A Comparative Investigation on D.I. Diesel by Using Different Blends of Diesel- Biodiesel- Additives: Performance and Emission Based Trade-off Analysis

Jibitesh Kumar panda, G.R.K. Sastry, Ram Naresh Rai

1Research Scholar, Production Engineering Department, NIT Agartala, India
2Professor, Mechanical Engineering Department, NIT Andhra Pradesh, India
3Associate Professor, Production Engineering Department, NIT Agartala, India

Corresponding Author E-mail: jibiteshpanda90@gmail.com

Abstract. Looking at the energy situations and global warming concerns, research on non-conventional and alternative fuel resources has ignited targeted to reduce emission and persistent dependence on conventional fuels for sectors like transportation, power generation and agriculture. The primary objective of this research is to design an alternative fuel having additive 2-Ethylhexyl nitrate of high cetane number and additive triacetin of low cetane number blended with palm kernel to analyse exhaust emission characteristics and engine performance. For the purpose, biodiesel made from palm kernel was added to pure diesel along with 20% (by volume) of two different additives (2-Ethylhexyl nitrate, triacetin). As compared with pure diesel, some of our fuel blends show better performance and have low emission which is much needed in the present scenario.

1. Introduction
Depletion of fossil fuel and environmental degradation are the two major issues that the world is confronting now. Thus, we need an alternative fuel which is well balanced concerning environmental preservation, energy conservation and sustainable development. According to Peak oil concept, the demand for oil will beat supply, and this gap will rise, which would result in an increased energy crisis starting between 2010 and 2050 [1-2]. Furthermore, the implementation of Biodiesels in a field on IC engines can generate high efficiency and reduce the dependency of conventional fuel [3]. Recently, various type of biofuel has been familiarized by industry and researchers. Palm Kernel oil has caught the attention as it is available globally and has similar properties as conventional diesel. Also, for reducing emission and increasing performance, a high cetane number and oxygen content of a fuel is a vital factor as compared to the other factors [4-5]. Therefore, a small amount of diesel additives in fuel with more oxygen content and high cetane number could play a key role in better performance.

2. Experimental setup and methodology

2.1 Fuel selection
Bio-diesel is an alternative fuel which is clean burning and prepared completely from renewable resources. When an ester is changed into another ester by the exchange of alkyl groups, it is termed as transesterification which is a general term in organic chemistry and is also called alcoholyis. Transesterification Reaction general Equation is given below:

$$\text{RCOO}^+ + \text{R}'' \text{OH} \leftrightarrow \text{RCOO}'' + \text{R}' \text{OH} \quad (1)$$

Here one stage Base-catalysed process has been selected for Methyl esterification of non-edible vegetable oils like palm kernel which is a forest product available in the region and methanol (99.95% purity) as reactants and NaOH as a catalyst [6]. 2-EHN is diesel additive normally used with diesel blend with a purpose of raising its cetane number [7]. Triacetin is a triglyceride obtained by acetylation of the three hydroxy groups of glycerol which has high oxygen content. Since we need to add a low volume of additive high in oxygen content as it can reduce the emission parameter, in this experiment, a blend of triacetin, 2- EHN, diesel and transestrified pkme was used in proper proportions.

In our experimental investigation, the outcomes are presented in Table 1 after which ester samples were verified in a D.I. C.I. engine for engine emission and performance test in a laboratory. Under stable conditions, eight blends were prepared for the experiment. The fuel blends are given below:

D100  Pure Diesel
BL1   Eighty (%) Diesel+ Twenty (%)PKME
BL2   Four (%) 2-EHN+ Eighty (%) Diesel+ Sixteen (%)PKME
BL3   Six(%) 2-EHN+ Eighty (%) Diesel+ Fourteen (%) PKME
BL4   Eight (%) 2-EHN+ Eighty (%) Diesel+ Twelve (%) PKME
BL5   Four (%) Triacetin+ Eighty (%) Diesel+ Sixteen (%) PKME
BL6   Six (%) Triacetin + Eighty (%) Diesel+ Fourteen (%) PKME
BL7   Eight (%) Triacetin + Eighty (%) Diesel+12(%) PKME

