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# Evaluation of Properties and use of waste vegetable oil (WVO), pure vegetable oils and standard diesel as used in a compression ignition engine

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## ABSTRACT

*This work aims to investigate the viability of using vegetable oils and waste oils an alternative to or additive to basic diesel fuel. Rapeseed oil, sunflower oil and waste cooking oils were used to manufacture bio-diesel oil by the transesterification process using a commercially available "fuelpod". The base oils were tested to first characterize them against diesel and the characteristics were remeasured after the conversion process. The fuels were then tested on a steady state engine test rig using a modern four cylinder compression ignition engine. Significant improvement in the viscosity was observed in the waste vegetable oils (WVO) after the transesterification process. The specific fuel consumption and exhaust gas emissions were reduced due to decrease in viscosity of the WVO. Acceptable thermal efficiencies of the engine were obtained with biodiesel. From the properties and engine test results it has been establish that biodiesel of WVO can be substituted for diesel without any engine modification and preheating of the fuels. Sustainability issues present an obstacle for general use so only small fleet operators may take advantage of the alternative fuel.*

**Keywords** waste vegetable oil, biodiesel, viscosity, alternative fuels, CI engine

## 1 INTRODUCTION

Every year the automotive industry manufactures and releases 70 million vehicles into the market. The numbers are 56 million cars & 10.5 million light CV, 2.5 Heavy CV and 0.5 Heavy Bus. Within the next 5 years to number of vehicles on the road will exceed one billion. That number equates to about 9 trillion litres of fuel needed each year. By 2020 there will be about 40 million electric vehicles on the road, this number including motor cycles. The total number of electric vehicles therefore represents less than 4% of the total vehicle market, the rest being CI engines. It is clear that for the foreseeable future there will be an increasing demand for CI engine fuels, of one form or another.

The objective of this study is to find an immediate alternative and sustainable energy solution, which does not involve a drastic overhaul of the world's engine structure. Obtaining a viable solution is one which will not only be sustainable but must reduce the global greenhouse emissions over the petroleum diesel counterpart whilst maintaining a similar output in terms of performance and efficiency. It is therefore the intention of this study to look at how the alternative bio-fuels compare to petroleum diesel and identify the benefits, and viability, of recycling used waste vegetable oil. It is recognized within the industry that there are a variety of problems associated with vegetable oils being used as fuel in compression ignition (CI) engines; typically, cold starting, water ingress, fuel pumps require extensive maintenance and injectors exhibit lacquering. It has been suggested that some of these issues are mainly caused by their high viscosity. Such problems cause the pump and injector manufacturers to issue a common statement each year condemning the use of bio-diesels. As such engine manufacturers suggest blends of bio-diesel with pure diesel of no more than 5%. Some do permit greater blends but impose such inspection and testing criteria that the use of increased blends becomes prohibitively expensive. Engine warranty thus becomes a significant barrier to the extensive uses of bio-diesels.

The high viscosity of oils is due to the large molecular mass and chemical structure of vegetable oils, which in turn leads to the problems of pumping and excessive load on the pumps, combustion and atomization in the injector systems of a diesel engine which leads to the lacquering issues. Therefore, a reduction in viscosity is of prime importance to make vegetable oils a suitable alternative fuel for diesel engines. The problem of high viscosity of vegetable oils has been approached in several ways

