An Experimental Study on Utilization of Waste Transformer Oil in a Single Cylinder Diesel Engine as an Alternative Fuel

Rupjeet Das1, Rajeev kumar1 and Amit K. Sharma2*

1Department of Electrical and Power Engineering, UPES Dehradun, Uttarakhand, India
2Engine and Biofuel Research Laboratory, UPES, Dehradun, Uttarakhand, India

Received Date: June 24, 2017, Accepted Date: August 04, 2017, Published Date: August 22, 2017.

*Corresponding author: Amit K. Sharma, Engine and Biofuel Research Laboratory, UPES Dehradun, Uttarakhand, India, E-mail: amit.orgchemistry@gmail.com.

Abstract

The price hikes due to the conflict of increasing energy demands and limited reserves of petroleum oils, coupled with environmental issues caused by limited degradation of spilled petroleum hydrocarbons have posed great pressure on human to explore alternative/renewable energy sources. To resolve above problems, Waste Transformer Oil (WTO) may be one of the best alternative fuels. This manuscript aims the upgradation of WTO and its application in Direct Injection (DI), diesel engine for emission reduction. Experiments were conducted in two phases. In the first phase, WTO was transesterified using methanol and a catalyst to reduce viscosity of WTO. The physico-chemical properties (e.g. viscosity, density, flash point, calorific value etc.) of Transesterified Waste Transformer Oil (TWTO) are compared with conventional diesel fuel. In the second phase, a single cylinder, water cooled, four Strokes diesel engine was used to run using TWTO and its blends with conventional. Diesel (diesel, B25, B50, B75 and B100) to evaluate the performance and emissions. The results showed that TWTO blends result in slightly increase of efficiency and reduction of emissions. At last it is concluded that WTO can be used as alternative fuel in DI diesel engine with reducing emissions.

Keywords: Transesterification; WTO; BTE; Emissions; Diesel engine

Introduction

Energy is the backbone of the modern world, which serves in all the sectors that includes transportation, agricultural, commercial and domestic and power generation. The demand of energy is increasing continuously due to increasing population, industrialization modernization of the world [1]. Currently, fossil fuel is mostly used to fulfill energy requirement of the world. However, there are limited sources of fossil fuel available worldwide and it tends to decrease due to continuously exploration [2]. It is estimated that fossil fuel reserve will be diminished within some decades. In addition, combustion of fossil fuel also results in the environmental pollution. Therefore, interest of energy researchers has increased towards renewable and clean energy sources. Presently, biodiesel, bio ethanol, biogas, pyrolysed oil, bio-butanol are the some alternative fuels which can be utilized in DI diesel engine without any modification. Besides, the application of Waste Transformer Oil (WTO) in diesel engine to reduce emissions and energy demands is also getting interest [3].

Power or electrical transformers, the main source for supply of electrical energy, are installed in small, medium and large power stations. In each transformer, lubricating oil, commonly called as transformer oil, employed for insulation and cooling purpose. During operation of transformer, transformer oil is subject to mechanical and electrical resistance which results to its deterioration and degradation. This may affect the life of electric transformer. Therefore, it is necessary to check the physico-chemical properties of transformer oil time to time. The quantity of WTO increasing day by day due to installation of new transformers and from scrap of old transformers [4,5]. As transformer oil is less bio-degradable and could contaminate our soil and waterways, if serious spills occur. The used transformer oil is disposed in many ways: including incineration, land spreading, and dumping on the ground and into water. All used transformer oil eventually creates environmental hazard. However, combustion and incineration of wastes is often difficult and cleaning of fuel gases is complex and expensive because they contain important quantities of contaminants.

The disposal of waste is now becoming difficult which is not only occupying valuable land resources but also causing a threat to surface and ground water bodies resulting into environmental hazards. Development of innovative methodologies for utilization of this industrial waste in various value added materials has become an essential [4–6]. The application of WTO in diesel engine seems a good option to solve the above problems.

