Experimental investigation on Preheating of Azadirachta indica biofuel and their performance analysis in a CI engine

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Abstract. This paper deals with evaluation of engine performance using preheated biofuel utilizing the waste heat generated from exhaust gases. The performance characteristics and emission parameters are compared with the trans-esterified biodiesel. It is understood that the preheated biofuel run in the engine was capable of producing appreciable brake thermal efficiency as that of biodiesel run CI engine. This effort simultaneously reduced the heat loss to the environment, thereby improving the exergy of the system. The neem biofuel was heated to 70°C and 80°C before injection by the exhaust gases. HC and CO emissions were reduced by 22.3% and 19.01% respectively. NOx emissions suffered an increase of 18.6%. The improvement in BTE was 5.5% compared to non-heated biofuel.

1. Introduction
Vegetable oils are suitable replacement for diesel based on their closeness in physical properties. These renewable energy sources are eco-friendly and reduce exhaustive emissions. Their availability makes them potentially suitable for CI engines. Large varieties of non-edible oils, viz. rubber seed oil, jatropha and cotton seed oil have been experimented by researchers in the last decade. The calorific value and cetane number are closer to diesel but other properties like viscosity and volatility remains a hurdle for smooth operation in CI engines.

The utility of bio-fuel in CI engines and their performance was studied extensively by many researchers in the past decade. Cernat et al [1] used 5% and 10% of animal fat oil blended with diesel. The animal fat that was preheated had resulted in decrease of pressure inside the cylinder. Smoke drastically decreased from 22% to 52%. Praveena et al [2] utilized waste from biomass as a source of energy for CI engine. Grape seed oil was transesterified and the grape seed biodiesel was blended with nano particles to improve the engine performance and combustion characteristics. HC emissions were subsidized by 13% due to addition of nano blends. Prakash et al [3] added pine oil that has very low viscosity to castor oil and its methyl ester. Better combustion characteristics were exhibited due to this technology and BTE was improved from 23.7% to 29% for castor oil methyl ester. Pine oil was added to a maximum of 30% and the addition percentage was limited based on knock.

In addition to fuel blending, other techniques like fitting of after treatment devices [4,5], chamber geometry modification etc. were carried out by researchers to reduce regulated emissions. Vedagiri et al [6] modified combustion chamber geometry from existing hemispherical shape to toroidal and shallow depth type. The shallow depth type produced the least NO emissions, whereas toroidal shape was preferred for maximum BTE. Anis et al [7] investigated the changes in spray pattern and injector performance by varying the inlet temperature of biodiesel. The preheated temperature was varied from
30°C to 70°C and the changing fuel spraying process was captured using a camera. This enabled to have a different fuel supply system that suits various biodiesel ranges. Subramanian et al [8] explored the contribution of different additives like diglyme, cumene and acetone to camphor oil fuel. This improves the evaporation and atomization process of camphor oil. Eugenol antioxidant at 10% volume has reduced NO emissions by 24% and acetone antioxidant has reduced NO emissions by 17.8%.

Thus it can be summarized that various techniques have been implemented in the past to reduce emissions. Sometimes, a combination of technologies like after treatment retrofits with fuel modification [9], hydrogen induction with biodiesel in a dual fuel mode [10] etc. has been explored. The current work deals with using pre-heated neem oil in CI engines and comparing the engine performance with that of non-heated neem oil and neem biodiesel. Pre-heating not only improves viscosity but also utilizes the energy, which otherwise would have been lost to the environment.

2. Materials and Methods

A single cylinder CI engine with its specifications listed in table 1 is used for experimental test runs. The engine was loaded using an electrical dynamometer and a dynamo controller. Diesel and neem oil were supplied through two different storage tanks. The air flow rate was calculated by the air box and orifice arrangement. Volumetric flow rate of fuel was measured with the burette and stop clock. Thermocouples positioned near the exhaust manifold measured the exhaust gas temperature precisely. Five gas digital analyzer helped to measure NO, HC, CO and CO₂ emissions. AVL smoke meter measured the smoke opacity at various load operating conditions of the engine. Figure 1 shows the experimental set up.

| Table 1. Engine specifications. |
|---------------------------------|
| Model       | Kirloskar                  |
| Cylinder    | 1                          |
| Compression ratio | 17.5                     |
| Rated power | 3.76 kW                    |
| Bore x stroke | 87.5 mm x 110 mm        |

![Figure 1. Experimental set up.](image-url)
The pure neem oil possesses a high fatty acid content of that requires base transesterification. Pure neem oil and methyl alcohol were taken in the ratio of 6:1 and treated at 65°C with 2% by volume of KOH. The mixture was heated for 1 hour at the same temperature. The solution was then allowed to settle for 24 hours. The collected methyl ester was washed thoroughly with water and the neem methyl ester was evaluated for its properties. As a measure to reduce its viscosity, transterification was carried out to convert the raw oil into its biodiesel.

The raw oil was heated to elevated temperatures of 70 °C and 80 °C by allowing it to pass through a heat exchanger. The heat exchanger was a non-contact type, where the exhaust gas was acting as a heat exchange medium. The mass flow rate of exhaust gases were controlled by means of a flow control valve in the pipeline. The emission parameters and specific energy consumption were observed and calculated at all operating loads, and at a speed of rpm. The properties of base fuel, raw oil and its biodiesel are listed in table 2. The variation in viscosity and preheated biofuel is clearly seen with rise in temperature.

