Experimental investigation on performance and emission characteristics of single cylinder CI engine using waste cooking oil (WCO) with diethyl ether (DEE)

A Jagotra¹, D K Singh¹, S S Sandhu¹, S Kango¹ and S S Bhadauria²

¹Department of Mechanical Engineering, Dr. B. R. Ambedkar NIT Jalandhar, India
²Department of Industrial Engineering, Dr. B. R. Ambedkar NIT Jalandhar, India

sandhuss@nitj.ac.in

Abstract. The objective of this paper is to investigate the performance and emission characteristics of WCOME (waste cooking oil methyl ester) blended with DEE (diethyl ether). The present work deals with the utilization of waste cooking oil (WCO) as feedstock for biodiesel production via transesterification process by using an alkali catalyst (KOH – 1.5 wt. %) with alcohol (methanol) under molar ratio (1:6). The concluding properties of WCOME like viscosity, density, flash point and c. were fitted by ASTM/EN standard and were resulted to be equivalent to ASTM/EN standard for diesel. Various test fuels were prepared for the engine trials by blending 10%, 20% and 30% of WCO biodiesel in diesel on volumetric basis and cognominated as diesel-biodiesel blends (B10,B20&B30 respectively) and also added 5% DEE (as an additive) in same diesel-biodiesel blends on volumetric basis and designated as diesel-biodiesel-DEE blends (B10DEE5, B20DEE5 & B30DEE05 respectively). Among all the tested blends in this study, it was observed that addition of 20% WCO biodiesel (i.e. B20 & B20DEE5 blends) spectacle the best-improved results at the full load as compared to diesel fuel, with and without the addition of 5% DEE. For 20% biodiesel blends (i.e. B20 & B20DEE5 blends) at the full load, BTE was found to be increased by 3.50 % without DEE and 0.5 % with 5% DEE addition respectively, BSFC decreased by 20.83% & no change with 5% DEE, EGT decreased by 13.33% & 8.13% with 5% DEE, NOx decreased by 9.69% & 8.59% with 5% DEE, HC decreased by 27.59% but increased by 17.24% with 5% DEE, CO does not show any change at full load, SO decreased by 49.24% & 64.89% with 5% DEE & decreased by 98.04% using DPF with 5% DEE and the CO₂ was increased by 1.89% & 3.77% with 5% DEE as compared to diesel fuel. Hence, 20% biodiesel blending shows the best performance and emissions results as compared to diesel fuel.

Keywords: WCO, transesterification, performance and emissions, biodiesel.
1. Introduction
In this modern era, researchers are more captivating on alternate fuel. It is due to increasing environmental concern and abating petroleum reservoir. Number of researchers have scrutinized on alternate renewable fuel sources and came to conclusion that vegetable oil based fuels can be used as substituted fuel. In countries like USA and Europe, rapeseed and soya bean oil are prevalent feedstock that is used in the production of biodiesel. The progression of transesterification of WCO with methanol has been explored by using KOH catalyst.

Biodiesel is paramount to ordinary diesel in relations of its sulphur concentration, aromatic content and flash point. It is fundamentally sulphur-free and non-aromatic whereas ordinary diesel can encompass up to 500 ppm SO₂ and 20–40 wt. % aromatic content. These recompenses could be a significant solution to lessen the issue of metropolitan pollution subsequently transport division is a major supporter of the total gas emissions. Many researches were abstracted to perceive the information related with conversion of waste cooking oil into biodiesel, which is used for blend with diesel, and then blend the same blending with diethyl ether and the performance testing adapted on CI engine. After done with the compiling following are the assorted researchers views related with the same, Lapuerta M et al. investigated the upshot of biodiesel fuel acquired from the waste cooking oil on a 4-cylinder, WC,4-S,TC,IC,D1 diesel engine emission. The core outcomes of this research ascertained that the PM, HC, CO, PAHs Reduced and NOx low variance (Magin Lapuerta, November 2008).

Kalam M A et al. has inspected out an investigation to study the performance and emission characteristics of an indirect ignition diesel engine powered by 5% (palm) and 5% coconut oil blended with diesel at constant 85% throttle position. The upshot illustrated a decline in both C5 and P5, reducing CO by 7.3% and 21% and HC by about 23% and 17% respectively. However, NOx emissions in C5 reduces by 1% and increases by 2% in P5. Higher CO₂ levels were witnessed in P5 than C5 (M.A Kalam, December 2003). J Predojevic Zlatica investigated the biodiesel produced by waste sunflower oils using two-step alkali transesterification by methanol and KOH as a catalyst. Also investigated the influence of various purification techniques on the properties and yields of the obtained biodiesel (Zlatica J. Predojevic, 2009).