Nabi MN et al. [7] stated in their study the suitability for using WTO as an alternative fuel for Compression Ignition (CI) engine. They refined WTO via transesterification process to utilize in diesel engine for performance evaluation. They compared fuel properties with WTO and RWTO with conventional Diesel Fuel (DF) and found that all properties were close to those of DF. The engine performance with WTO and RWTO was much better than that of DF. Based on these findings, they suggested that WTO and RWTO can be used as alternative fuels for CI engine.

Behera P et al. [3] studied the combustion, performance and emission parameters of a single cylinder, four stroke, and air cooled, DI diesel engine, fuelled with WTO and six of its diesel blends on varying the WTO concentration from 10% to 60%, at a regular interval of 10% by volume basis. The results were analysed and compared with diesel operation. Increase in thermal efficiency with significant improvement in reduction of smoke was observed for WTO and its diesel blends. Emissions were also reduced for WTO and its diesel blends.

Orhan Arpa et al. [8] stated that the Diesel Like Fuel (DLF) is produced from waste engine lubrication oil by purification of dust, heavy carbon soot, metal particles, gum-type materials and other impurities. The DLF is produced by using the system and applying pyrolytic distillation method. Characteristics, performance and exhaust emissions tests of the produced DLF are carried out at the end of the production. Performance and exhaust emission tests for the DLF are performed using diesel test engine. It is observed that the produced DLF can be used in diesel engines without any problem in terms of engine performance. The DLF increases torque, brake mean effective pressure, brake thermal efficiency and decreases brake specific fuel consumption of the engine for full power of operation. From the literature, it is observed that most of studies were carried out using 0 to 60% WTO – diesel blends.

However, very fewer studies were carried out on up-gradation...
of WTO via transesterification and its application in single cylinder four stroke diesel engine. Therefore, the present study aims to upgrade the transformer oil by transesterification, analysing its fuel properties and application in single cylinder four stroke diesel engine. The various blends of the transesterified WTO (TWTO) such as 25%, 50%, 75% and 100% was named as B25, B50, B75 and B100 respectively. TWTO was analysed and compared to that of the neat diesel fuel. The experiment investigation was conducted and the results are recorded.

**Materials and Methodology**

**Upgradation of WTO**

WTO was collected from local power station, Dehradun. For upgradation, it was transesterified using methanol as co-solvent and KOH as catalyst at 65°C and 400 rpm for four hrs in a biodiesel reactor. TWTO were analysed for physico-chemical properties such as viscosity, density, flash point and calorific value. Different blends (Diesel, B25, B50, B75 and B100) with conventional diesel were also prepared. The fuel properties of TWTO and its blends were shown in table 1.

**Experimental Setup**

The experimental setup is shown in figures 1, 2. A Single cylinder water-cooled four-stroke direct injection diesel engine Kirloskar TV-I, compression ratio of 17.5:1, developing 5.2 kW at 1500 rpm was used for this work. Details of the engine are given in table 2. AVL Di-gas analyser is used to measure the emissions (CO, CO₂, HC and NOₓ). A burette is used to measure the fuel consumption for a specified time interval. To examine the performance and emissions, a diesel engine was run with B25, B50, B75 and B100 fuel blends at different loads and compared with base line fuel i.e. neat diesel. The experiments were repeated three times and average values are shown in results and discussion.

<table>
<thead>
<tr>
<th>Property</th>
<th>Diesel</th>
<th>WTO</th>
<th>TWTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic Viscosity cSt @ 27°C</td>
<td>2.8</td>
<td>19</td>
<td>7.3</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>830</td>
<td>910</td>
<td>893</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>68</td>
<td>165</td>
<td>156</td>
</tr>
<tr>
<td>Pour point (°C)</td>
<td>-1.2</td>
<td>-5.6</td>
<td>-2.3</td>
</tr>
<tr>
<td>Caloric value (kJ/kg)</td>
<td>43890</td>
<td>36245</td>
<td>37245</td>
</tr>
<tr>
<td>C (%)</td>
<td>83.6</td>
<td>87.56</td>
<td>86.35</td>
</tr>
<tr>
<td>H (%)</td>
<td>14.8</td>
<td>11.34</td>
<td>12.89</td>
</tr>
<tr>
<td>N (%)</td>
<td>0.38</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>S (%)</td>
<td>0.7</td>
<td>0.39</td>
<td>.57</td>
</tr>
</tbody>
</table>