such as preheating the oils (PRAMANIK (2003), blending with other fuels, transesterification process and thermal cracking/pyrolysis. This study will be focus on the transesterification process.
The emissions and engine performance of diesel engines fuelled with biodiesels have been examined by many investigators. The biodiesels used in this investigation are all first generation and were produced from a range of different vegetable oils such as palm, soybean, Karana and waste cooking oils. Vegetable oils have an ignition quality equivalent to diesel oils and their combustion characteristics are much the same - but their viscosity is too high for the modern fuel pumps designed to work with standard diesel or at worst 5% blend (B5). Researchers have indicated that higher viscosity results in incomplete atomisation of neat vegetable oil fuel which in turn prevents complete combustion of large fuel droplets resulting in carbon deposits (lacquering). It was also found that knocking, encountered during the test at low load and low cylinder temperature, was due to the low cetane number of vegetable oil (NWAFOR et al (2000)). The use of vegetable oils investigated by Barnwal et al (2005), such as palm, soya bean, sunflower, peanut, and olive oil, as alternative fuels for diesel engines dates back almost nine decades, but due to the rapid decline in crude oil reserves, it is again being promoted in many countries. Depending upon the climate and soil conditions, different countries are looking for different types of vegetable oils as substitutes for diesel fuels. For example, soya bean oil in the United State, rapeseed and sunflower oils in Europe, palm oil in South-east Asia (Malaysia and Indonesia) and coconut oil in the Philippines are being considered. Biodiesel which is accepted as an attractive alternative fuel is prepared by transestrifiaction of vegetable oils and animal fats with an alcohol in the presence of a catalyst. However, the land use for production of edible oil for biodiesel feedstock competes with the use of land for food production and this is an argument that concerns all researchers – is the fuel sustainable regardless of its properties? Moreover, the price of edible plant and vegetable oils is usually higher than petrodiesel. The use of waste vegetable oil as biodiesel base oil reduces the cost of biodiesel production (Canakci (2007)), since feedstock costs constitutes approximately 70-95% of the overall cost of biodiesel production (Connemann (1998)). Hence, the use of waste vegetable oils and non-edible oils should be given higher priority over the edible oils as biodiesel feedstock. Huge quantities of waste vegetable oils and animal fats are available throughout the world. Management of such oils poses a significant challenge because of their disposal problems and possible contamination of water and land resources. The Energy Information Administration in the United States estimated that some 100 million gallons of waste cooking oil is produced per day in USA, where the average per capita waste cooking oil was reported to be 9 pounds (Radich (2006)). In the EU countries, the total waste cooking oil production was approximately 700,000-1,000,000 tons/year (Kulkarni et al (2006)). The UK produces over 200,000 tons of waste cooking oil per year (Carter et al (2005)) and large amounts of waste cooking oils are illegally dumped into rivers and landfills, causing environmental pollution (Yang et al (2007)). The use of waste cooking oil to produce biodiesel as petrodiesel substitute offers significant advantages because of reduction in environmental pollution. Biodiesel has been reported as a possible substitute or extender for conventional diesel and is comprised of fatty acid methyl/ethyl esters (FAME), obtained from triglycerides by transesterification with methanol or ethanol. Transesterification of vegetable oils with simple alcohol has long been the preferred method for producing biodiesel. Through transesterification, high viscosity is reduced to a value closer to that of diesel fuel while cetane number and heating value are maintained (Canakci et al (2008)).

## 2 MATERIALS

The Rapeseed oil and Sunflower oil is readily available from most general stores and the waste cooking oil was supplied by Huddersfield University Catering Services. The diesel oil (B0) is not commercially available, as general sales is B5, therefore B0 needs to be obtained for specialist oil suppliers.

## 3 EXPERIMENTAL FACILITIES AND PROCEDURES

### 3.1. Biodiesel production process

The University of Huddersfield have procured a "Fuelpod" for the production of biodiesel from any first or second generation oils. In this study the oils converted to bio-diesel were rapeseed oil, sunflower oil and Waste Vegetable Oil (WVO). The general production procedure is to fill the "Fuelpod" with about 50 litres of each type of oil and heated at to heat it to 65 $^{o}$C and main that temperature for 2-3 hours. A separately prepared mixture of 200 gm of sodium hydroxide NaOH (the amount of NaOH needs to be increased if the oil contains a measurable amount of free fatty acid. The free fatty acid consumes the sodium hydroxide (NaOH), converting it to the sodium salt). The NaOH required for the transesterification is dissolved in 8 litres of methanol and added to the tank. Ester forms in the upper layer - in the separating funnel whereas glycerol forms the lower layer. The "Fuelpod" used to convert base oils to biodiesel. It is complete system and corresponding methodology for making biodiesel within the Automotive Laboratory at The University of Huddersfield.

### 3.2 Biodiesel as a fuel for CI engine

The performance of the biodiesel produced by the transesterification process was evaluated on a Euro 4 diesel engine mounted on a steady state engine test bed. The engine was a four-stroke, direct injection diesel engine, turbocharged diesel, 2009 2.2L Ford Puma Engine as used on the range of Ford Transit vans. The general specification was Bore = 89.9 mm, stroke = 94.6 mm, engine capacity = 2402 cc, compression ratio = 17.5:1, fuel injection release pressure = 135 bar, max power = 130 kW @ 3500 rpm, max torque = 375.0 Nm @ 2000-2250.
Emissions were measured using a Horiba EXSA 1500 system, measuring CO2, CO, NOx and THC. The test procedure was to run the engine at 25, 50, 75 and 100% engine load over a range of predetermined speeds, 1500, 2200, 2600, 3000 & 3300 rpm. At each of these settings the torque, fuel consumption and emissions were measured for each of the diesels, the standard diesel forming the benchmark.

