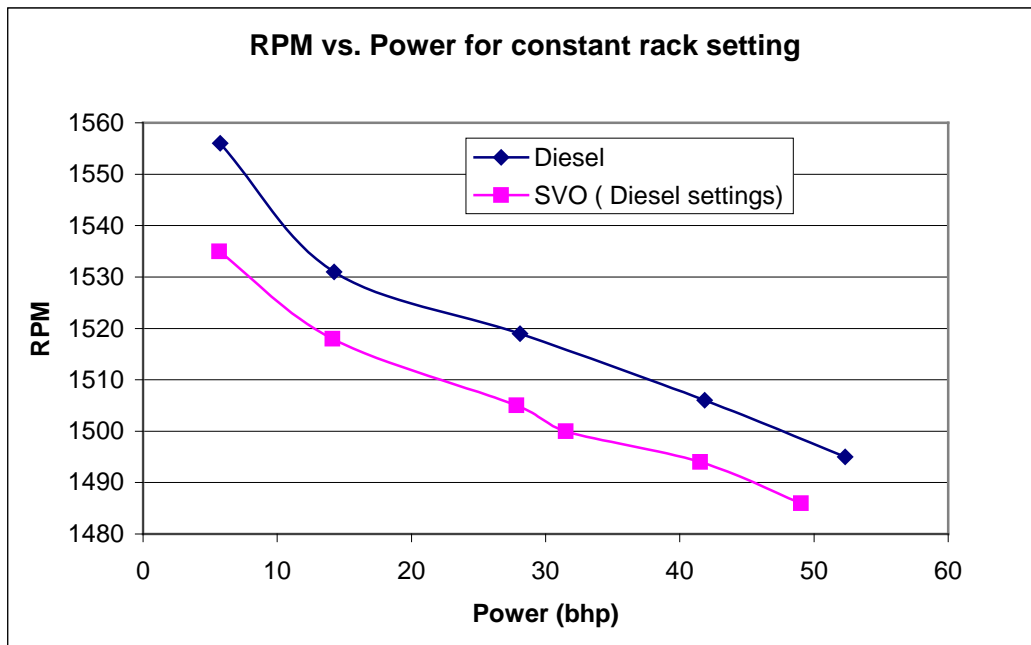


Figure 3.1 Specific Fuel Consumption vs. Power for constant rack setting

Figure 3.1 shows how specific fuel consumption, SFC varies with power for two different fuels. It is observed that SFC reduces as load increases, becoming almost constant at high loads, and that the engine has a greater SFC when operating on SVO as compared to diesel. This is caused by the lower calorific value of SVO on mass basis.

## RPM



**Figure 3.2 RPM vs. Power for constant rack setting**

Figure 3.2 shows the relationship between engine speed, RPM and power with a constant rack position. Engine RPM on SVO is consistently lower than diesel, and drops as load increases. This is because engine consumes more fuel when operated on SVO to deliver the same torque and the governor settles at lower speed to compensate.

