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# Non-Edible oils Blends in Direct Injection Diesel Engines

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**ABSTRACT**

The use of non edible oils blend in direct injection diesel engine shows its potential to reduce or control the $NO_x$ emissions. Combustion analysis of non edible and non edible blends revealed that the blends had a shorter ignition delay than diesel alone, at both full and light load, and a lower premixed burn fraction at full load. However, the diffusion burn rates were similar. The shorter ignition delay due to high cetane number of non edible oil blends has been suggested as being one of the causes of $NO_x$ increase the peak pressure and temperature increase in flame temperature in either pre mixed or diffusion burn has been followed by subsequent increase in $NO_x$ emission. This was due to reduction of carbonaceous soot concentration. The performance characteristics of an engine such as brake thermal efficiency, brake specific fuel consumption, brake power and engine torque were not much affected, up to a blend of 20% with neat diesel. The Co and particulate emissions were found to be decreasing with the % increase in blend with a subsequent increase of $NO_x$. Thus the blending of fuel is being limited to 20% in majority of cases to obtain optimum performance and emission characteristics. This paper suggests about by using various types of non edible oils as fuel and blends directly in diesel engines by modifying properties by injecting or Trans-esterification.

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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 [I] 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 [II], 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 need to be explored. Blending of the fuel with alcohol will not only reduce viscosity but will oxygenate fuel.

## 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 [3]. The blend with ethanol (5 %) have kinemtic viscosity in the range of 21 – 22 cSt .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.

| Fuel Type | Calorific Value (MJ/KG) | Specific Gravity at 25'c | Viscosity at 27 'C, N.S/m2 | Cetane No. |
|---|---|---|---|---|
| Diesel | 42.3 | 0.815 | 0.13 | 47a |
| Repeseed Oil | 37.62 | 0.914 | 39.5 | 37.6a |
| Pongamia Oil | 35.8 | 0.94 | 1.22 | - |
| Jatropha Oil | 36 | 0.92 | 1.1 | - |
| Esterified Jatropha | 36.5 | 0.9 | 0.52 | - |

**Table I. Non edible Oil Properties**

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

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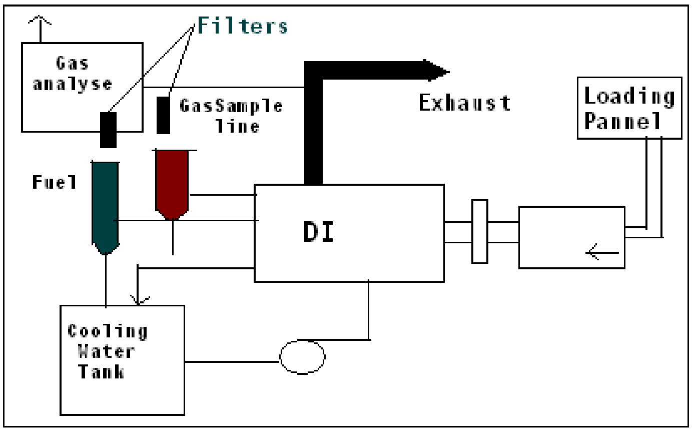
of 1500 rpm with the injection timing set at 13° was used in the present study: The nominal injector pressure was 180 atms. the experimental set up is shown in the figure 1.

***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 time set 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[4]. 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.

**Table II-Fuel consumption of Diesel, Neem oil, and its blend with 5% ethanol**

| Fuel | Diesel | Neem oil | Neem Oil + 5% Ethanol |
|---|---|---|---|
| Load | Fuel Consumption (g/s) | | |
| 57% | 0.15 | 0.24 | 0.25 |
| 86% | 0.23 | 0.3 | 0.3 |
| 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 |

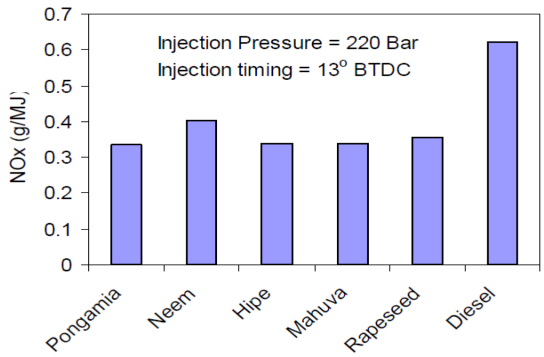
Table 3, 4, 5 and 6 contain measured values of $NO^x$, HC (hydrocarbon), CO and $SO^x$ obtained for pure pongamia oil, its blend with 5 % ethanol and pure diesel obtained at various engine loads at three injection pressures.

***Data of Nox Emissions***

***Emission index For Nox for Vegetable oil***

As can be noticed from Table 3, the emission index for NOx 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.

**Nox Emissions**

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***Data of Hydrocarbon Emissions***

***Hydrocarbon Emission & Blend in Engine***

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.

***Hydrocarbon Emissions***

***CO Emissions from Engine Burning***

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 favorable 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.