| Fuels | Properties | Density@15 °C (g/cc) | Viscosity @40 °C (mm$^2$/s) | Ceten No | CV (MJ/kg) |
|-------|------------|----------------------|-----------------------------|----------|------------|
| D100  |            | 0.82                 | 2.5                         | 51.3     | 44         |
| B100  |            | 0.87                 | 4.7                         | 49.4     | 39.8       |
| 2-EHN |            | 0.719                | 1.8                         | 62       | 52.4       |
| Triacetin |        | 1.15                 | 7.8                         | 15       | 29.6       |
| BL1   |            | 0.794                | 2.41                        | 48.1     | 41.93      |
| BL2   |            | 0.781                | 2.39                        | 52       | 44.05      |
| BL3   |            | 0.786                | 2.38                        | 51.6     | 43.81      |
| BL4   |            | 0.791                | 2.37                        | 49.5     | 42.51      |
| BL5   |            | 0.762                | 3.15                        | 51.4     | 43.58      |
| BL6   |            | 0.771                | 3.24                        | 51       | 43.11      |
| BL7   |            | 0.774                | 3.34                        | 48.8     | 42.22      |

2.2 Apparatus Used (Performance and Emission)

The engine used for the experiment is directly injected (DI) diesel engine, single cylinder and water cooled (Fig-1). Ranging from 0% to 100%. Various loads like Zero load, Three kilo gram, six kilo gram, nine kilo gram, twelve kilo gram can be applied to the engine. A glass burette is provided separately for measuring the flow of diesel and bio-diesel. Table-2 gives the details of engine specification.

| Make and type | Kirloskar, cylinder (One), Diesel (Four Stroke) |
Engine type: Vertical CI Engine
Stroke length: 110 millimeter
Swept volume: 661 cubic centimeters
Compression ratio: 17.6
Power: 3.5 kilo Watt
Rated speed: 1500 Revolutions per minute
Bore size: 87.5 millimeter

**Dynamometer**

Make: Power mag
Type: Eddy current
Load measurement method: Strain Gauge
Maximum load: 12 kilo gram
Cooling: Water

To obtain the emission characteristics, a gas analyser was used for the determination of Unburnt Hydrocarbon (UHC), nitric oxide (NO\(_X\)) and carbon monoxide (CO). HC was measured as percentage volume, and NO was determined in parts per million fitted at the engine exhaust. During the experiment, specific fuel consumption is measured by a stopwatch and burette, the engine exhaust (CO, HC, CO\(_2\), O\(_2\) and NO\(_X\)) were analysed and calculated by five gas analysers (Testo-350) fitted at the exhaust. The stipulations of five gas analysers are given below in Table (3).

**Table 3. Precision for five gas analyser**

| Apparatus | Measurement range | Accuracy for instrument |
|-----------|-------------------|-------------------------|
| CO        | Zero to Ten Thousand (parts per million) | ±Ten parts per million (zero to +one hundred ninety-nine ppm) ±five% of mv (+two hundred to +2000 ppm) ±ten% of mv (+2001 to +10000 ppm) |
| CO\(_2\)  | Zero to Fifty Volume (%) | + 1.5% of mv (>twenty five to fifty Vol. %) ±0.3 Vol. % ±0.5 Vol. % + one% of mv (zero to twenty five Vol. %) |
| HC        | Hundred to Forty Thousand (ppm) | < 400 ppm (hundred to 4000 ppm) < ten % of mv (> 4000 ppm) |
| NO\(_X\)  | Zero to Four Thousand (parts per million) | ±five ppm (zero to +99 ppm) ±five% of mv (+hundred to +1999.9 parts per million) ±ten% of mv (+2000 to +3000 parts per million) |
| O\(_2\)   | Zero to Twenty five Volume (%) | ±0.8% of fsv (zero to + twenty five Vol. % O\(_2\)) |
Figure 1. Experimental setup

The engine was fixed with the dynamometer (eddy current type). The engine was run 30 minutes with pure diesel initially for warm up and to take the engine in stable condition. Then biodiesel with additive was used for running the engine to record the performance, and emission parameters for investigation.

3. Results & discussion

3.1. Cylinder pressure

Figure 2 gives a comprehensive idea regarding the variation of pressure inside the engine cylinder of different blends. At different loads, blend-2 showed higher cylinder pressure among all blends because of its lower auto-ignition temperature and higher cetane number. If we talk about engine output, then cylinder pressure is the key parameter [8-9]. It is also noticed that with an increase in load, the inside temperature of the cylinder for all blends also increases.