## Volumetric Fuel Consumption

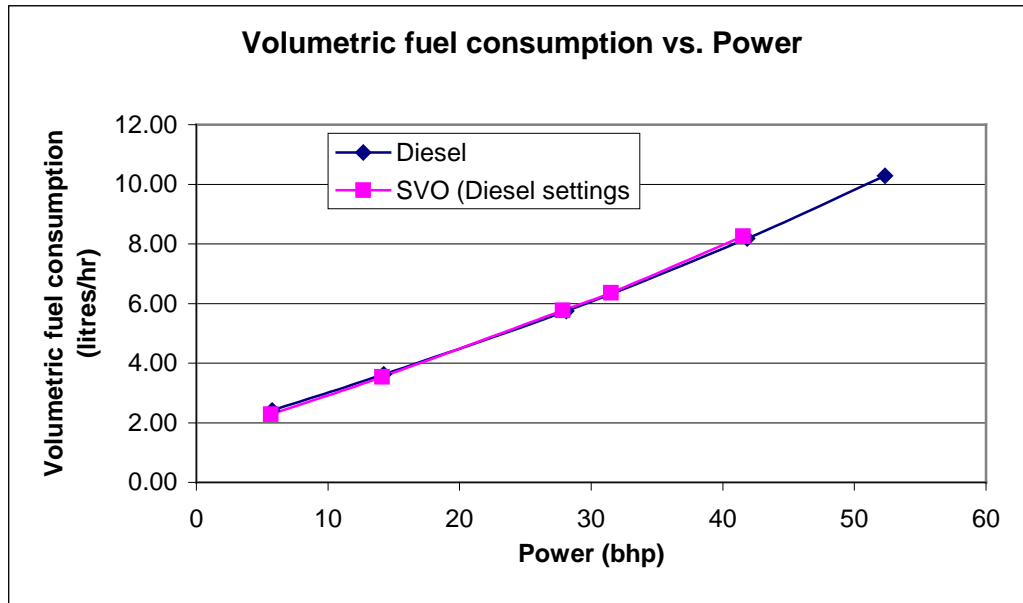


Figure 3.3 Volumetric fuel consumption vs. Power

Figure 3.3 shows the variance of volumetric fuel consumption with increasing power. As expected, consumption increases almost linearly with BHP. The values for SVO and diesel are similar, with only minor variations. The higher specific gravity of the SVO compensates for its lower calorific value, giving similar volumetric fuel consumption.

## Smoke

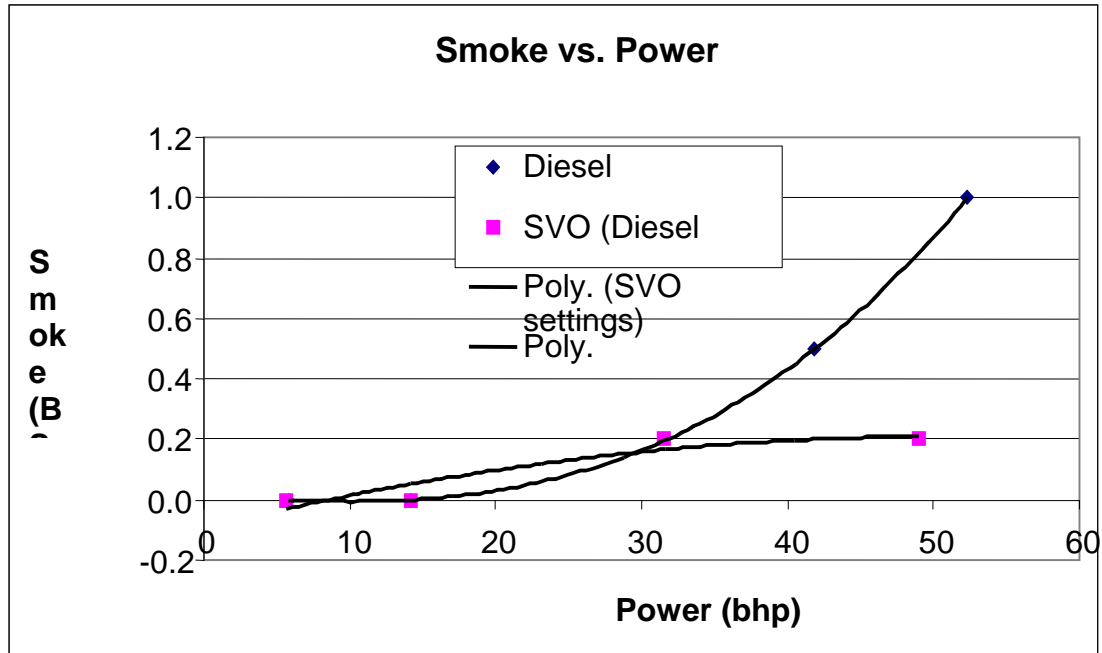
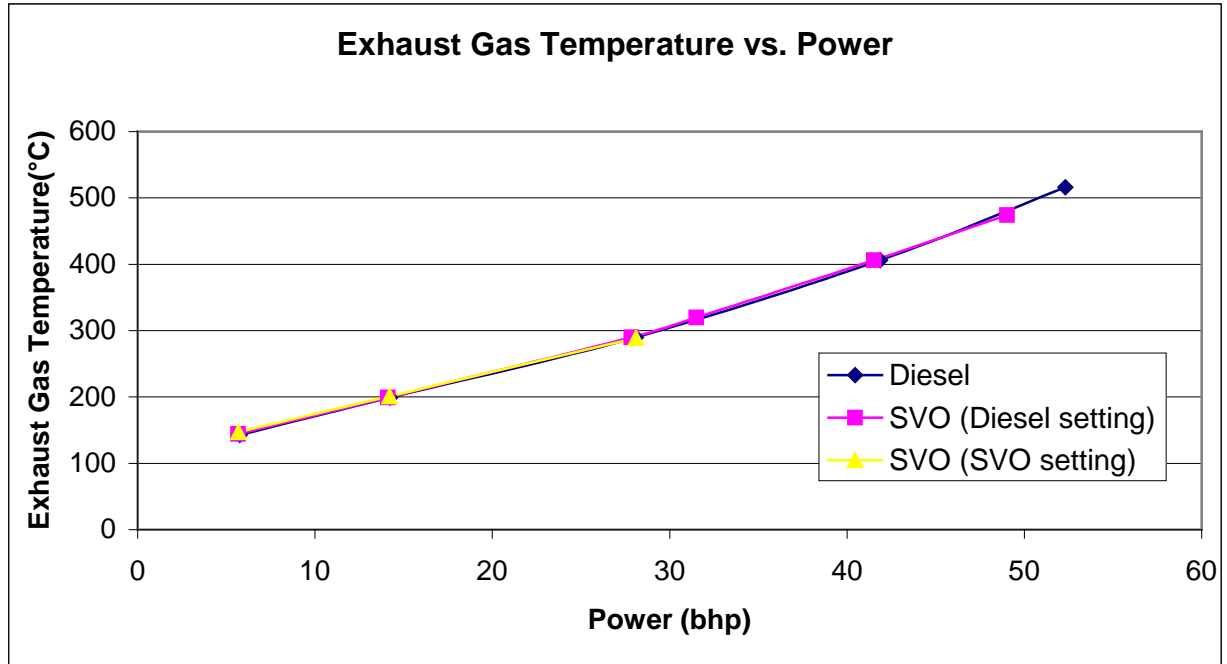


