Comparison of properties of ternary fuel blends of diesel-octanol with biodiesel

Sidharth¹², Naveen Kumar²
¹Mechanical and Automation Engineering Department, Maharaja Agrasen Institute of Technology, Delhi, India
²Centre for Advanced Studies and Research in Automotive Engineering, Delhi Technological University, Delhi, India

Email: sidraje2002@yahoo.com

Abstract. Biodiesel is adopted by many countries as a substitute to diesel and is used in blended form in a diesel engine. It has very similar properties to diesel. However, owing to slightly higher viscosity, density and nitrogen oxide (NOₓ) emissions on burning, it still is not the best choice. Octanol, have similar properties to diesel. Octanol has added oxygen and also reduces the NOₓ emissions due to the quenching effect in the cylinder. However, its lower calorific value shall reduce engine performance. In the current study, waste cooking oil biodiesel is produced by a single step transesterification process and several blends of diesel, biodiesel and octanol were prepared. Fourier-transform infrared spectroscopy (FTIR) and oxidation stability tests of the produced biodiesel were performed. FTIR test confirmed the presence of biodiesel. Oxidation stability test of biodiesel was also passed as the induction time in over 6 hours. Blends of diesel and octanol were prepared in proportion of diesel (95%, 90%, 85% and 80%) and octanol (5%, 10%, 15% and 20%). These blends were added to 3%, 5% and 10% biodiesel. Several physico-chemical properties namely density, viscosity, calorific value, flash point and cold filter plugging point (CFPP) were determined as per ASTM standards. It is concluded that the 10% octanol, 90% diesel when mixed with 10% biodiesel showed very similar properties to diesel and shall be a viable alternative to petroleum diesel.

Keywords: octanol, diesel, biodiesel, density, viscosity, calorific value

1. Introduction

Diesel engines are the backbone of the Indian economy because of their major usage in transportation, agriculture and power sectors. India is facing the problem of pollution due to petroleum diesel and its limited resources. This has led the researchers to seek an alternative for diesel. Vegetable oils have been used at the beginning of the 20th century by Rudolf Diesel [1] and quoted as a feasible fuel for the diesel engine. However, many researches have been carried in the last few decades which have proven the usage of vegetable oil as an undesirable choice in the current high-speed engines. High viscosity, higher engine deposits, injector coking, piston ring sticking [2,3] are the major problems of using them in a diesel engine. Vegetable oils also have higher engine emissions and lower performance characteristics as compared to diesel [4–6]. The researchers are giving serious attention to biodiesel as a replacement to diesel owing to its similar properties [7–9] which may help to cope with the depleting
petroleum reserves. A long chain alkyl ester named as biodiesel is a very promising eco-friendly fuel compared to vegetable oil because of its lower viscosity, fewer engine deposits, higher cetane number, better performance and emission characteristics [10–13]. Therefore biodiesel is a viable option for developing countries who aim to be self-sustainable and also for saving the foreign exchange in procuring crude oil from oil-rich countries.

Octanol is another promising fuel to be used in the diesel engine due to its higher cetane number than other low carbon chain alcohols. Moreover, added oxygen in octanol [14] shall also help in better combustion and lower emissions. However, octanol cannot be used directly in diesel engine due to its lower heating value and higher viscosity. It is, therefore, preferable to use octanol partially in diesel engine in the form of blends. Table 1 summarizes the works carried in the past with ternary fuel blends for comparing their physico-chemical properties.

