Non-edible oils and blends in Direct Injection Diesel Engines

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Introduction

Since the calorific value and Cetane number of the non-edible oils in their pure form are comparable to diesel oil, the changeover is considered relatively simple; however, the impediments are their high viscosity. In the light of this, the present study is conducted in order to investigate engine performance and the exhaust emissions using various non-edible oils as fuel, in pure form as well as their blends, in direct injection (DI) diesel engine. The primary aim is to arrive at a basic strategy that can be adopted for reducing emission levels using these fuels.

The basic strategies reported in the literature are: 1) Adaptation of the engine to the fuel by modifying engine to suit fuel properties (particularly its viscosity and Cetane number) by making engine adiabatic, changing lubricant/ coolant, lubrication system, increase injection pressure etc 2) Adaptation of the fuel to the engine by modifying physico-chemical properties by blending or trans-esterification. Utilizing these strategies in an appropriate way can lead to the most practical and economical methodology that can ease the required swift changeover from diesel to bio-derived oils.

Gopalkrishna and Rao (1985), Bhasker et al. (1992), Subramaniyam and Jayaraj (1994) have conducted engine tests using vegetable oils in a semi-adiabatic engine and have found reduced particulate emissions and increase in brake thermal efficiencies. Elsbett Engine [1] developed by a private engine researcher based on the first strategy is capable of utilizing raw vegetable oils.

However, this engine is about two and a half times more expensive. Although the trans-esterification of triglycerides is an established process for reducing fuel viscosity and improving Cetane number (Ma and Hanna, 1999, Srivastava and Prasad, 2000), it is not clear if it is essential for application in the rural areas. Keeping these facts in view, a more practical and economical strategy involving both the strategies needs to be explored. Blending of the fuel with alcohol will not only reduce viscosity but will oxygenate fuel

The Experiments

In the present investigation, ethanol, a bio-derivative, is used as a blender with various vegetable oils with primary aim of reducing viscosity and emissions. The volume of ethanol was restricted to 5 % in order to prevent expected deterioration of engine performance at peak load because of reduction of fuel heating value and cetane number, caused by addition of ethanol (heating value 22 ~ 25 MJ/kg).

Most pure vegetable oils have kinematic viscosity in the range of 30 to 40 cSt at 30 C, volumetric heating value in the range of 39 to 40 MJ/kg and cetane number in the range of 32 to 40 (Srivastava and Prasad, 2000). The blend with ethanol (5 %) have kinemtic viscosity in the range of 21 – 22 cSt

Fuel Type	Calorific Value, (MJ/kg)	Specific Gravity At 25 C	Viscosity at 27 C, N.s/m^2	Cetane No
Diesel	42.3	0.815	0.13	47[a]
Repeseed Oil	37.62	0.914	39.5	37.6[a]
Pongamia Oil	35.8	0.94	1.22	-
Jatropha oil	36.0	0.92	1.1	-
Esterified Jatropha	36.5	0.90	0.52	-

Table 1: Non-edible oil properties

It was physically observed that sprays of both, vegetable oil as well as their blends with ethanol, obtained at standard injection pressure of 180 bar was very coarse and contained large droplets in the spray core. When the spray was ignited, a lot of single particle combustion was physically observed, indicating larger droplets in the spray. This, however, had a reducing trend when injection pressure was increased up to 350 bar. A 3.5 kWe direct injection, naturally aspirated water cooled diesel engine (cylinder diameter of 80 mm and stroke of 110 mm with a compression ratio of 17 running at a nominal speed of 1500 rpm with the injection timing set at 13° was used in the present study: The nominal injector pressure was 180 atms.

The experimental set up is shown in the figure 1.

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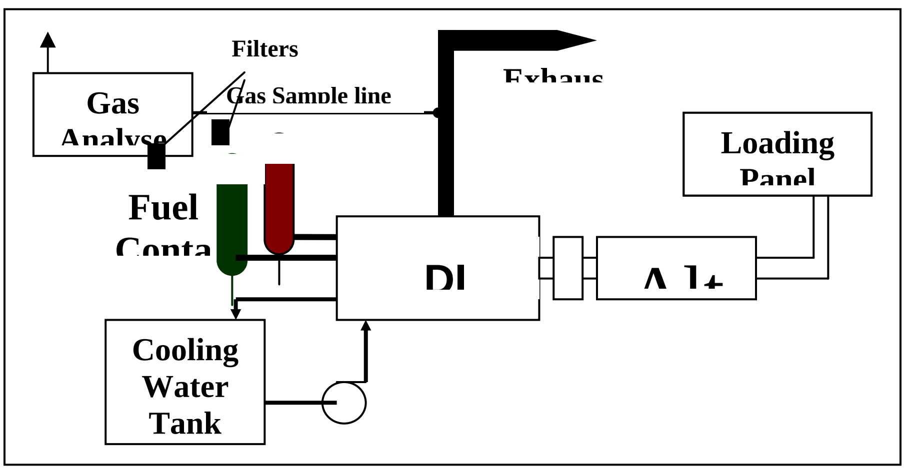