Utlu Z et al. has reconnoitered the outcome of biodiesel from waste frying oil methyl ester on a turbocharged 4-cylinder direct injection diesel engine. From the research, it was detected that the average emission reduction was 17.14% for CO, 1.45% for NOx and 8.05% for CO₂ (Zafer Utlu, August 2008). Cheung C.S. et al. investigated the influence on emissions of 4-cylinder naturally aspirated direct injection diesel engine with various blends of WCO biodiesel (B10, B20, B30 and B100). They came to the conclusion that there is decrease in HC, CO, PM concentrations but increase in NOx (C.S.Cheung, 15 May 2017).

Howbeit, waste cooking oils (WCO) are 2–3 times more economical than vegetable oils, which subsequently, reduces the cumulative manufacturing cost of biodiesel. In addition, correspondence to the quality of biodiesel from WCO and vegetable oils can be accomplished at an optimum operating condition. Increasing food consumption has amplified the production of a large extent of waste cooking oils/fats. It was, for illustration, 4.5–11.3 million liters per year in the USA or 4105–6105 ton a year in Japan. The transformation of this amount of WCO into fuel also jettisons the impacts on environment triggered by the destructive dumping of these waste oils, such as into drains.

2. Materials
The basic feedstock required for biodiesel production is waste cooking oil and further materials like methanol, KOH (catalyst), diethyl ether were procured from Deejay chemical Jalandhar. Unwanted contaminants in the oil such as macro level particle like solid particle and food residues were separated using cotton filtration process.

3. Methods
3.1 Transesterification process
In the process of transesterification, oils and fats are filtered and pre-processed which removes water molecules and various contaminants present in it. Free fatty acids are removed or transformed into biodiesel using special pre-treatment methods. These oils and fats are then treated with an alcohol (usually methanol) in the presence of a catalyst (usually potassium hydroxide). The oil molecules (triglycerides) are then transformed into ester and glycerol, which are then separated from one another and purified. In our laboratory, we used non-edible seeds of apricot and potassium hydroxide as a catalyst with methanol to produce biodiesel.

Transesterification reactor of 5 liters per batch is used to prepare the waste cooking oil methyl ester. The WCO is fed to transesterification reactor along with 20% (by weight) methanol and 1.5% (by weight) KOH as shown in figure above. The mixture was stirred and heated to 60-65°C and left for 1 hour to continue the transesterification reaction. After the completion of reaction, the mixture of waste cooking oil methyl ester and glycerin were taken out from transesterification reactor tank to a separating funnel where two layers were separated. The top layer (methyl ester) was then washed with the distilled water at 45-50°C. For complete removal of moisture, the methyl ester was taken out in a big beaker and heated it on a heater to 110°C and bottom layer (glycerin) is taken out in other beaker which can be further purify which can be used for pharmaceutical purpose. It is to be noted that total biodiesel production depends on methanol used, base catalyst quantity, reaction time, reaction temperature and stirrer speed.

3.2 Selection of Additives- Di Ethyl Ether (DEE)
Additives are those chemicals which are used for improving various properties of the fuel. Additives are mixed to improve the efficiency and economy of fuel. Additives improve engine performance and emissions and also helps to meet environmental emission control standard. Higher molecular weight and viscosity of biodiesel leads to lower volatility and poor fuel atomization, also causing injector choking and piston ring sticking leading to incomplete combustion. Also having relative lower cold flow property act as a barrier to use it in cold or chilly weather.