3.2 B.T.E. (Brake thermal efficiency)

The actual useful work done by the chemical energy present in fuel is known as BTE [10]. The ratio of brake power to the chemical energy in the fuel is its expression. From Figure 3., it can be observed that the BTE of the engine with fuel blends progressively improved once the weight was increased. BL3, BL2 had the peak thermal efficiency of 3.8%, 6.3% higher than pure diesel at hundred percent load. When compared with pure diesel, BL1, BL4, BL5, BL6 and BL7 has BTE more by 2.3%, 2.6%, 3.1%, 3.0% and 2.4% among other blends. Due to the higher percentage of oxygen content and higher cetane number in blends it gives an ideal thermal efficiency compared to diesel. Also, the high flame velocity of blends causes higher combustion rate, which is credited to increase the BTE [11].
3.3 B.S.F.C. (Specific fuel consumption)
The amount of the fuel used for getting a unit of mechanical energy is known as specific fuel consumption. At hundred percentage load, BSFC of BL2, BL3 and BL5 are 19%, 17%, 13% less than D100. The relationship between fuel properties (oxygenation, low calorific value, higher viscosity of the biodiesel) and the fuel injection system governs the engine output parameter, i.e. BSFC [12, 13].

3.4 NOx. (Oxides of nitrogen)
The NOx emission is found to be 22%, 20% and 17% higher in case of BL2, BL3, and BL4 at full load condition. Higher NOx indicates higher combustion temperature inside the engine cylinder affecting the separation of two molecules like $O_2$ and $N_2$ to form NO. But BL5, BL6 and BL7 produced 5.6%, 4.37% and 2.1% less NOx compare to D100. The basic characteristics like lower heating value and cooling effect dominate the temperature inside the combustion chamber, which is why triacetin proves to be the best additive for reduction in NOx in this case [12].

3.5 U.H.C. (Unburned hydrocarbon)
UHC emission primarily depends on partial combustion of rich/lean air-fuel mixture when the quantity of oxygen is not plentiful enough to react with all the carbon. At full load conditions, the blends like BL5, BL3 and BL2 had remarkably lowest (16%, 17% and 19%) UHC emission compared to D100. One of the basic reason for low UHC emission is proper combustion of fuel. The better combustion indicates a shorter delay period which is directly proportional to the high cetane number of fuel blends [10-11].

4. Trade-off (BSFC- BTE- NOx)
This experimental study pacts by the broad investigation (Trade-off study) done on various load (25% to 100%) levels involving NOx (Emission) and BSFC, BTE (performance). For 25% load figure 7. (a) depicts the trade-off characteristics between performance and emission. It can be observed that PKME and 2-ethyl hexyl nitrate enriched D100 has lower BTE prominently as the corresponding of D100 (shown as BL4, BL1) and has decrease a substantially lower value. Due to the rise in BTE and
NOx, BL2 lifts the trade-off area to top-zone. Figure 7. (b) shows that the load condition of 50% also displays a convincing trade-off integral with an abrupt increase in BTE and NOx. Due to the 2-EHN and PKME enrichment in BL4, the zone draws towards improved NOx readings in the left middle zone with a perceptible decrease in BTE. In figure 7. (c) (75% Load) gives a completed idea on the enhancement of trade-off zone. By enhancement in the percentage of 2-EHN and PKME in the blends, BTE and NOx are higher, and BSFC for BL2 and BL3 are lesser. BSFC and NOx emission for BL5 and BL6 is reduced for diesel blend, and BTE rises as compared to conventional diesel. At 100% load, figure 7. (d) gives a reliable trade-off zone of different fuel blends (PKME, Triacetin, 2-EHN and diesel). 2-EHN present in the blend significantly reduces the BSFC, but with higher BTE and NOx emission it is seen to rise with the rise in the amount of 2-EHN present of the fuel. In the case of BL3 and BL4 fuel, blend shows an improved trade-off zone. For both blends, BSFC is less compared to D100. In same loading conditions, BL6 shows both fuel consumption and NOx decreasing, at the same time BTE is increasing. The ideal blend just like BL5 shows a better trade-off with improved performance and controlled emission.