Figure 3.4 Smoke vs. power

Figure 3.4 shows the trend of smoke increasing as power increases. The smoke is significantly less for SVO, and is only one-fifth of the smoke on diesel at 50BHP. Less smoke is generally a good indicator of lower hydrocarbon and particulate emissions, but cannot be used to judge NO<sub>x</sub> emissions.

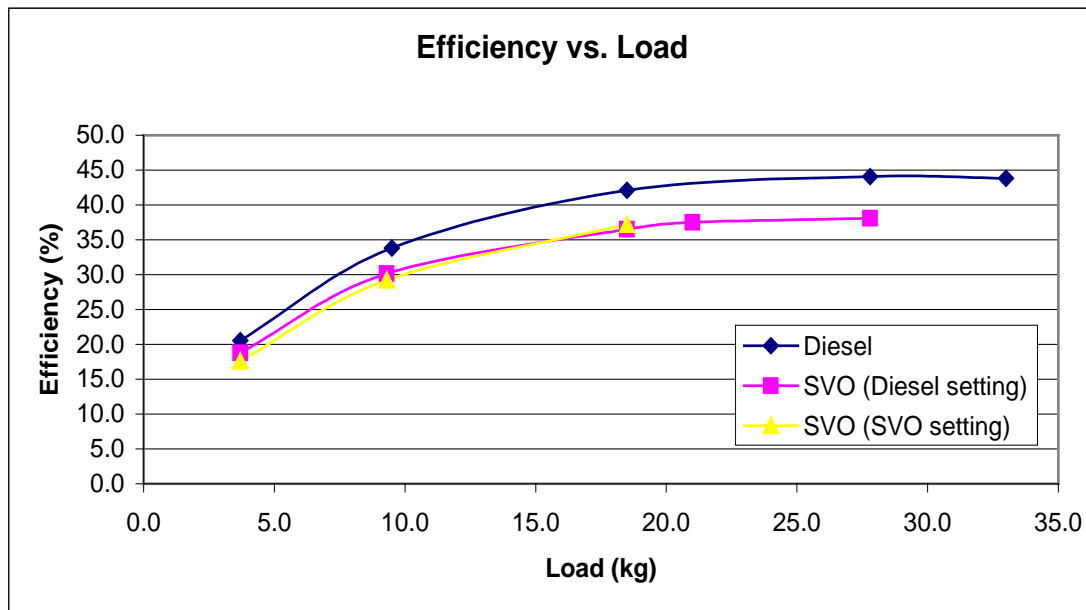
## Exhaust Gas Temperature



**Figure 3.5 Exhaust Gas Temperature vs. Power**

Figure 3.5 shows the relationship between exhaust gas temperatures and power. Exhaust temperature increases with load, and is similar for both SVO and diesel, indicating that the nature of combustion is similar with both fuels.

## Efficiency



**Figure 3.6 Efficiency vs. Load**

Figure 3.6 shows the efficiencies of diesel and SVO run engines at different loads. Efficiencies are maximum at approximately 75% load. Efficiency for SVO on both settings is consistently lower than diesel, but the differences are not large. One reason for the reduced efficiency is the greater amount of power required to drive the more viscous fuel through the fuel pump.