4. Experimental procedure
The performance and emission characteristics of the fuel were performed on a Kirloskar Single cylinder engine coupled with an eddy current dynamometer. This is water-cooled, indirect injection, four strokes and single cylinder diesel engine. The eddy current dynamometer is equipped with a dynamometer controller to regulate loading of the engine at the required speed/load combination (Figure 2). Detailed specifications of the engine used are enlisted in Table 2.
### Table 1. Properties of fuel

| Property                        | ASTM Standards | EN Standards | Diesel | B100 (WCO) | Waste Cooking Oil | Diethyl Ether (DEE) |
|---------------------------------|----------------|--------------|--------|------------|------------------|---------------------|
| Density @ 20°C (Kg/m³)          | 860-900        | 830 - 840    | 880.97 | 907.54     | 713.4            |
| Kinematic Viscosity @ 40°C (cSt)| 1.9-6.0        | 3.5-5.0      | 1.2 -3.5 | 4.77       | 36.67            | 0.22                |
| Acid number (mg KOH/g)          | 0.50 (max.)    | 0.50 (max.)  | ------ | -----      | 6.06             | ------              |
| Flash point(°C)                 | 90°C (min.)    | Above        | 65.5°C | 125°C      | 185°C            | -45                 |
| Calorific Value (MJ/Kg)         | 42.50          | 39.25        | 38.53  | 33.89      |                  |                     |

### Table 2: Engine Specifications

| Maker   | Kirloskar          |
|---------|--------------------|
| Model   | TV1                |
| Type    | Four Stroke, Water Cooled, Diesel Engine |
| Number of Cylinder | Single cylinder       |
| Bore and Stroke  | 8705mm × 110mm   |
| Compression Ratio | 17.5:1          |
| Cubic Capacity  | 661               |
| Rated Power    | 5.2kW @ 1500rpm |

### 5. Result and discussion

#### 5.1 Performance analysis result

Figure 3. indicates the increase in BTE of B10 and B20 blends as compared to conventional diesel. However, B30 shows lower BTE at all loads compared to diesel. The higher BTE observed in the case of the B10 and B20 blends are due to the additional lubricity provided by the bio-diesel.

Figure 4. shows the results of BTE when 5% DEE is added in all the diesel-biodiesel blends. The small amount of DEE is added to improve the cold flow property of biodiesel for the better operation of an engine in excessive cold weather condition. The result shows that there is an increase in BTE of all the diesel-biodiesel-DEE blends compared to diesel, generally at all loads. This increase in BTE may be because of DEE is a highly oxygenated fuel. In addition, it has a high cetane number compared to diesel & biodiesel fuel and acts as a cetane improver for biodiesel. The addition of DEE leads to
better ignition of biodiesel that provides excess availability of oxygen, which helps to the complete and improved combustion. It was observed that B10DEE5 and B30DEE5 shows slightly decreased BTE at full load compare to diesel fuel, same as B30 blend in the earlier study (without using DEE). Among all the diesel-biodiesel-DEE blends, B20DEE5 blend shows best BTE result at full load compared to diesel fuel. While B30DEE5 shows, lower BTE result generally at all loads, when compared with diesel fuel. D95DEE5 shows the best result among all the fuel tested in this study.

Figure 5. shows that among all the diesel-biodiesel blends, B20 blend has lowest BSFC than diesel and diesel-biodiesel blends. B30 has higher BSFC, when compared to all the blends with diesel fuel but not much higher than diesel. This rise in BSFC is due to biodiesel and its blends having lower calorific value compared to diesel. So, more amount of fuel is needed for same power output.

Figure 6. shows that BSFC follows the similar trends to that of diesel with addition of 5% DEE. Thus, no adverse effect of oxygenated additive (5% DEE) is observed. All the biodiesel blends showed lower BSFC compared to diesel fuel at all loads. D95DEE5 has the lowest BSFC compared to diesel in general at all loads.

Figure 7. indicates that B20 blends have lowest EGT among all the diesel-biodiesel blends and diesel fuel. This can be explained because B20 has the highest BTE among all the blends that means complete combustion due to the maximum percentage of heat utilization during the combustion process. This leads to lower heat wastage through the exhaust, causes lower EGT.

Figure 8. shows the decrease in EGT of all the diesel-biodiesel-DEE blends compared to conventional diesel at all loads. This decrease in EGT is because of both DEE and biodiesel is an oxygenated fuel. DEE is a highly oxygenated fuel additive, which provides the excess availability of oxygen. This leads to the complete combustion of fuel and an increase in BTE. Hence, EGT decreases; because higher the BTE lower is the EGT.
5.2 Engine emission results

Figure 9. NOx vs. Load curve
Figure 10. NOx vs Load curve with 5% DEE

Figure 9. shows that NOx formation is least for B10 among all the diesel-biodiesel blends. There is a reduction in NOx emission of B20 near to full load. This reduction in NOx emissions is mainly due to reduction in the rate of heat release because of reduced pre-mixed combustion.