. **Figure 1: Schematic of experimental set-up under test**

Except for the change in injection pressure and timing, there were no changes made in the engine**.** Injection pressure was varied from 180 – 340 bars. A standard fuel nozzle tester was used to characterize the spray**.**

A Single Phase AC alternator was coupled to the engine main shaft and a resistance coils / light bulbs were used to load the engine. The fuel flow rate / consumption was directly measured by taking fuel level drop in a metering jar and corresponding timeset the injector pressure. The injection timing was based on the point of ejection of fuel from the three holes of the injector and not at the fuel pump exit plane, as is considered in common practice. This is due to the observed injection delay that sets in when injection pressure is increased in the range of present study. The observed difference is about 6° – 8° at 180 bars and this difference increases at higher pressure.

Fuel injection was advanced up to 35° by increasing the effective length of the fuel pump plunger by 1.8 mm without affecting it fuel-metering performance. Injection delay with respect to the maximum advance was obtained by introducing thin slip disk between the pump body and engine body.

A K-type thermocouple was used to measure exhaust gas temperature at the location close to the point from where sample gas was drawn for analysis. Quintox flue gas analyzer was used to measure CO, CO_2, O_2, NO_x, SO_x and HC (hydrocarbon) concentrations in engine exhaust. The gas was cooled, filtered and dried prior to analyses.

The vegetable oil and their blends were injected at room temperature. No emulsion stabilizers were added to fuel blends since the emulsion was prepared just before its use and was completely consumed. The fuel was filtered by allowing it to pass through the tandem of standard diesel filters prior to pumping.

Results and Discussions

The first sets of experiments were conducted in order to study effect of increasing injection pressure on engine exhaust emissions at varying loads. The injection delay was set to manufacturer's standard 13° BTDC. The vegetable oils used were Pongamia (Karanjia), Mahauva, Neem, Hippe and Rapeseed obtained from market. Experiments with cold and hot (70 C) caster oil were also successfully conducted. Oil from Cashew was also used however; this oil had very adverse effect on the fuel injection system causing immediate damage to the injector needle and fuel delivery valve.

Fuel	Diesel	Neem Oil	Neem Oil + 5% Ethanol
Load	Fuel Consumption (g/s)		
57%	0.15	0.24	0.25
86%	0.23	0.30	0.30
100%	0.27	0.31	0.32
	Heat input (kW)		
57%	6.8	9.3	9.4
86%	10	11.8	11.4
100%	11.8	12.2	12

Table 2: Fuel consumption of diesel, neem oil and its blend with 5 % ethanol.

Table 3, 4, 5 and 6 contain measured values of NO_x, HC (hydrocarbon), CO and SO_x obtained for pure pongamia oil, its blend with 5 % ethanol and pure diesel obtained at various engine loads at three injection pressures.

NOx Emissions

Electrical Load %	Fuel: Diesel NOx (g/MJ)			Fuel: 100 % Oil NOx (g/MJ)			Fuel: 95 % Oil / 5% Ethanol NOx (g/MJ)		
	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar
45	---	---	0.820	0.356	0.435	0.524	0.435	0.356	0.356
61	0.793	0.658	0.740	0.353	0.407	0.487	0.404	0.353	0.396
76	---	---	0.780	0.421	0.394	0.522	0.435	0.421	0.405
91	0.703	0.628	0.703	0.423	0.356	0.468	0.363	0.423	0.377
100	0.711	0.620	0.624	0.408	0.336	0.455	0.375	0.408	0.389

Table 3: Measured data of NO_x ($NO + NO_2$) obtained from engine burning pure pongamia oil, its blend with 5 % ethanol and pure diesel at various engine loads at different injection pressure.

As can be noticed from Table 3, the emission index for NO_X for vegetable oil and its blend with 5% ethanol are lower than for diesel oil.

In the case of diesel and pure vegetable at higher loads, the lowest value of NOx is obtained at 220 Bar injection pressure oil while it is not clear in the case of for the blended fuel.