### Table 2. Fuel properties.

| Property                  | Diesel | Neem oil | Neem methyl ester | Preheated neem oil to 70°C | Preheated neem oil to 80°C |
|---------------------------|--------|----------|-------------------|---------------------------|---------------------------|
| Density (kg/m³)           | 835    | 970      | 892               | 842                       | 813                       |
| Calorific value (kJ/kg)   | 44400  | 39700    | 40600             | 40820                     | 40967                     |
| Kinematic viscosity (cSt) | 2.9    | 38.4     | 4.21              | 3.6                       | 3.01                      |
| Cetane index              | 51     | 56       | 53                | 52                        | 53                        |

### 3. Results and Discussion

#### 3.1. Brake specific energy consumption (BSEC)

Figure 2 shows the variation of BSEC with brake power. BSEC for diesel and raw neem oil are 12.5 MJ/kWh and 14.6 MJ/kWh respectively. The viscosity and density of neem oil is very high compared to pure diesel. This requires excess amount of energy consumption to produce same brake power. Neem oil methyl ester provides an improvement of 4.7% in BSEC. Heating the raw oil to 80°C reduces the viscosity to 3.01 cSt. This enables the minimum BSEC to be attained with preheated neem oil.

![Figure 2. Brake specific energy consumption variation at different loads.](image)
3.2. Brake thermal efficiency (BTE)
Figure 3 shows the BTE for CI engine using diesel, neem oil (unheated), neem oil methyl ester and neem oil preheated at 80°C. The BTE of neem oil is much lesser than diesel, due to its low calorific value. The preheated neem oil has an improved heating value, thus creating a positive effect on BTE. A significant decrease in BTE is noticed for neem biodiesel and preheated neem oil. BTE of preheated neem oil is raised from 27.3% to 32.8%.

![Figure 3. Brake thermal efficiency variation at different loads.](image)

3.3. Exhaust gas temperature (EGT)
The range of EGT for diesel, neem oil (unheated), neem oil methyl ester and neem oil preheated at 80°C is shown in figure 4. EGT of neem oil is 428°C which is greater than diesel. This is attributed to the delay in combustion phase. The poor volatility of neem oil, shifts the combustion towards the expansion stroke. The reduction in viscosity of the preheated oil has reduced the EGT from 428°C to 367°C.

![Figure 4. Exhaust gas temperature variation at different loads.](image)
3.4. HC emission

The HC emission levels for diesel and neem oil are 135 ppm and 179 ppm respectively as shown in figure 5. The increase in HC emissions for raw neem oil was 32.5% higher than diesel. This was reduced by fueling the engine with methy ester and preheated neem oil. HC emissions in terms of ppm reduce as the fuel temperature is raised. Better quality of atomization and vaporization is produced due to preheated mixture.

![Figure 5. HC emission variation at different loads.](image)

3.5. CO emission

The CO emissions for diesel and neem oil are 0.193% and 0.22% respectively as shown in figure 6. Poor volatility of neem oil creates difficulty in atomization. A significant drop in CO emission is observed to an extent of 9% by using neem oil methyl ester. The preheated oil further improves the combustion efficiency and thereby reduces CO emissions to 0.178%.

![Figure 6. CO emission variation at different loads.](image)
3.6. NO emissions
The NO emissions increase for all fuel with increase in load. This is due to high in-cylinder combustion temperature. The premixed phase duration decides the temperature inside the cylinder. The neem methyl ester produces higher NO emissions than diesel. Further heating of neem oil raises NO emissions from 1498 ppm to 1785 ppm as shown in figure 7. This is attributed to the rapid burning caused by inflated neem oil temperature.

![Figure 7. NO emission variation at different loads.](image)

3.7. Smoke
Smoke opacity increases for all fuels with raise in brake power output as shown in figure 8. More smoke is produced for raw neem oil and methyl ester compared to diesel, due to increased viscosity and inferior mixture formation. Smoke emission for preheated oil is lesser than all other fuels. This is due to less diffusive phase. Also, the results obtained are consistent with the reduced viscosity values. Better air fuel ratio and air entrainment around the fuel is obtained.

![Figure 8. Smoke emission variation at different loads.](image)
4. Conclusion
The engine performance and emission results are well understood by fueling the CI engine with raw neem oil and preheated oil at 80°C. The following conclusions were obtained from the experiments.
1. BTE of raw neem oil was 27.3% compared to the base fuel diesel of 33.4%. Fuel preheating method helped to raise the BTE to 32.8%.
2. The exhaust gas temperature is reduced to 367 ºC by using preheated neem oil and neem methyl ester due to reduced viscosity.
3. HC, CO and smoke emissions were considerably reduced for preheated oil due to reduction in viscosity and density. The premixed reaction phase contributed to reduction in the above emissions.
4. NO emission for neem oil methyl ester and preheated neem oil were higher than diesel. This is due to the increased adiabatic flame temperature. However, after treatment methods can be helpful to reduce these NO emissions.
Hence, it is summarized that preheating of pure neem oil to 80° C and then injecting into the engine would be an effective way of reducing the regulated emissions.

5. References
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