## 4. Recommendations

### 1. Use a heat exchanger

Karanja oil is a very viscous fluid at room temperatures. No heating was required for this test because of the high ambient temperature, but heating will be both necessary and beneficial at lower temperatures.

A heat exchanger that operates with engine coolant as hot fluid and SVO as cold fluid will serve the purpose.

### 2 Engine Optimisation.

All tests were carried out on an unmodified 4R1040NA KOEL engine. While performance was satisfactory, it could be greatly improved by the following changes:

- Fuel Timing Optimisation
- Increase in Fuel Injection Pressure
- Larger injector nozzles
- Modification of combustion chamber
- Modification of Inlet Ports

### 3. Emission Testing at Automotive Research Association of India ( ARAI)

No emission tests were done because the CRE Emissions Laboratory was not equipped to test for alternative fuels. While the smoke test was encouraging, it is by no means a conclusive test. As better emissions is one of the driving forces behind the use of SVO, it is recommended that further testing be carried out at ARAI.

### 4. Endurance testing

Previous tests carried out elsewhere suggest that the continued use of SVO wears out piston rings, clogs injectors and reduces the life of rubber hoses. Long term testing was not possible given the time frame of this project, but subsequent tests should fulfill this requirement.

## 5. Conclusion

As seen from the test results, the engine may be operated on SVO (at ambient conditions in Pune) without modifications. Overall efficiencies were 44.5% (diesel) and 38.5% (SVO), and SVO RPM values were consistently lower than diesel for the same load. Volumetric fuel consumption was similar, but the smoke emissions were considerably lower for SVO ( at maximum load, smoke was 0.2 BSU for SVO and 1.0 BSU for diesel). Exhaust gas temperatures were similar for the two fuels.

While performance is satisfactory, it may be further improved by implementing the recommendations. The initial tests are promising, and further investigation is highly recommended.



## References

1. Chennai Online news Service, January 17<sup>th</sup>, 2007.  
<http://www.chennaionline.com/colnews/newsitem.asp?NEWSID=%7B5DDD7D0D-A421-4492-A94E-7E1AA3FEB956%7D&CATEGORYNAME=Business>
2. Biodiesel Association of Australia, <http://www.biodiesel.org.au/>
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5. “Sustainable Energy from vegetable Oil”, Jan Steinman, 12<sup>th</sup> Jan 2005, BC Sustainable Energy Association.
6. “Variation in Oil Content of Pongamia Pinnata as Influenced by Agro-ecozones and Soil Types of Tamil Nadu”, K. Kumaran, K.T. Parthiban and M. Paramathma, 2003, Proceedings of the National Workshop in Pune, India.

## Appendices

Appendix I – Engine Data

Appendix II – Tables of results

## Appendix I - Engine data

**Engine:** 4R1040NA  
**No. of cylinders:** 4  
**Rating:** 56 HP @ 1500 RPM  
**Bore X Stroke :** 105\*120  
**Assly No:** 12-1662  
**Fuel Timing:** 15° BTDC  
**FIP Sr. No:** 69225044 ( 376)  
**Tests conducted at CRE, KOEL from Jan 22nd to Jan 24th 2007**

## Appendix II – Tables of results

### Diesel

No.	Time min	% Load	Load kg	RPM	BHP	Time s	SFC gm/hp-hr	Air Temp		Water Temp		Lub Oil Pressure kg/cm <sup>3</sup>	Lub Oil Temp ° C
								° C		° C			
								Room	A/C	Inlet	Outlet		
1	5			644.0									
2	10			1565.0									
3	60	10%	3.7	1556	5.75	74.6	350.39	29.4	32.2		76.8	5.1	87.6
4	60	25%	9.5	1531	14.23	49.7	212.52	29.5	32.5		76.4	5.0	88.6
5	60	50%	18.5	1519	28.1	31.3	170.89	28.8	31.2		77.2	4.9	90.6
6	60	75%	27.8	1506	41.86	22	163.21	27.8	30		77.8	4.8	92
7	60	100%	33.0	1495	52.32	17.5	164.15	26.7	28.6		79.2	4.7	93.5
8	30	100%	33.0	1500	49.5	18.8	161.50	30.6	35.4		77.4	5.4	77.8
9	30	100%	33.0	1500	49.5	18.8	161.50	30.6	35.4		77.7	5.0	90.5