Hydrocarbon Emissions

Electrical	Fuel: Diesel			Fuel: 100 % Oil			Fuel: 95 % Oil / 5% Ethanol		
Load	HxCx (g/MJ)			HxCx (g/MJ)			HxCx (g/MJ)		
%	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar
45	---	---	1.384	0.562	0.537	0.501	0.835	0.825	0.825
61	0.814	0.664	1.189	0.327	0.409	0.418	0.661	0.468	0.727
76	---	---	1.110	0.272	0.321	0.332	0.450	0.354	0.584
91	0.612	0.442	1.085	0.260	0.278	0.289	0.389	0.322	0.460
100	0.383	0.401	1.146	0.360	0.272	0.269	0.361	0.273	0.415

Table 5: Measured data of hydrocarbon obtained from engine burning pure Pongamia oil, its blend with 5 % ethanol and pure diesel at various engine loads at different injection pressure.

Hydrocarbon emission is low in the case of 100 % oil and its blend as compared to diesel at almost all loads. It decreases with increase in load up to full load indicating better fuel oxidation. At 220 Bar IP, the best performance with respect to HC emission in obtained in the case of all the fuels tested.

CO Emissions

Electrical	Fuel: Diesel			Fuel: 100 % Oil			Fuel: 95 % Oil / 5% Ethanol		
Load	CO (%)			CO (%)			CO (%)		
%	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar
45	---	---	0.052	0.088	0.084	0.082	0.095	0.100	0.090
61	0.041	0.057	0.041	0.088	0.081	0.078	0.089	0.082	0.086
76	---	---	0.033	0.098	0.088	0.100	0.110	0.074	0.061
91	0.05	0.045	0.035	0.111	0.119	0.122	0.155	0.100	0.066
100	0.07	0.062	0.051	0.200	0.222	0.222	0.197	0.115	0.090

Table 6: Measured data of CO obtained from engine burning pure Pongamia oil, its blend with 5 % ethanol and pure diesel at various engine loads at different injection pressure.

CO emission is lowest for diesel oil as compared to vegetable oil and its blend. This can be related to fuel viscosity effect. There seems to be a favourable effect of increase in injection pressure in the case of diesel and oil emulsion. However, there is no obvious effect in the case of pure oil. As compared to pure oil, oil emulsion seems to be combusting better