**Table 1. Effect of adding different ternary fuel blends on the properties of diesel**

| References          | Ternary Fuels                  | Effect of adding different fuels in diesel on physico-chemical properties                                                                 |
|---------------------|-------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Atmali[15]          | Diesel            | Density, kinematic viscosity, flash point and CFPP increase on increasing biodiesel content and decrease on increasing the alcohol content.   |
|                     | Biodiesel         | Lower heating value and Cetane number decrease in increasing biodiesel and alcohol percentage.                                              |
|                     | Propanol          |                                                                                                                                          |
|                     | /n-butanol/1-pentanol |                                                                                                                                          |
| Redel-Macías et al.[16] | Diesel          | CFPP increase on increasing oil percentage and decrease on increasing ethanol percentage.                                                  |
|                     | Ethanol           | Viscosity increase on increasing oil percentage and decrease on increasing ethanol percentage.                                              |
|                     | Castor oil        |                                                                                                                                          |
| EL-Seesy et al.[17] | Diesel            | Density increase on increasing oil content and decrease on increasing ethanol content.                                                     |
|                     | Ethanol           | Viscosity increase on increasing oil percentage and decrease on increasing ethanol percentage.                                              |
|                     | Castor            | Calorific value decrease on increasing oil or ethanol percentage.                                                                           |
|                     | oil               |                                                                                                                                          |
| Nanthagopal et al.[18] | Diesel          | Calorific value and cetane index decrease in increasing biodiesel or decanol percentage. However, diesel and decanol have nearly equal calorific values. |
|                     | Decanol           | Density, flash point and kinematic viscosity increase on increasing decanol and biodiesel percentage.                                        |
|                     | Calophyl lumInophyl lum biodiesel |                                                                                                                                         |
| Babu D et al.[19]   | Diesel            | Density, flash point, cloud point and pour point increase on increasing biodiesel percentage and decrease on increasing n-pentanol/n-hexanol percentage. |
|                     | Biodiesel         | Viscosity increase in increasing biodiesel and n-pentanol/n-hexanol content.                                                              |
|                     | n-pentanol/n-hexanol | Calorific value decrease in increasing biodiesel and n-pentanol/n-hexanol.                                                               |
| Qi et al.[20]       | Diesel            | Density and viscosity increase on increasing biodiesel percentage and decrease on increasing methanol percentage.                           |
|                     | Biodiesel         | Calorific value decrease in increasing biodiesel and methanol content.                                                                      |
|                     | Methanol          | Oxygen content increase with both biodiesel and methanol.                                                                                |
In the current study, several blends of diesel, waste cooking oil biodiesel (WCOB) and octanol were formulated and their properties were determined. The physico-chemical properties of waste cooking oil biodiesel were also determined for this study. Oxidation stability and Fourier-transform infrared spectroscopy (FTIR) tests were also carried out for the WCO biodiesel. Waste cooking oil was for the present work owing to the concern that most of the restaurants and cafeterias dispose of the waste oil in the drains as per the practice employed in the industry. This oil shall mix with the water bodies and contaminate it. Therefore, the oil can be used to produce biodiesel due to the favorable properties.

2. Material and Methods

Waste cooking oil was procured from a local restaurant in New Delhi, India. Chemicals of analytical grade were purchased from a local vendor. Free fatty acid (FFA) of the oil is determined using equation 1 and 2.

\[
FFA = \frac{Acid \ Number}{2}
\]  

\[
Acid \ number = \frac{56.1 \times amount \ of \ 0.1N \ sodium \ hydroxide \ solution \ consumed}{Weight \ of \ oil \ sample \ taken}
\]

(1)

(2)

Biodiesel is mainly produced from vegetable oil or animal fats by following both the esterification and transesterification processes or only by the transesterification process[21]. The process to be followed depends upon the free fatty acid (FFA) content of the fuel[22]. If the FFA of the fuel is more than 2 then a two-step process (both esterification and transesterification) is to be carried out for conversion of vegetable oil or animal fat to biodiesel. If the FFA is less than 2 then a direct transesterification process can be carried out. In the current study, waste cooking oil was used to make methyl ester in the presence of alcohol (methanol) and base catalyst (potassium hydroxide) through transesterification process.

For producing biodiesel, WCO was first passed through a fine sieve to remove heavy particles and then it is passed through filter papers to remove unwanted particles. The oil is then heated over a hot plate to reach a temperature of over 100°C to remove moisture from it. The oil is kept at that temperature for nearly 30 minutes. The oil is then cooled to the desired temperature. Catalyst (potassium hydroxide- 0.05% weight of oil) is first mixed thoroughly with methanol (20% volume of oil). The mixture of catalyst and oil is then added to the oil. This mixture of oil, catalyst and methanol is then constantly stirred over the hot plate for the desired time. The methyl ester or biodiesel so formed is allowed to settle in the separating funnel to separate out the heavy glycerine. Figure 1 shows the separation of Glycerine and biodiesel in a separating funnel.