## 4 RESULTS AND DISCUSSION

### 4.1. Biodiesel production

It was important to manufacture the diesels and test them within a short space of time as this eliminated the "aging" and contamination element that may occur with fuels standing for long periods of time. The experiment of biodiesel production was repeated for each batch of oils to determine the yield of biodiesel and glycerin in "Fuelpod" machine. The average yield of biodiesel were found to be 47 litres thus, the average yield of biodiesel obtained after transesterification process was about 94% by volume from the oils. The average amount of glycerol obtained as a by-product from 50 litres of vegetable oils was 6 litres.

### 4.2. Fuel properties

The fuel properties of standard diesel and biodiesel are presented in Table 1. The calorific values of the biodiesel were found using a "bomb calorimeter" to be about 37 MJ/ kg. However, the calorific value of standard diesel fuel was 42.5 MJ/kg, about 13% more than the biodiesel. The reason for the lower value is because of the presence of chemically bound oxygen in vegetable oils which lowers their calorific values (by about 13 % in this case) as shown in the table. It is also shown in Table 1 that the kinematic viscosity of vegetable oils was found to change from 40 to 5 mm$^2$/s at 40 $^o$C – this is a significant change. The initial high viscosity of these oils is due to their large molecular mass in the range of 600-900, which is about 20 times higher than that of diesel fuel (Barnwal et al (2005)). The reduction in viscosity during transeserification process reduces the problem associated with using vegetable oil in the engine such as cold starting and pump loading in the colder climates. The density of biodiesel and diesel were determined and found to be about 885 and 845 kg/m$^3$, respectively - similar. The flash point of biodiesel was found between 167 and 179 $^o$C. Cloud and pour point were also determined and found between -39.7 and 2$^o$C.

**Table 1: Properties of standard diesel and biodiesel**

| Fuels | Kinematic Viscosity At 40$^o$C (mm$^2$/s) | Calorific Value (MJ/kg) | Cloud Point ($^o$C) | Pour Point ($^o$C) | Flash Point ($^o$C) | Density (kg/m$^3$) At 15$^o$C |
|---|---|---|---|---|---|---|
| Rapeseed oil | 37.98 | 37.37 | -3.9 | -6.7 | 246 | 910 |
| Sunflower oil | 33.72 | 37.26 | 7.2 | -15.0 | 274 | 920 |
| WVO | 41.7 | 37.16 | 0 | -39.7 | 279 | 910 |
| Rapeseed Biodiesel | 4.47 | 37.70 | -1 | -11 | 163 | 880 |
| Sunflower Biodiesel | 4.53 | 37.00 | 1 | -6 | 173 | 885 |
| WVO Biodiesel | 5.58 | 37.90 | 2 | -7 | 179 | 885 |
| Diesel | 2.4 | 42.54 | -5 | -17 | 76 | 845 |

### 4.3. Effect biodiesel on engine performance

Figure 1 shows the variation in the brake power with the engine speed of the test engine operated at full load condition of standard diesel and different type of biodiesel. The brake power reached its peak value at the speed of about 2600 rpm for all fuels. The brake power of the engine with standard diesel was higher than that biodiesel for all types. At higher speeds of 2600 and 3300 rpm, standard diesel produced 5.5% and 5.8% higher power compare with rapeseed biodiesel, whereas it was produced 10.5% and 12.9% higher power compare with sunflower and WVO biodiesel. Due to the fact that the lower calorific value of biodiesel was about 13% lower than that of standard diesel, both torque and brake power reduces. However, difference in the brake power between standard diesel and biodiesel were very small in most cases. Figure 2 shows the variation in the torque of the engine fuelled with standard diesel and different type of biodiesel versus engine speed. It was observed that the engine yields the maximum torque for all fuels in the speed range of 1500 to 2000 rpm, while the minimum torque was obtained in the range of 3000 to 3300 rpm. The torque of the engine fuelled with standard diesel was higher than that biodiesel. The reason for the reduction of torque with biodiesel can also be attributed to the lower calorific value of the biodiesel. The mean increase in the torque between standard diesel and biodiesel was determined as 8.2%. Figure 3 shows the variations in the BSFC of both standard diesel and biodiesel with respect to the engine speed. The Brake Specific Fuel Consumption (BSFC) is the ratio of the fuel consumption to the engine brake power. The BSFC for biodiesel operation was on an average 11.6% higher than that for standard diesel operation. This increase may be attributed to the collective outcomes of the higher fuel density, higher fuel consumption and lower brake power due to lower calorific value of the biodiesel. The higher BSFC was obtained at WVO compared with other type of biodiesel. Compared to WVO biodiesel, the BSFC was averagely 13.2% and 2.8% lower for standard diesel and rapeseed biodiesel, respectively.

