Effects of biodiesel-pentanol-diesel blends with varied EGR in a CRDI engine

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Abstract: Emission standards are getting stricter day by day, due to the rise in the growth of automobiles globally. When compared to other IC engines, Diesel engines cause more harmful exhaust gas and this has led to potentially catastrophic impact on the environment like global warming and ozone layer depletion. To overcome this problem, we need renewable sources but since it is currently in high demand, this has led to the development of alternative fuels in India. This study investigates the impact of n-Pentanol/Karanja oil biodiesel/diesel fuel blends in a common rail direct injection engine. The addition of higher-order alcohol (n-Pentanol) will improve the low temperature properties of the biodiesel-diesel blend and high volatility and low viscosity of Pentanol will significantly reduce the emissions. The fuel blend B20P10D70 (KME 20%, n-Pentanol 10% and Diesel 70%) was carried out at 21°C and 25° CA respectively with varied EGR at 10% and 20% to test both the engine parameters (BTE and BSFC) as well as exhaust gas emissions (CO, NOx, HC and Smoke).

1. Introduction:

Global demand for energy is expected to double by 2040 due to population and economic growth. Energy storages will be depleted as more than 70% of the energy consumption is derived from fossil fuels. Therefore, finding enough assets to power the future is one of the most frightening challenges for society. The Internal Combustion (IC) engine was developed in the 18th Century by Rudolf Diesel. Since then, rapid growth was noticed in terms of evolution and technologies regarding diesel engine. It replaced small scale operations including animal work, coal engine, human labor etc. In the late 19th Century, diesel engines were installed to power trucks and tractors which increased the consumption of fossil fuels exponentially. Karanja or Pongamia Pinnata is a medium sized tree which is easy to grow and nurture in four to five years. Karanja oil is ideal for growing in countries like India, Philippines, East indies, Thailand, Malaysia, and Indonesia. It is also found in the United States and Egypt from recent studies. It is one of potential oil that can be produced in million tons per annum. So, Karanja oil can be the best alternative for jatropha oil because it emits less harmful substances and is less expensive. Numbers of papers in Karanja oil biodiesel are limited when compared to jatropha oil. Hence this research aims on biodiesel production through transesterification and utilization of alcohol-biodiesel-diesel blends in CRDI engine with study on combustion, performance and exhaust gas emissions by varying injection timings and EGR.

Santhosh et al [1] performed an experimental research on the characteristics of a two-cylinder diesel engine using pentanol-diesel blends with varied concentration and EGR. He noted the negative effect of EGR on BTE reduction (16.21% to 3.8%) and the positive effect on NOx reduction (23.25% to 50.07%) along with...
an increase in ignition delay and HC with increased pentanol concentration. At 10% pentanol addition and 20% EGR, the gas emission is decreased without any compromise in performance characteristics when compared with neat diesel. Avinash Kumar [2] investigated the combustion, performance and emission parameters on CRDI engine fueled by Karanja oil biodiesel (10%, 20% and 50%) and diesel blends with varied injection pressure and start of ignition (SOI). It is reported that an increase in BTE and BSFC with increase in Karanja biodiesel concentrations, however utilization of 50% biodiesel resulted in negative response. NOx was reduced at lower injection pressure of 500bar at all concentrations of biodiesel.

Zheng and Jichao [3] conducted experiment on the feasibility of using ternary fuels (B10P20D70 and B20P10D70) over binary fuels (B30D70 and P30D70) and diesel. Ternary fuels showed a slight increase in BTE and a drastic decrease in NOx and THC emission. However, with increase in EGR rates, soot and NOx were low but HC and CO were high, hence up to 30% EGR rates were finalized to be optimum. Radheshyam [4] studied the engine characteristics using pentanol/diesel blends at (5, 10, 20, 30 and 40%) by volume and its effect with EGR (10 and 20%) on a diesel engine at constant speed 2000rpm. Increase in BSFC (12.7%) and delay period with decrease in BTE (7.5%) was noted with rise in 1-pentanol concentration. Blended fuel up to 30% can be used without any modification to the engine. Reduction in NOx (up to 35%) was noticed at all loads, however 23% and 52% reduction were obtained at EGR rates 10% and 20% respectively. Utilization and steps involved in biodiesel production using Karanja oil and their influence on the catalyst concentration for high free fatty acid (FFA) oil were investigated. Nandagopal et al [5] reported the production of Karanja Oil Methyl Ester (KOME) using catalyst KOH at 65°C under constant mixing rate of 360rpm for 3 hours. Due to the increased FFA, acid esterification was done prior to the transesterification process in order to prevent soap formation and to reduce FFA to <4% which provided 92% yield during production.