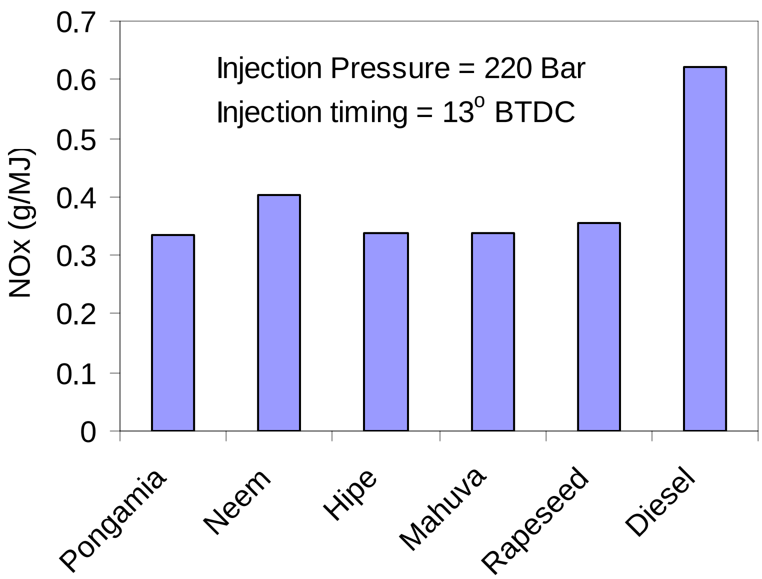
SOx Emissions

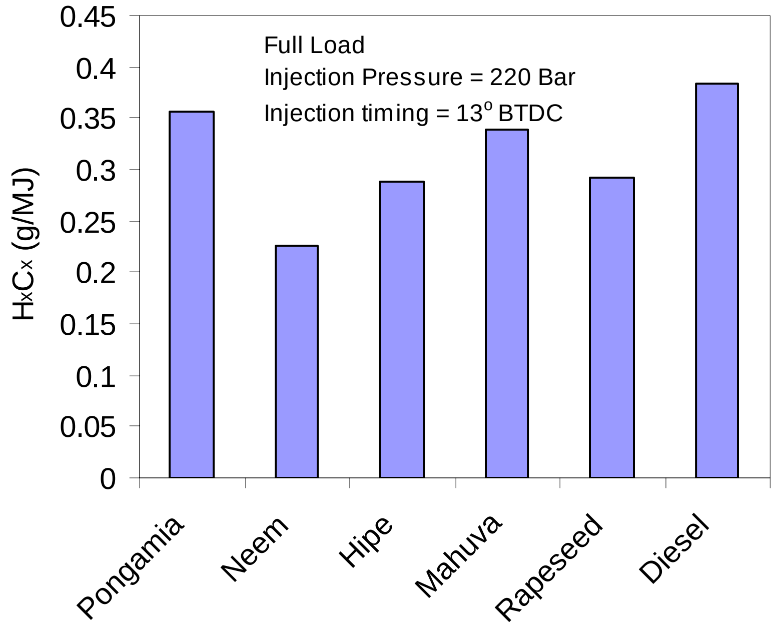
Electrical	Fuel: Diesel			Fuel: 100 % Oil			Fuel: 95 % Oil / 5% Ethanol		
Load	SOx (g/MJ)			SOx (g/MJ)			SOx (g/MJ)		
%	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar	IP = 180 Bar	IP = 220 Bar	IP = 300 Bar
45	---	---	0.000	0.000	0.000	0.000	0.000	0.000	0.000
61	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000
76	---	---	0.000	0.000	0.000	0.000	0.000	0.000	0.000
91	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000
100	0.000	0.000	0.000	0.012	0.013	0.016	0.016	0.000	0.000

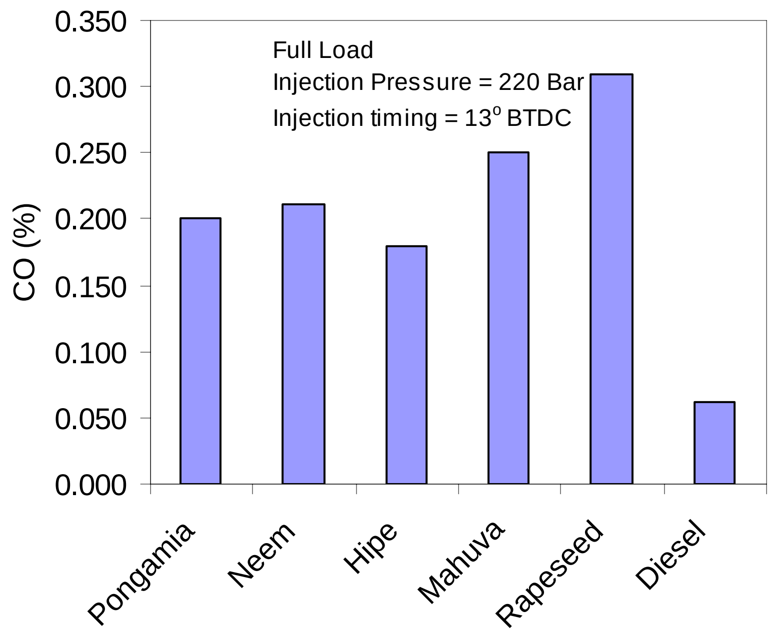
Table 7: Measured data of SO_x obtained from engine burning pure Pongamia oil, its blend with 5 % ethanol and pure diesel at various engine loads at different injection pressure.

SO_x has negligibly small value in case of diesel oil while in the case of 100 % oil and its blend it is detected at full or near full load. There is no obvious effect of increase in injection pressure on SOx emission except for in the case of oil with 5 % ethanol where the value becomes negligibly small.

The results for other non-edible oils are displayed in the following diagrams.




Full Load
Injection Pressure = 220 Bar
Injection timing = 13^{o} BTDC
HxCx (g/MJ)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Pongamia
Neem
Hipe
Mahuva
Rapeseed
Diesel


Full Load
Injection Pressure = 220 Bar
Injection timing = 13^{o} BTDC
CO (%)
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
Pongamia
Neem
Hipe
Mahuva
Rapeseed
Diesel

Reference:

1. (http://www.elsbett.com/eteche.htm)

2. Subramaniyam, S. and Jayaraj, S. (1994), 'Alternate fuels for semi adiabatic engine', Proceedings of XIII National Conf. on IC Engines and Combustion, pp. 111 – 119.

3. Bhaskar, T., Nagalingam, B. and Gopalkrishnan, K. V. (1992), 'The use of Jatropha oil and its blends with diesel in low heat rejection diesel engine', 'Proceedings of XII National Conference on IC Engines and Combustion, pp. 111 – 119.

4. Ma. F., and Hanna, M. A. (1999), 'Biodiesel Production: a review', 'Bioresource Technology, No. 70, pp. 1 – 15.