![Figure 1](image-url)
Excess methanol is collected by heating the biodiesel. Water washing was also carried out for removing any other un-dissolved chemicals from the biodiesel and then heating it to above 100°C to remove water from it.

Octanol having 99% purity is mixed in diesel in the proportions 95:5, 90:10, 85:15 and 80:20 in percentage volume basis. Varying amount of biodiesel 3%, 5% and 10% were added to the above-mentioned proportions of the test fuels to form blends of ternary fuel.

Table 2 shows different properties of diesel, biodiesel and Octanol determined using different setups. The equipments used for the measurement of density- Anton Parr DMA 4500, Viscosity-Capillary tube, Calorific value- Parr 6100 oxygen bomb calorimeter, Flash point- BavenoPensky Martens apparatus, Cold filter plugging point (CFPP)- Normalab automatic NTE 450, Oxidation stability- Metrohm 873 Rancimat and FTIR- Thermo scientific Nicolet 380.

3. Result and Discussion

The test fuels of diesel, octanol and WCO biodiesel were kept in an undisturbed state for over 4 months. No phase separation is observed in any of the test fuel blends. FTIR test results and oxidation stability results of the produced biodiesel are shown in Figure 2 and Figure 3.

![Figure 2. FTIR of Waste cooking oil biodiesel](image)

It is seen from Figure 2 that a large peak at 1750 cm\(^{-1}\) shows the presence of biodiesel. This peak is very evident as the transesterification reaction sometimes produce the compounds which are not methyl esters and they may behave in a different manner in a diesel engine. Therefore the presence of this peak confirms the transesterification process is successful to produce biodiesel.

![Figure 3. Oxidation stability test of WCO biodiesel](image)
The oxidation stability gives us an idea about the presence of unsaturated fats in the methyl ester that may degrade the methyl ester. Since the test runs successfully for over 6 hours, therefore, the fuel qualifies both EN 14214 and ASTM D6751 standards.

It is seen from Table 2, that biodiesel has very high viscosity and density as compared to diesel. Moreover, octanol also has high viscosity as compared to petroleum diesel. It is therefore not advisable to use biodiesel and octanol in neat form. However, it is seen from the literature that oxygen content of biodiesel and octanol shall promote better combustion and hence produce less harmful emissions.

Therefore ternary fuel blends of the three are formed in different proportions and their properties are seen in Table 3 to Table 6. As discussed earlier, diesel and octanol are added in the proportions 95:5, 90:10, 85:15 and 80:20 in percentage volume basis. Varying amount of biodiesel 3%, 5% and 10% were added to the above-mentioned proportions of the test fuels to form blends of ternary fuel.

Table 2. Properties of diesel, WCO biodiesel and octanol

| S.No | Property                      | Diesel | Biodiesel | Octanol |
|------|-------------------------------|--------|-----------|---------|
| 1    | Density (at 15°C) in Kg/m³    | 837.1  | 890.7     | 822.9   |
| 2    | Viscosity (at 40°C) in cSt    | 2.51   | 5.91      | 4.98    |
| 3    | Calorific value (MJ/Kg)       | 45.42  | 41.85     | 39.74   |
| 4    | FFA                           | -      | 1.9       | -       |
| 5    | Flash Point (°C)              | 59     | 165       | 82      |
| 6    | CFPP (°C)                     | -11    | -6.1      | -12.3   |

Table 3. Properties of 95% diesel and 5% octanol when blended with 3%, 5% and 10% WCO biodiesel

| S.No | Property                      | Diesel and octanol in 95:5% volume |
|------|-------------------------------|------------------------------------|
|      |                               | WCOB 3%   | WCOB 5%   | WCOB 10%  |
| 1    | Density (at 15°C) in Kg/m³    | 838.1     | 840.4     | 842.1     |
| 2    | Viscosity (at 40°C) in cSt    | 2.74      | 2.81      | 2.98      |
| 3    | Calorific value (MJ/Kg)       | 44.85     | 44.74     | 43.91     |
| 4    | Flash Point (°C)              | 64        | 65        | 70        |
| 5    | CFPP (°C)                     | -10.7     | -10.4     | -10.1     |