**Table 1:** Fuel properties of conventional diesel and WTO.

![Figure 1: Schematic view of the experimental setup.](image1)

![Figure 2: Experimental setup used for TWTO Testing.](image2)
Results and Discussion

Upgradation and Fuel Properties of WTO

The fuel properties of upgraded Transformer Waste Oil (TWTO) were shown in table 1. To make it eligible to run in engine, it is necessary to reduce viscosity. Higher viscosity leads to poor mixing and atomisation, thus results in higher emissions due to incomplete combustion [9]. The results revealed that the viscosity of transesterified WTO was reduced from 19 cSt to 7.3 cSt. In addition density of TWTO was observed 893 kg/m³ in comparison to WTO (910 kg/m³). Flash point and calorific value of TWTO was found to be 156°C and 37245 kcal/kg. On the basis of these fuel properties it can be decided that TWTO has a great potential as alternative fuel in diesel engine. Therefore, different blends of diesel and TWTO were prepared and used in single cylinder diesel engine to analyse performance and emissions.

Brake Thermal Efficiency

Brake Thermal Efficiency (BTE) is the ratio of brake power to the energy delivered by the fuel. Brake thermal efficiency increases with the increase in engine load (brake power) for all fuels/blends (Figure 3).

The BTE for B25 fuel is very close to that of diesel. The maximum BTE for diesel at full load is 27.10%, for B25 the value is 27.60%, B50 is 27.66%, B75 is 26.02% and B100 is 25.45%. Generally, the increasing shares of TWTO in fuel blends results into higher density, viscosity and lower calorific value. The engine efficiency is mostly affected by the following four properties: inherent oxygen, higher density, higher viscosity, and lower calorific value [9]. In case of B25 and B50 inherent oxygen presence dominates over higher density, viscosity and lower calorific value. Due to which engine performs better with B25 and B50 in comparison to diesel. On the other hand, B75 and B100 fuel blends showed lower BTE than diesel which are due to dominance of higher density, viscosity and lower calorific value over inherent oxygen. Brake Specific Fuel Consumption (BSFC) is a measure of volumetric fuel consumption for any specific fuel. BSFC of all blends was increased with increasing load. In addition, the BSFC also increased with increasing concentration of TWTO in fuel blends. The maximum BSFC was 0.3026g/kWh, 0.3055g/kWh, 0.3099g/kWh, 0.3470g/kWh and 0.3797g/kWh for Diesel, B25, B50, B75 and B100 at full load. Similar results are obtained by khan et al. [10] and Behera et al. [3] with diesel -biodiesel blends and diesel-WTO blends. The reason behind this is that increasing share of TWTO in fuel blends results into lower calorific value which leads to higher fuel consumption.

Carbon Monoxide Emissions

Normally for diesel engine the amount of CO in the emission will be less since it works with lean air-fuel mixture. The variation of carbon monoxide with brake power is shown in figure 4. The results revealed that CO emissions increase with increase in load. In addition, the increase of TWTO concentration in fuel blends also results in lower carbon monoxide emissions. B25 shows the higher carbon monoxide emission when compared to diesel fuel and all other blends. Except B25, all other blends similar to that of diesel fuel up to part load beyond to that it decreases marginally. B100 emits less carbon monoxide which indicates the complete combustion of the fuel. Reduced CO emissions were maintained due to presence of inherent oxygen in fuel blends which makes it easier to be burnt at higher temperature in the cylinder [9,11].