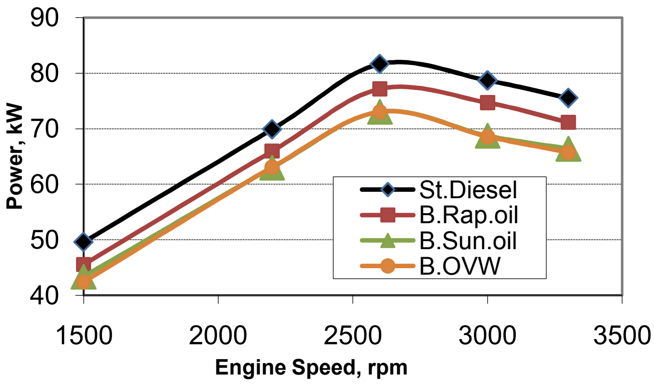


**Figure 1: Brake power versus engine speed for fuels tested at full load**

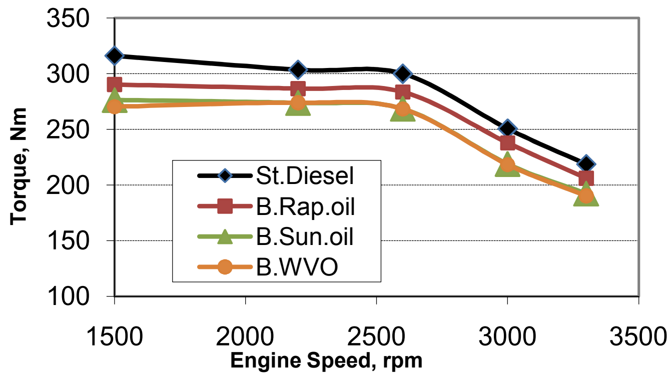


**Figure 2: Brake torque versus engine speed for fuels tested at full load**

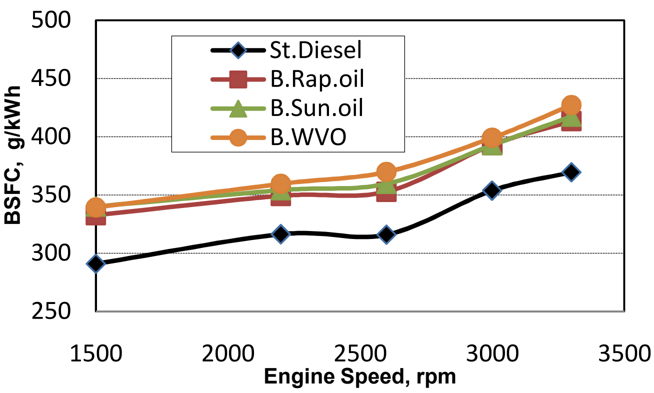


**Figure 3: BSFC versus engine speed for fuels tested at full load**

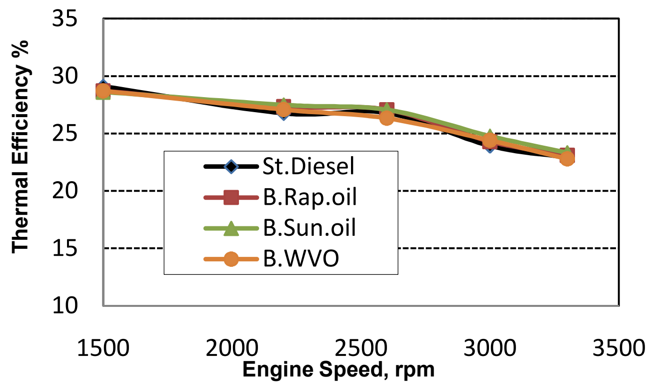


**Figure 4: Thermal efficiency versus engine speed for fuels tested at full load**

Brake thermal efficiency for standard diesel and biodiesel as a function of engine speed are shown in figure 4. The maximum thermal efficiency values were observed in the range 1500 to 2200 rpm for the standard diesel and biodiesel. It was seen that biodiesel has higher thermal efficiency than standard diesel and the mean difference between them was about 1.5%. The improvement of thermal efficiency with biodiesel can be attributed to the oxygen content and higher cetane number of biodiesel. These properties lead to favourite effects on the combustion process and improve thermal efficiency slightly in biodiesel operation in spite of lower calorific value of biodiesel.