Table 4. Properties of 90% diesel and 10% octanol when blended with 3%, 5% and 10% WCO biodiesel

| S.No | Property                      | Diesel and octanol in 90:10% volume |
|------|-------------------------------|------------------------------------|
|      |                               | WCOB 3%   | WCOB 5%   | WCOB 10%  |
| 1    | Density (at 15°C) in Kg/m³    | 837.4     | 838.3     | 840.1     |
| 2    | Viscosity (at 40°C) in cSt    | 2.89      | 2.93      | 3.09      |
| 3    | Calorific value (MJ/Kg)       | 44.71     | 44.67     | 44.52     |
| 4    | Flash Point (°C)              | 65        | 66        | 71        |
| 5    | CFPP (°C)                     | -10.9     | -10.7     | -10.4     |
Table 5. Properties of 85% diesel and 15% octanol when blended with 3%, 5% and 10% WCO biodiesel

| S.No. | Property                  | Diesel and octanol in 85:15 % volume |
|-------|---------------------------|--------------------------------------|
|       |                           | WCOB 3%  | WCOB 5%  | WCOB 10% |
| 1     | Density (at 15°C) in Kg/m³ | 837.2    | 837.5    | 841.8    |
| 2     | Viscosity (at 40°C) in cSt | 3.10     | 3.13     | 3.31     |
| 3     | Calorific value (MJ/Kg)   | 44.44    | 44.38    | 44.15    |
| 4     | Flash Point (°C)          | 66       | 68       | 73       |
| 5     | CFPP (°C)                 | -11.0    | -10.8    | -10.4    |

Table 6. Properties of 80% diesel and 20% octanol when blended with 3%, 5% and 10% WCO biodiesel

| S.No. | Property                  | Diesel and octanol in 80:20 % volume |
|-------|---------------------------|--------------------------------------|
|       |                           | WCOB 3%  | WCOB 5%  | WCOB 10% |
| 1     | Density (at 15°C) in Kg/m³ | 836.6    | 837.1    | 839.9    |
| 2     | Viscosity (at 40°C) in cSt | 3.22     | 3.35     | 3.48     |
| 3     | Calorific value (MJ/Kg)   | 44.16    | 44.02    | 43.81    |
| 4     | Flash Point (°C)          | 67       | 68       | 74       |
| 5     | CFPP (°C)                 | -11.1    | -10.9    | -10.6    |

It is seen from Table 3 to Table 6 that all the properties of the ternary fuel blends are very much similar to petroleum diesel. However, for more than 15% octanol blends viscosity tends to increase to a larger value. However, not much prominent change is observed for other properties of test fuel blends. Therefore, it is advisable to use to the ternary fuel blends in a diesel engine 10% octanol, 90% diesel mixed with 10% biodiesel.

4. Conclusions

The current research examined the properties of diesel, biodiesel and octanol. Biodiesel was prepared from Waste cooking oil using direct transesterification process owing to less than 2% FFA of oil. FTIR test was performed for the WCO biodiesel to verify the presence of methyl ester. A strong peak at 1750 cm⁻¹ confirms for the same. Oxidation stability was also passed for the WCO biodiesel. Several properties namely density, viscosity, calorific value, flash point and CFPP were determined. The results indicated that when 10% octanol and 90% diesel is mixed with 10% biodiesel, a very minor change is observed in the properties of the ternary fuel blends. However, for blends containing 15% and 20% octanol, higher viscosities are observed. This may lead to problems in the engine in the long run. Therefore, ternary fuels blend of 10% octanol, 90% diesel when mixed with 10% biodiesel and shall be a possible substitute to current petroleum diesel. Performance, emission and combustion studies need to be carried out in the future to get a clear insight about the test fuel blends in a diesel engine.

5. References

[1] Dash S K and Lingfa P 2018 An overview of biodiesel production and its utilization in diesel engines IOP Conf. Ser. Mater. Sci. Eng. 377 012006
[2] Tarabet L, Loubar K, Lounici M S, Hanchi S and Tazerout M 2012 Eucalyptus Biodiesel as an Alternative to Diesel Fuel: Preparation and Tests on DI Diesel Engine J. Biomed. Biotechnol. 2012 1–8
[3] Pipitone E and Costanza A 2018 An experimental investigation on the long-term compatibility of preheated crude palm oil in a large compression ignition diesel engine Biofuel Res. J. 5 900–8
[4] Dabi M and Saha U K 2019 Application potential of vegetable oils as alternative to diesel
fuels in compression ignition engines: A review J. Energy Inst.