Hydrocarbon Emissions

Hydrocarbon emissions are generally the unburned HC residue of fuel after combustion, which indicate the combustion inefficiency of the engine. The effect of engine load on hydrocarbon emissions has been shown in figure 5. The hydrocarbon emissions of various fuels/ blends basically increase at higher loads but lower in low and medium loads. This is because, at higher loads, when more fuel is injected into the cylinder of engine, free oxygen availability

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make</td>
<td>Kirloskar TV- 1 Engine</td>
</tr>
<tr>
<td>Type</td>
<td>Single cylinder, vertical, water cooled, 4-Stroke diesel engine</td>
</tr>
<tr>
<td>Bore × Stroke</td>
<td>87.5 mm × 110 mm</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>17.5:1</td>
</tr>
<tr>
<td>Fuel</td>
<td>Diesel</td>
</tr>
<tr>
<td>Rated brake power</td>
<td>5.2 kW (7HP)</td>
</tr>
<tr>
<td>speed</td>
<td>1500 rpm</td>
</tr>
<tr>
<td>Ignition system</td>
<td>Compression Ignition</td>
</tr>
<tr>
<td>Ignition timing</td>
<td>23° BTDC (rated)</td>
</tr>
<tr>
<td>Injection Pressure</td>
<td>220 kgf/cm²</td>
</tr>
<tr>
<td>Loading Device</td>
<td>Eddy current dynamometer</td>
</tr>
<tr>
<td>Orifice Diameter</td>
<td>0.02 m</td>
</tr>
<tr>
<td>Dynamometer arm length</td>
<td>0.195 m</td>
</tr>
</tbody>
</table>

Table 2: Specifications of the test engine.
is relatively less for the reaction [9,11]. This leads to incomplete combustion resulting higher HC emissions.

**Oxides of Nitrogen**

The formation of oxides of nitrogen in the exhaust depends on cylinder temperature and the amount of oxygen available during combustion. Ignition delay is due to high viscosity and molecular structure. Higher cetane number indicates shorter ignition delay time, meaning more combustion products, have a longer residence time at high temperatures for complete combustion [12] of fuel which leads to NOx emission. It is observed that the NOx emission is increased with increase in the load (Figure 6). At full load, B100 gave 218 ppm lower NOx emission compared to that of diesel. This reduction in NOx emission is due to the reduced rate of heat release. It is observed that oxygenated fuel blends can result in increase in NOx emission. Higher combustion temperature due to complete combustion results in higher NOx formation. Diesel engines release significant quantities of NOx emissions since the combustion temperature is higher than 1800K which is reported as the threshold temperature for NOx formation by Zeldovich mechanism. At this point, it should be said that three important parameters which are effective on the NOx formation are temperature, oxygen concentration and combustion duration. Because of the enhancement of combustion quality with the increment of combustion temperature and pressure, in general, the NOx emission increases. At the stoichiometric mixtures, NOx formation is maximum while it decreases with the fuel-rich and fuel-lean mixtures. The reason for this reduction in NOx formation is oxygen deficiency and lower in-cylinder temperatures for fuel-rich and fuel-lean mixtures, respectively.

**Conclusion**

The experiments are carried out on a single cylinder diesel engine using TWTO derived from WTO as an alternate fuel. The main objective of this experiment was to use transformer oil as an alternative fuel. Blending the transformer oil in diesel and used in DI diesel engine for better use. The performance and emission characteristics of blends are evaluated and compared with diesel. From the above results, the following conclusions are drawn. High brake thermal efficiency at low and medium loads. For B25 there is 2.1% increase in brake thermal efficiency at low loads as compared to diesel. It is found when compared to those of diesel that hydrocarbon emission reduces, carbon monoxide and smoke slightly increases while oxides of nitrogen reduces slightly by 1%. The present experimental results show that TWTO can be used as an alternative fuel in diesel engine. Alternate fuel from waste resources is a popular and promising environment friendly alternative fuel due to its renewable nature, less greenhouse effect, clean burning characteristics and more greenery and rural economy.

**Conflict of Interest**

The authors declared there is no conflict of interest.

**References**


*Corresponding author: Amit K. Sharma, Engine and Biofuel Research Laboratory, UPES Dehradun, Uttarakhand, India, E-mail: amit.orgchemistry@gmail.com.

Received Date: June 24, 2017, Accepted Date: August 04, 2017, Published Date: August 22, 2017.

Copyright: © 2017 Das R, et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.