### 4.4 Effect of biodiesel on exhaust emissions

Figure 5 shows the variation of HC emission with load for standard diesel and three different type of biodiesel. It was observed from the figure 5 that biodiesel produces relatively lower HC emission, compared to that of standard diesel at all cases. This may be attributed to the availability of oxygen in biodiesel, which facilitates better combustion. Also it was seen that HC emission of biodiesel was almost identical. There was a reduction of 25.3% in hydrocarbon emission for WVO biodiesel, whereas it was 39.5% for sunflower biodiesel. The variation of carbon dioxide emission at different loads for standard diesel and biodiesel is shown in figure 6. At 25% and 50% loads, $CO_2$ emissions of the diesel were not much different from those of biodiesel. However, at full load, $CO_2$ emissions of the standard diesel decrease significantly when compared with those of biodiesel. $CO_2$ emissions of biodiesel operation were averagely 7% lower than those of standard diesel operation. Biodiesel has higher cetane number compared standard diesel, which causes lower ignition delay period and autoignition capability. High oxygen content of biodiesel associated with lower ignition delay period provides an important reduction in $CO_2$ emission by improving combustion.

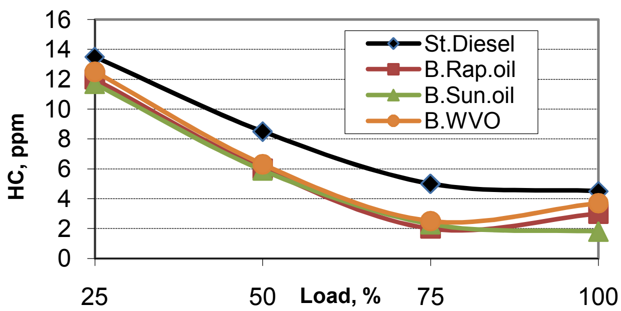


**Figure 5: Variation of hydrocarbon emissions with load for fuels tested**

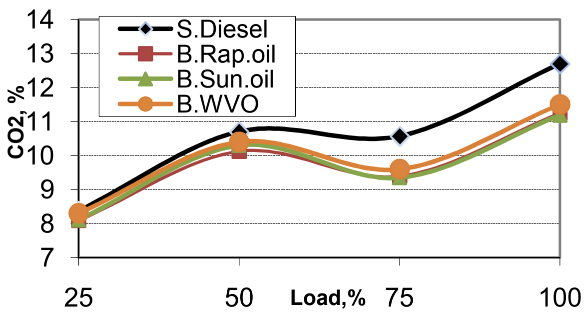


**Figure 6: Variation of carbon dioxide emissions with load for fuels tested**

## 5 DISCUSSION & CONCLUSIONS

Based on the results of this study, the following specific conclusions were drawn.

Biodiesel processor "Fulpod" was used for the production of biodiesel from WVO and pure vegetable oil by using alkali-catalyzed transesterification process. The maximum ester yield was obtained by using 16% methanol and 8% NaOH at 65$^{o}$C reaction temperature. Production of biodiesel from WVO for diesel substitute is particularly important because of the decreasing trend of economical extracted oil reserves and environmental problems caused due to the use of fossil fuel. The fuel properties, such as kinematic viscosity, density, calorific value and cloud, pour and flash point, were measured and found significant reduction in viscosity was achieved by esterification of WVO and pure vegetable oil. It is significant to note that after esterification of oils, the kinematic viscosity was reduced to 5 mm$^2$/s from 40 mm2/s. For the analyzed samples, the properties were similar in some cases and diverge in other. The brake power and torque of the engine with standard diesel were higher than those with biodiesel at all engine speed operation. Due to the fact that the lower calorific value of biodiesel was lower than that of diesel fuel, both torque and brake power reduce. Because of higher fuel density and lower calorific value, biodiesel showed slightly higher BSFC in comparison with standard diesel. The NOx emission with biodiesel was higher than that with diesel fuel, while CO2 and HC emissions were lower, when compared to those of standard diesel. The results showed a 33 % reduction in HC emissions and a 8% reduction in CO2 emissions for biodiesel with a 8.7% increase in NOx emission. Thus, any types of vegetable oils biodiesel can be used as an alternate and nonconventional fuel to run all types of CI engine and use of WVO helps improve the biodiesel economics.
Sustainability will always be an issue with replacement fuels as it may affect food-stock supply. There is a need to find alternative fuels but the quantities available from recycled oils will not provide the significant, and increasing, levels needed – 9 trillion litres per year. There is potential with second

generation fuels but as this did not form part of the study comment is limited. It has to be accepted that bio-diesel fuels will always produce less performance therefore the greatest advantage is cost and emissions. The waste oil is "free" but there are costs associated with the production process and indeed hidden costs associated with increased engine maintenance.

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