**Figure 7 Trade-off study (BSFC- BTE- NOx)**

5. Conclusions

- The main aim of this experimental study is to understand and utilise the effects of 2-EHN and triacetin as additives and study the engine output characteristic like performance and emission using PKME and additives with different blends. Outcomes are given below:
  - With the injection of different blends, the overall performance and emissions paradigm seems to have improved due to higher combustion rate.
  - Brake thermal efficiency (BTE) prominently improved for all blends as compared to conventional diesel at no load to full load. BL2 and BL3 had 6.3%, 3.8% BTE higher than D100 at 100% load which is maximum.
  - Brake specific fuel consumption of BL2, BL3 and BL6 are 19%, 17%, 13% respectively as compared to D100. Remaining load conditions are also observed to give a reduced BSFC.
• The NOx emission is found to be 22%, 20% and 17% higher in case of BL2, BL3, and BL4 at full load condition. But BL5, BL6 and BL7 produced 5.6%, 4.37% and 2.1% less compared to pure diesel. The basic characteristics like lower heating value and cooling effect dominate the temperature inside the combustion chamber, which is why triacetin proves to be the best additive for reduction in NOx in this case.

• It can be easily understood from the figure that, all blends give low UHC compared to pure diesel. In case of 100% load, blends like BL5, BL3 and BL2 gives lowest UHC as 16%, 17% and 19% respectively.

References
[1] Sastry, G. R. K., Deb, M., & Panda, J. K. (2015). Effect of Fuel Injection Pressure, Isobutanol and ethanol addition on performance of diesel-biodiesel fuelled DI diesel engine. *Energy Procedia*, 66, 81-84.
[2] Deb, M., Paul, A., Debroy, D., Sastry, G. R. K., Panua, R. S., & Bose, P. K. (2015). An experimental investigation of performance-emission trade off characteristics of a CI engine using hydrogen as dual fuel. *Energy*, 85, 569-585.
[3] Armas, O., García-Contreras, R., & Ramos, Á. (2012). Pollutant emissions from engine starting with ethanol and butanol diesel blends. *Fuel Processing Technology*, 100, 63-72.
[4] Dwivedi, G., & Sharma, M. P. (2015). Investigation and improvement in cold flow properties of Pongamia biodiesel. *Waste and Biomass Valorization*, 6(1), 73-79.
[5] Panda, J. K., Sastry, G. R. K., & Rai, R. N. (2017). A Taguchi-fuzzy-based multi-objective optimization of a direct injection diesel engine fueled with different blends of Leucas zeylanica methyl ester and 2-ethylhexyl nitrate diesel additive with diesel. *Journal of Energy Resources Technology*, 139(4), 042209.
[6] Sastry, Gadepalli Ravi Kiran (2008). “Bio-diesel: Biodegradable Alternative Fuel for Diesel Engines”. *Readworthy*.
[7] Kuszewski, H. (2018). Effect of adding 2-ethylhexyl nitrate cetane improver on the autoignition properties of ethanol–diesel fuel blend–Investigation at various ambient gas temperatures. *Fuel*, 224, 57-67.
[8] Panda, J. K., Sastry, G. R. K., & Rai, R. N. (2018). Experimental analysis of performance and emission on DI diesel engine fueled with diesel-palm kernel methyl ester-triacetin blends: a Taguchi fuzzy-based optimization. *Environmental Science and Pollution Research*, 25, 1-17.
[9] Ganesan, V. (2012). Internal combustion engines. *McGraw Hill Education* (India) Pvt Ltd.
[10] Paul, A., Bose, P. K., Panua, R., & Debroy, D. (2015). Study of performance and emission characteristics of a single cylinder CI engine using diethyl ether and ethanol blends. *Journal of the energy institute*, 88(1), 1-10.
[11] Panda, J. K., Krishna, V. G., & Sastry, G. R. K. (2014). Performance and Emission Analysis of Compression Ignition Diesel Engine With Diesel Additives and Mahua Biodiesel. *International Journal of Engineering*, 3(4).
[12] Sastry, G. R. K., Panda, J. K., & Dutta, P. (2015). A Study with Diesel Additives and Fish Methyl Ester on Diesel Engine at Full Load Condition. *In Applied Mechanics and Materials* (Vol. 789, pp. 179-183). Trans Tech Publications.
[13] Deb, M., Paul, A., Debroy, D., Sastry, G. R. K., Panua, R. S., & Bose, P. K. (2015). An experimental investigation of performance-emission trade off characteristics of a CI engine using hydrogen as dual fuel. *Energy*, 85, 569-585.