A single cylinder CRDI engine was used to study the performance (BTE and BSFC) and emission (CO, HC, NOx and smoke) characteristics of Karanja oil biodiesel blends at varied loads. Yogaraj et al [6] reported a rise in BTE and decrease in BSFC with increased load for concentrations up to 30%. Decrease in NOx and equal CO of that of diesel is noted with increase in HC and CO at higher loads. Punnet et al [7] investigated the performance characteristics of esters of Karanja oil (KOME, KOEE, KOPE, KOBE and KOPnE) blends on CRDI engine at varied engine loads with constant speed 1500rpm. Usage of high FFA content Karanja oil and its pretreatment and transesterification using different esters is explained. During KOPnE blend, decrease in BTE and CO is noted with increase in BSFC and NOx but KOME shows a promising result by decrease in NOx emission without any decrease in performance characteristics. Suresh Kumar et al [8] reported that blends of methyl esters of Pongamia Pinnata with diesel up to a concentration of 40% could be used as a replacement of neat diesel promising better performance and reduced exhaust gas emissions.

Babu and Anand et al [9] tested for the influence of performance and emission parameters on different injection timings fueled by blends of biodiesel/alcohol/diesel. Biodiesel blends with hexanol and pentanol has maximum ignition delay period at lower pressures which showed reduction in NO emission at 27°C BTDC and minimized smoke up to 24.76% that of neat diesel. Baiju et al [10] tested for utilization of Karanja oil biodiesel produced from ethyl and methyl esters in a four stroke IC engine. Methyl esters have better performance when compared with ethyl esters and diesel. Exhaust pollutants (HC, NO and smoke) were reduced but NOx emission increased by 15-25% with both esters. Reduced BTE and increased BSFC is noted with reduction in exhaust gas emissions. Rupesh et al [11] reviewed the usage of biodiesel in diesel engine from both edible as well as non-edible oils. A detailed comparison on Jatropha, Neem, Cotton seed, Rubber seed, Soybean, Mahua, Corn and Sunflower oils engine performance and emission characteristics were reported and Karanja oil was found to be the best among them. 20% blends of KOME with diesel showed slight increase in performance with high reduction in exhaust gas particulates. Production methods, blending nature and economic aspect of biodiesel production from Indian perspective is focused in this review paper.
Chandan Kumar et al [12] experimented on KOME with varied concentration by volume (20%-80%) in DI engine. Reduction in UBHC and CO were noted with a slight increase in NOx. There is no significant power loss with B20 and B40 but slight increase in BSFC and BSEC is recorded. Lower net heat releases and increased ignition delay were notable at all concentrations of KOME blends. RaviKumar et al [13] tested for performance and exhaust gas emission on a CRDI engine with blends of biodiesel with additives. Experiments were conducted by varying spill timings and EGR which revealed a fall in HRR and peak pressure when spill timings were retarded. Performance characteristics were reduced up to 4% with up to 55% NOx reduction and 10% smoke reduction. Addition of alcohol to the biodiesel blend enhanced the performance slightly with drastic reduction in exhaust gas emission. Gopal [14] studied the effects of varied EGR (0%, 10% and 20%) and injection timings (23°bTDC, 18°bTDC and 13°bTDC) on a diesel engine with high density polyethylene (30%) blend with diesel. Results showed deterioration BTE when injection timings were changed from 23° to 13°bTDC and reduction of NOx up to 70% when EGR were changed from 0% to 20%. HC, CO and smoke had a slight increase with EGR when compared with neat diesel. Meher et al [15] studied the optimum characteristics required to obtain above 95% yield value while preparing biodiesel from Karanja oil by transesterification. 1% KOH catalyst at 6:1 molar ratio, 65°C, stirred at 300rpm for around 2 hours was found to be optimum, however during the first 45 minutes, 85% yield was obtained and with further stirring, up to 95% yield value was obtained. Results were varied without constant stirring.

The current research involves preparation of biodiesel from high free fatty acid Karanja oil by acid esterification followed by transesterification. Blends of Karanja oil biodiesel (20%), Pentanol (10%) and diesel (70%) were utilized at varied injection timings of 21°CA bTDC and 25°CA bTDC with EGR rates (10% and 20%). Experiments were conducted on a modified common rail direct injection (CRDI) engine connected with gas Analyzer and smoke meter to study the combustion, performance and exhaust gas emission characteristics.

2. Experimental Investigation

2.1. Esterification

Acid esterification process reduces the high FFA content in the Karanja oil bought. Due to the high FFA content (6.9%), a two-step acid esterification was done. Oil is preheated and taken in a closed vessel where methanol and acid catalyst (H₂SO₄) are added at 60°C for about 120 minutes. A closed-reactor vessel was taken to prevent moisture and was kept under constant stirring to obtain the best results. Oil to methanol ratio (1:3) with 1.75 ml of acid catalyst reduced the FFA content to 4.45% and was further reduced to 3.05% with 1.25 ml of catalyst addition.

Transesterification was followed with the addition of 5 gram of base catalyst (NaOH) at 60°C for 90 minutes. The product is stirred and heated in the presence of alcohol (methanol). A three-step chemical conversion of breaking down glycerol takes place during the reaction. Upon methyl ester formation after cooling the product for 8 hours, the glycerol formed at the base of the container is removed. A yield percentage of 80.76 was obtained after the completion.