[5] Che Mat S, Idroas M Y, Hamid M F and Zainal Z A 2018 Performance and emissions of straight vegetable oils and its blends as a fuel in diesel engine: A review Renew. Sustain. Energy Rev. 82 808–23

[6] Gad M S, El-Araby R, Abed K A, El-Ibiari N N, El Morsi A K and El-Diwani G I 2018 Performance and emissions characteristics of C.I. engine fueled with palm oil/palm oil methyl ester blended with diesel fuel Egypt. J. Pet. 27 215–9

[7] Abed K A, El Morsi A K, Sayed M M, Shaib A A El and Gad M S 2018 Effect of waste cooking-oil biodiesel on performance and exhaust emissions of a diesel engine Egypt. J. Pet. 27 985–9

[8] Abed K A, Gad M S, El Morsi A K, Sayed M M and Elyazeed S A 2019 Effect of biodiesel fuels on diesel engine emissions Egypt. J. Pet.

[9] Goga G, Chauhan B S, Mahla S K and Cho H M 2019 Performance and emission characteristics of diesel engine fueled with rice bran biodiesel and n-butanol Energy Reports 5 78–83

[10] Selaimia R, Beghiel A and Oumeddour R 2015 The Synthesis of Biodiesel from Vegetable Oil Procedia - Soc. Behav. Sci. 195 1633–8

[11] Issariyakul T and Dalai A K 2014 Biodiesel from vegetable oils Renew. Sustain. Energy Rev. 31 446–71

[12] Huang D, Zhou H and Lin L 2012 Biodiesel: an Alternative to Conventional Fuel Energy Procedia 16 1874–85

[13] Roy M M, Wang W and Bujold J 2013 Biodiesel production and comparison of emissions of a DI diesel engine fueled by biodiesel–diesel and canola oil–diesel blends at high idling operations Appl. Energy 106 198–208

[14] Rajesh Kumar B, Saravanan S, Rana D and Nagendran A 2016 A comparative analysis on combustion and emissions of some next generation higher-alcohol/diesel blends in a direct-injection diesel engine Energy Convers. Manag. 119 246–56

[15] Atmanli A 2016 Comparative analyses of diesel-waste oil biodiesel and propanol, n-butanol or 1-pentanol blends in a diesel engine Energy Procedia 117 209–15

[16] Redel-Macías M D, Pinzi S, Leiva-Candia D E, López I and Dorado M P 2017 Ternary blends of diesel fuel oxygenated with ethanol and castor oil for diesel engines Energy Procedia 142 855–60

[17] EL-Seesy A I, Hassan H and Kosaka H 2019 Improving the Performance of a Diesel Engine Operated with Jojoba Biodiesel-Diesel-n-Butanol Ternary Blends Energy Procedia 156 33–7

[18] Nanthagopai K, Ashok B, Saravanabab Ramesh Pathy M, Sahil G, Ramesh A, Nurun Nabi M and Golam Rasul M 2019 Study on decanol and Calophyllum Inophyllum biodiesel as ternary blends in CI engine Fuel 239 862–73

[19] Babu D and Anand R 2017 Effect of biodiesel-diesel-n-pentanol and biodiesel-diesel-n-hexanol blends on diesel engine emission and combustion characteristics Energy 133 761–76

[20] Qi D H, Chen H, Geng L M, Bian Y Z and Ren X C 2010 Performance and combustion characteristics of biodiesel–diesel–methanol blend fuelled engine Appl. Energy 87 1679–86

[21] Gnanaprakasam A, Sivakumar V M, Surendhar A, Thirumarimuthu M and Kannadasan T 2013 Recent Strategy of Biodiesel Production from Waste Cooking Oil and Process Influencing Parameters: A Review J. Energy 2013 1–10

[22] Chai M, Tu Q, Lu M and Yang Y J 2014 Esterification pretreatment of free fatty acid in biodiesel production, from laboratory to industry Fuel Process. Technol. 125 106–13