Figure 10. shows that addition of DEE in diesel-biodiesel blends shows same result NOx emissions as that to diesel-biodiesel blended fuels. As the DEE is highly oxygenated fuel, therefore overall oxygen content in blends with DEE become higher than simple diesel-biodiesel blends. This leads to higher NOx formation with the addition of DEE than simple diesel-biodiesel blends but much lower than the diesel fuels.

Figure 11. HC vs Load curve
Figure 12. HC vs Load curve with 5% DEE

The variation of HC emissions with load are shown in figure 11. HC emissions are mainly dependent on engine configuration, combustion temperature, fuel temperature, availability of oxygen and residence time. Unburnt hydrocarbon (UHC) emissions were found to be lower at partial load conditions and increased at higher load conditions due to relatively lesser amount of oxygen available for the reaction when more fuel was injected into the engine.

Figure 13. CO vs Load curve
Figure 14. CO vs Load curve with 5% DEE
Figure 12. shows trend of HC emissions on the addition of DEE in diesel-biodiesel blends and is approximately similar to diesel. At no load and low load conditions, B10DEE5 and B20DEE5 blends have lower HC emissions than diesel fuels. This is because of complete combustion due to the availability of excess oxygen.

In Figure 13, it has been observed that diesel-biodiesel emits considerably lower CO as compared to diesel at all loads. This lower emission of CO is due to the fact that produced CO has been converted (oxidation) into CO2 by reacting with extra oxygen present in the molecule of biodiesel fuel and thus reduced CO formation.

Figure 14. shows all the diesel-biodiesel-DEE blends have CO emission near to diesel fuel or lower than diesel fuel except B10DEE5 and B30DEE5, which shows slightly higher level of CO emissions only at full load than conventional diesel fuel in spite of the presence of oxygen within biodiesel. Nevertheless, the deviation from diesel is negligible & no adverse effect on performance and environment. This is because, as for more power output more fuel is injected into the diesel that increases the fuel/air ratio, resulting in incomplete combustion. Also, the increased value of viscosity of biodiesel further deteriorates the combustion leading to additional CO emissions.

From figure 15, it has been observed that all the tested fuels showed lower SO emission at full load operating conditions as compared to diesel fuel. Moreover, B20 shows lowest SO emission among all the diesel-biodiesel blends as compared to diesel fuel. The main reasons for lower smoke may be that the lean blends of biodiesel have additional oxygen content, no aromatic substances, higher thermal efficiency, lower fuel consumption, shorter ignition delay and lower calorific value.

Figure 16. indicates that the addition of 5% DEE in all the blends leads to a high reduction in the SO emission level compared to diesel-biodiesel blends and diesel fuel. The main reason being DEE as a highly oxygenated fuel additive having more oxygen content, no aromatic compounds, shorter ignition delay and lower calorific value. Moreover, it enhances the combustion performance ensuring complete combustion and hence reduced SO emissions.

Figure 17. SO vs Load curve using DPF

Figure 18. CO₂ vs Load curve
From Figure 17, it has been observed that the SO emission reduced nearly to zero by using DPF on the engine’s exhaust side. The DPF test was conducted with B20DEE5 and B30DEE5 blends.

Figure 18 shows the CO₂ emission of biodiesel and their blends were higher than diesel fuel. This is due to the complete combustion of the fuel because of the excess availability of oxygen in the biodiesel that causes to oxidation of more and more CO into CO₂; hence, reduction in CO emissions automatically leads to higher CO₂ emission.

Figure 19 shows that the addition of a small percentage of DEE in diesel-biodiesel blends shows same result and trends of increase in CO₂ as that in the case of diesel-biodiesel blends.