No.	Time min	% Load	Exhaust Temp ° C	Smoke Bosch	Fuel Temp ° C	Volumetric Consumption litres/hr	BSEC MJ/hp-hr	Efficiency %
1	5							
2	10							
3	60	10%	143	0.0	40.2	2.41	12.91	20.5
4	60	25%	199	0.0	42.1	3.62	7.83	33.8
5	60	50%	290		42	5.75	6.30	42.1
6	60	75%	406	0.5	42.2	8.18	6.01	44.1
7	60	100%	516	1.0	42.1	10.29	6.05	43.8
8	30	100%	471	0.3	32.6			44.5
9	30	100%	483	0.3	38			44.5

**Table 1. Results of Diesel test**

SVO on Diesel Settings

No.	Time min	% Load	Load kg	RPM	BHP	Time s	SFC gm/hp-hr	Air Temp		Water Temp		Lub Oil Pressure kg/cm <sup>3</sup>	Lub Oil Temp ° C
								° C		° C			
								Room	A/C	Inlet	Outlet		
1	60	10%	3.7	1535	5.67	78.7	383.21	29.9	33.7		75.2	5.2	87.6
2	60	25%	9.3	1518	14.11	50.8	238.56	29.9	33.6		76.6	5.0	88.1
3	60	50%	18.5	1505	27.84	31.2	196.87	30.2	34.8		76.6	5.0	88.8
4	60	60%	21.0	1500	31.5	28.3	191.82	30.5	34.8		76.7	5.0	89.5
5	60	75%	27.8	1494	41.53	21.8	188.88	31.4	36.5		77.3	5.0	90.5
6	60	100%	33.0	1486	49.03			31.8	35.6		77.6	5.0	91.4
1500 RPM rack adjust on full load													
7	60	100%	33.0	1500	49.5			32	36.7		77.4	5.0	90
No.	Time min	% Load	Exhaust Temp ° C	Smoke Bosch	Fuel Temp ° C	Volumetric Consumption litres/hr	BSEC MJ/hp-hr	Efficiency %					
1	60	10%	144	0.0	39.6	2.29	14.12	18.8					
2	60	25%	199	0.0	41.2	3.54	8.79	30.1					
3	60	50%	290		39.3	5.77	7.25	36.5					
4	60	60%	320	0.2	39.1	6.36	7.07	37.5					
5	60	75%	406		37.8	8.26	6.96	38.1					
6	60	100%	474	0.2	36.3								
1500 RPM rack adjust on full load													
7	60	100%	465	0.2	37.5								

**Table 2. Results of SVO on Diesel settings test**

SVO on SVO settings

No.	Time min	% Load	Load kg	RPM	BHP	Time s	SFC gm/hp-hr	Air Temp ° C		Water Temp ° C		Lub Oil Pressure kg/cm <sup>3</sup>	Lub Oil Temp ° C	
								Room	A/C	Inlet	Outlet			
1	60	10%	3.7	1537	5.68	73.7	408.49	32	35.8		75.6	5.0	87.6	
2	60	25%	9.3	1529	14.21	48.9	246.09	31.5	35.6		76	5.0	87.9	
3	60	50%	18.5	1519	28.1	31.5	193.19	31.7	36.5		76.5	5.0	88.5	
4	60	75%	27.8	1506	41.86			31.1	36.6		77.3	4.9	89.5	
5	60	100%	33.0	1500	49.5			32.5	36.8		77.6	4.8	91.5	
6	60		34.0	1505	51.17	41.5	161.05	29.5	32.8		77.6	4.9	90	
7	60		35.0	1500	52.5	42.3	154.00	29.5	32.8		77.6	4.9	90.4	
8	60		37.0	1500	55.5	16.5	186.73	29.4	32.5		78.1	4.9	92.2	
No.	Time min	% Load	Exhaust Temp		Smoke		Fuel Temp		Volumetric Consumption		BSEC		Efficiency	
			° C		Bosch		° C		litres/hr		MJ/hp-hr		%	
1	60	10%	147				42.8		0.68		15.05		17.6	
2	60	25%	201				44.2		1.02		9.07		29.2	
3	60	50%	289				41.8		1.59		7.12		37.2	
4	60	75%	400				39.6							
5	60	100%	489				37.6							
6	60		485		0.1		34.6		1.20		5.93		44.7	
7	60		500		0.1		34.4				5.67		46.7	
8	60		541				37.3				6.88		38.5	

**Table 3. Results of SVO on SVO settings test**