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\text{Karanja Oil + Methanol} \xrightarrow{\text{Catalyst}} \text{Glycerol + Karanja Oil Methyl Ester}
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2.2. Test fuel

Proceeding from our literature survey, we found that up to 30% of biodiesel can be used in an engine without any external or internal modifications. Hence B20P10D70 (Karanja oil biodiesel (20%), Pentanol (10%) and diesel (70%)) was finalized and tested with injection timings of 21°CA bTDC and 25°CA bTDC by varying the EGR (10% and 20%). Upon constant stirring, biodiesel and pentanol were added to diesel by volume.
Table 1. Properties of fuel

| Fuel Property                      | Diesel | Karanja Oil | Karanja Oil Methyl Ester (KME) | B20P10D70 Blend |
|------------------------------------|--------|-------------|--------------------------------|-----------------|
| Density (kg/m³) at 15°C            | 820    | 925         | 885                            | 851             |
| Kinematic Viscosity (mm²/s) at 40°C| 3.11   | 28.4        | 10.64                          | 2.1             |
| Gross Calorific Value (MJ/kg)      | 41.58  | 34.0        | 35.56                          | 42.472          |

Table 2. Specification of test engine

| Make and Model | Kirloskar TV1 engine |
|----------------|---------------------|
| Product        | CRDI VCR            |
| No of cylinders| Single cylinder     |
| No of strokes  | 4                   |
| Power          | 3.5 kW              |
| Bore length    | 87.5 mm             |
| Stroke length  | 110 mm              |
| Speed          | 1500 rpm            |
| Cooling system | Water cooled        |
| Dynamometer    | Eddy current type   |

2.3. Experimental setup and procedure

Figure 1 shows a single-cylinder, CRDI engine coupled to an eddy current dynamometer and encoders to monitor crank angles, fuel flow, air flow, temperature and load acting is used for this experimentation. The setup has a panel box with fuel tank, airbox, manometer, fuel flow meter and piezoelectric unit. A programmable ECU allows to monitor the pressure and injection rates of fuel used at various EGR and compression ratios. BP, IP, BMEP, IMEP, BTE, ITE, BSFC, A/F ratio and combustion analysis are studied with the results obtained through the data acquisition device to the computer.

Figure 1. Experimental set-up
3. Results and Discussion

3.1. Performance Analysis

Brake thermal efficiency (BTE) determines probability of reaching complete combustion. It mainly depends on the calorific value of the test engine fuels. Figure 2 shows that BTE increases with increase in brake power. At 20% EGR and advanced crank angle 25°CA bTDC, a decrease in BTE is noted. However, a slightly increased BTE is noted at all others due to the alcohol addition to the fuel blend compared to that of diesel.

Brake specific fuel consumption (BSFC) calculates the utilized power. With increase in brake power, a decrease in BSFC is noted. Figure 3 shows similar values of that of diesel due to the presence of oxygen content in methyl ester giving complete combustion. Low calorific value of the test fuel is a major cause for the decreased BSFC at lower brake power.

![Figure 2. Variation of brake thermal efficiency under different brake power](image1)

![Figure 3. Variation of brake specific fuel consumption under different brake power](image2)
3.2. Emission Analysis

Hydrocarbons (HC) are increased at all brake power due to the complete combustion and unfavorable air to fuel ratio as shown in Figure 4. With increase in power, increase in HC is noted at all EGR. However, at 10% EGR and retarded crank angle 21°C bTDC, a slightly better value is obtained compared with others. Increased Carbon monoxide (CO) is noted due to the presence of unburned carbon and oxygen contents in Figure 5. At lower EGR rates (10%), slightly better CO emission is noted compared to that of higher EGR rates. Smoke formation mainly depends on the lubricant oil and oxygen content during combustion. An increase in smoke is noted at higher power in Figure 6. However, at low EGR rates, opacity is comparatively lower than at high EGR rates. NOx is opposite to that of all other emission particulates. At high EGR rates, NOx is reduced at greater extent as depicted in Figure 7. However irrespective of processes the NOx emission is decreased due to the oxygen composition of the test fuel.

Figure 4. Variation of hydrocarbons (HC) under different brake power

Figure 5. Variation of carbon monoxide (CO) under different brake power
4. Conclusion

Blends of Karanja oil biodiesel (20%), Pentanol (10%) and diesel (70%) were utilized at varied injection timings of 21°CA bTDC and 25°CA bTDC with EGR rates (10% and 20%). The results shows that;

- NOx was reduced at all processes with a slight compromise in other emission particulates (CO, HC and smoke).
- The tested fuel B20P10D70 at 10% EGR and 25°CA BTDC was found to be the best suitable due to the balance of performance along with exhaust gas emissions.
- Usage of biodiesel-pentanol-diesel blends can be a best alternative to neat diesel.

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