***CO Emissions***

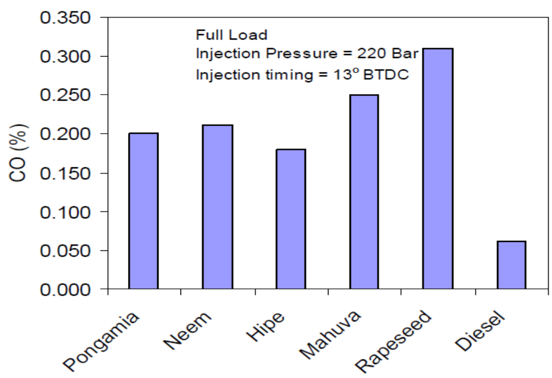

**Table III. Measured data of Nox ($No+No_2$) obtained from engine burning pure pongamia oil, its blend with 5% ethanol and pure diesel at various engine loads at different injection pressure**

| Electrical Load % | Fuel:Diesel | | | | fuel 100% Oil | | Fuel : 95 % oil/5% Ehanol | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nox(g/MJ) | | | Nox (g/MJ) | | | Nox (g/MJ) | | |
| | P= 180 Bar | P=220 Bar | P= 300 Bar | P=180 Bar | P=220 Bar | P= 300 Bar | P= 180 Bar | P=220 Bar | P= 300 Bar |
| 45 | - | - | 0.82 | 0.356 | 0.435 | 0.524 | 0.435 | 0.356 | 0.356 |
| 61 | 0.793 | 0.658 | 0.74 | 0.353 | 0.407 | 0.487 | 0.404 | 0.353 | 0.396 |
| 76 | - | - | 0.78 | 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 | 0.62 | 0.624 | 0.408 | 0.336 | 0.455 | 0.375 | 0.408 | 0.389 |

**Table V- 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**

| Electrical Load % | Fuel :Diesel | | | fuel 100% Oil | | | Fuel : 95 % oil/5% Ehanol | | |
|---|---|---|---|---|---|---|---|---|---|
| | HxCx(g/MJ) | | | HxCx(g/MJ) | | | HxCx (g/MJ) | | |
| | P= 180 Bar | P=220 Bar | P= 300 Bar | P=180 Bar | P=220 Bar | P= 300 Bar | P= 180 Bar | P=220 Bar | P= 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 | - | - | 1.11 | 0.272 | 0.321 | 0.332 | 0.45 | 0.354 | 0.584 |
| 91 | 0.612 | 0.442 | 1.085. | 0.26 | 0.278 | 0.289 | 0.389 | 0.322 | 0.46 |
| 100 | 0.383 | 0.401 | 1.146 | 0.36 | 0.272 | 0.269 | 0.361 | 0.273 | 0.415 |

**Table VI- 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 different injection pressure.**

| Electrical Load % | Fuel :Diesel | | | | fuel 100% Oil | | Fuel : 95 % oil/5% Ehanol | | |
|---|---|---|---|---|---|---|---|---|---|
| | CO (%) | | | CO (%) | | | CO (%) | | |
| | P= 180 Bar | P=220 Bar | P= 300 Bar | P=180 Bar | P=220 Bar | P= 300 Bar | P= 180 Bar | P=220 Bar | P= 300 Bar |
| 45 | - | - | 0.052 | 0.088 | 0.084 | 0.082 | 0.095 | 0.1 | 0.09 |
| 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 | 0.1 | 0.11 | 0.074 | 0.061 |
| 91 | 0.05 | 0.045 | 0.035 | 0.111 | 0.119 | 0.122 | 0.155 | 0.1 | 0.066 |
| 100 | 0.07 | 0.062 | 0.051 | 0.2 | 0.222 | 0.222 | 0.197 | 0.115 | 0.09 |

**Table VII- 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**

| Electrical Load % | Fuel :Diesel | | | | fuel 100% Oil | | Fuel : 95 % oil/5% Ehanol | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sox (g/MJ) | | | Sox (g/MJ) | | | Sox (g/MJ) | | |
| | P= 180 Bar | P=220 Bar | P= 300 Bar | P=180 Bar | P=220 Bar | P= 300 Bar | P= 180 Bar | P=220 Bar | P= 300 Bar |
| 45 | - | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 76 | - | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 91 | 0 | 0 | 0 | 0 | 0 | 0 | 0.007 | 0 | 0 |
| 100 | 0 | 0 | 0 | 0.012 | 0.013 | 0.016 | 0 | 0 | 0 |

***Data of Sox Emissions from Engine Burning***

$SO^x$ have 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.

***Sox Emissions***

***Influence of Temperature***

The temperature influence is statistically significant in the range studied. This effect has a positive influence on the response. As the temperature increases, the solubility of ethanol [V] in the oil increases and so does the speed of reaction. As a matter of fact, at low temperatures, methanol is not soluble at all in the oil; when the stirring is started an emulsion appears. The reaction takes place at the interface of the droplets of alcohol in the oil and then as soon as the first FAMEs are formed, the alcohol solubilises progressively because the esters are mutual solvents for the alcohol and the oil.

***Result***

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.

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