![Figure 19. CO₂ vs Load curve with 5%DEE](image)

6. Conclusion

Engine performance and emission tests were conducted on diesel, diesel-biodiesel blends (B10, B20 & B30), diesel-DEE (D95DEE5) and diesel-biodiesel-DEE blends (B10DEE5, B20DEE5 & B30DEE5). Biodiesel performance and emissions analysis were also conducted to evaluate the effect of additive (5% DEE) with the help of diesel engine test rig, AVL smoke meter and AVL Gas analyser. From the above experimental observations, it has been concluded that:

- It is feasible to convert waste cooking oil into biodiesel & physio-chemical properties of the produced biodiesel are as per the ASTM D6751 & EN 14214 standards. There is increase in BTE of blends of biodiesel with diesel compared to conventional diesel fuel at all loads except B30 blend. And among all the diesel-biodiesel blends B20 blend has the best BTE, when compared with diesel fuel.
- Also, the result shows that there is the increase BTE of all the diesel-biodiesel-DEE blends compared to conventional diesel fuel generally at all loads. Among all the diesel-biodiesel-DEE blends; B20DEE5 blend shows the best BTE result at full load. While B30DEE5 shows poor result among all the diesel-biodiesel-DEE blends. Hence B20DEE5 has best result for operation of CI engine in excessive cold weather conditions when using the diesel-biodiesel-DEE fuel in place of diesel fuel.
- Among all the diesel-biodiesel blends, B20 blend have lowest BSFC than other blends of biodiesel with diesel as compared to conventional diesel fuel. While B30 has highest BSFC among the diesel-biodiesel blends, when compared all the blends with diesel fuel but not much deviation from diesel results. In the study of all the diesel-biodiesel-DEE blends, B20DEE5 showed the best improved performance result of BSFC compared to diesel fuel.
- D80B20 blend has the lowest EGT among all blends of biodiesel with diesel when compared with diesel fuel. The addition of small amount of diethyl ether (5% DEE) as an additive also shows the decrease in EGT of all the diesel-biodiesel-DEE blends at all loads conditions compared to diesel.
- It is observed that among all the diesel-biodiesel-DEE blends, B20DEE5 showed the best result at full load but slightly increased at low loads when compared with diesel fuel but the difference is negligible & no adverse effect is observed. Hence B20DEE5 shows best EGT result for the operation of CI engine in excessive cold weather conditions when using WCO biodiesel as a biofuel in place of diesel fuel.
References

[1] C.S.Cheung, L. Z. (15 May 2017). Influence of waste cooking oil biodiesel on combustion, unregulated gaseous emissions and particulate emissions of a direct-injection diesel engine. Energy, 175-185.

[2] M.A Kalam, M. H. (December 2003). Exhaust emission and combustion evaluation of coconut oil-powered indirect injection diesel engine. Renewable Energy, 2405-2415.

[3] Magin Lapuerta, J. M.-C. (November 2008). Effect of the alcohol type used in the production of waste cooking oil biodiesel on diesel performance and emissions. FUEL, Pages 3161-3169.

[4] Zafer Utlu, M. S. (August 2008). The effect of biodiesel fuel obtained from waste frying oil on direct injection diesel engine performance and exhaust emissions. Renewable Energy, 1936-1941.

[5] Zlatica J. Predojevic, B. D. (2009). Alkali-catalyzed production of biodiesel from waste frying oils. Journal of the Serbian Chemical Society, 993-1007.

[6] United Nations, 2009, Status of Ratification of the Kyoto Protocol. United Nations Framework Convention on Climate Change, http://unfccc.int/2860.php.

[7] Rahmstorf S, and Ganopolski A, 1999, Long-term global warming scenarios computed with an efficient coupled climate model, Climatic Change, 43(2), pp.353-367.

[8] United Nations, 2011, "Environment Statistics Country Snapshot: United States", United Nations Statistics Division.

[9] Avinash K.A, Biofuels applications as fuels for internal combustion engines, Progress in Energy and Combustion Science 33 (2007): pp. 233-271.

[10] Sinha S, Agarwal A K, Garg S. Biodiesel development from rice bran oil: Transesterification process optimization and fuel characterization. Energy Conversion and Management.2008; 49: 1248-57.

Notation

B10 Blending of 10% biodiesel with 90% diesel
B20 Blending of 20% biodiesel with 90% diesel
B30 Blending of 30% biodiesel with 90% diesel
B10DEE5 10% biodiesel and 5% diethyl ether blended with 85% diesel
B20DEE5 20% biodiesel and 5% diethyl ether blended with 75% diesel
B30DEE5 30% biodiesel and 5% diethyl ether blended with 65% diesel
D95DEE5 95% diesel blended with 5% diethyl ether
WCO Waste Cooking Oil