# Assessment of the Viability of Vegetable Oil Based Fuels

**I. F. Thomas, N. A. Porter and P. Lappas**

**Abstract** This paper provides results of extensive trials using a 50/50 blend of unheated vegetable oil and diesel fuel in an unmodified vehicle on roads in Victoria, Australia. The work was inspired by the success of an on-road trial using 100 % waste vegetable oil in 2004 and positive indications in the literature. As well as being a sustainable alternative fuel, vegetable oil has the added safety advantage of having a much higher flash point than any other. Constant routes were used analogous in-part, to using prescribed drive cycles. Results were logged and bar-charts comparing fuel consumption for various fuel blends are presented. There was no clearly discernible difference (within the uncertainty of the measured data) in fuel consumption between the 50/50 blend and diesel fuel.

## 1 A Brief Literature Appraisal

A review of literature covering the period from 1982–2012 revealed 119 papers describing the use of vegetable oil as a transport fuel. A wide range of oil types have been researched with most concentrating on non-food sourced oils such as Jatropha (Bhupendra et al. 2010) Camelina (Bernardo et al. 2003), Hazelnut (Murat 2007),

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Karanja (Deshmukh 2009), Cottonseed (Fontaras et al. 2007), Mustard seed (Niemi 2003), Rice Bran (Agarwal 2010), Neem (Shiva 2005) and Silk Cotton Tree oils (Orwa et al. 2009). Some workers have studied multiple oil types (Abolle et al. 2009). Waste vegetable oil has also been studied in laboratory test engines (Dorado 2002; Pugazhvadivu 2005). Most report that the reasons for not using Straight Vegetable Oil are related to its high viscosity and injector and engine fouling. These can be offset by preheating and use of saturated oils (Babu and Devaradjane 2003). Several in particular Tippayawong (2003), indicate that SVO may be used only in the short term and that longer term usage needs further investigation. Tippayawong also states *'Vegetable oils and their products appear to be obvious choices as future fuels and are of exceptional importance'*. Nabi (2003) cites Elbert and Kaiser, '*Considering overall energy, health, environmental, and economic aspects, vegetable oils could be the fuel of the future'*. Many claim that vegetable oils are viable in substantially unaltered engines provided that the oil concentration is not greater than 30 % unless the fuel is preheated (Haldar 2009). Others are staunch advocates of the improved lubrication impacts (lubricity) of vegetable oil in improving the life of injector pumps, pistons, piston rings, cylinder bores and combustion chambers (Roegiers and Zhmud 2009). Some claim an increase in PAHs (Polycyclic Aromatic Hydrocarbons)(Lance and Andersson 2004; Krahl 2009) and others claim a reduction (Abbass 1990). The absence of sulphur in vegetable oil is known to reduce sulphur oxide emissions but claims regarding other emissions relative to diesel fuel vary. Table 1 shows some examples and includes noise impacts.

## 2 The On-road Trial

Two instances have been found where on-road trials have been conducted by others (Fontaras et al. 2007; Lance and Andersson 2004). The first involved a Euro 2 Volkswagen Golf 1.9L Tdi over a distance of 20,000 km and a Euro 3 Renault Laguna 1.9L dCi common-rail vehicle driven for 14,000 km. Both vehicles fueled with a 10 % cottonseed oil/diesel blend, met EU Emissions Directive 2003/30/EC. The second involved two secondhand Euro 2 compliant vehicles, a 1.9L DI vehicle with 52,000 km odometer reading at commencement and a 1.5L IDI vehicle with a reading of 21,000 km. Each was fitted with a fuel preheating kit and driven on 100 % Canola (Rapeseed) oil which complied with the German Rapeseed Fuel Standard, for multiple 200 mile runs. Both of these groups of workers conducted extensive engine performance and exhaust emission testing. They urged others to perform further tests in view of the potential importance of SVO and of blends with diesel as future fuels.

The present work used a second-hand (odometer reading 252.000 km), mechanically injected, pre-Euro 2, 1996 model Mitsubishi Triton utility vehicle, equipped with a 2.5L In-Direct Injection (IDI) turbocharged diesel engine. This model as sold in the UK was required to comply with the Euro 3 standard. Current diesel engines in Australia are Direct Injection (DI) common-rail, complying with

**Table 1** Emission and Noise Impacts for Various Oil Types

| Reference | CO | $CO_2$ | HC | PM | $NO_X$ | Smoke | Noise | Oil type etc. |
|---|---|---|---|---|---|---|---|---|
| Bhupendra et al. (2010) | Up | Up | Up | – | Down | – | – | Jatropha |
| Deshmukh (2009) | Up | – | – | – | Same | – | – | Karanja |
| Pugazhvadivu (2005) | Down | – | – | – | – | Down | – | WVO |
| Babu and Devaradjane (2003) | Down | – | Down | – | – | Down | Down | Rapeseed |
| Lance and Andersson (2004) | Up | – | Up | Up | Down | – | – | Canola |
| Abbass (1990) | Up | – | Up | Up | – | – | – | Sunflower |
| Mormino (2009) | – | – | – | – | Down | – | – | Rapeseed etc. |
| Vojtisek-Lom (2007) | Up | – | Up | Up | Down | – | – | Canola (in traffic) |
| Vojtisek-Lom (2007) | Down | – | Down | Down | Down | – | – | Canola (country) |
| Yoshimoto (2001) | – | – | – | – | – | Down | – | Rapeseed |
| Nettles-Anderson and Olsen (2009) | – | – | – | – | Down | – | – | Saturated VOs |
| Cheng and Lee (2008) | – | – | – | – | Down | – | Down | Cottonseed etc. |
| Kumar and Khare (2004) | – | – | – | – | – | Down | Down | Linseed etc. |
| Devan and Mahalakshmi (2009) | Up | Down | Up | – | Down | Up | – | Poon |
| Gangwar and Agarwal (2008) | Down | Same | Down | – | Up | Down | – | Jatropha |

Euro 4. Euro 5 will apply to all Australian vehicles from November 2013 and Euro 6 in 2017. The test vehicle was powered using 100 % waste cooking oil for a 1000 km pre-trial period in 2004. The vehicle ran well until a 5 mm wire mesh filter inside the fuel injector pump became partially blocked with paint particles from the drums that the waste oil was stored in and would not travel above 80 km/hr. The fuel injector pump was repaired, injectors refurbished and the vehicle operated on conventional diesel fuel for a year. Trials were recommenced in November 2005 using a 10 % blend of vegetable oil with conventional diesel fuel. Following successful operation, the oil concentration was progressively increased to 50 %. The reported thirty trials consisted of seven diesel fuel control runs, four 50/50 blend runs and a total of nineteen runs comprising 50/50 blend with an additive. Additives used were isopropanol, ethanol, ethyl acetate and a range of industrial perfumes. Trials were conducted over 21 months from April 2008 to January 2010, covering a total distance of 42,269 km. They were not without fault. The fuel filter blocked regularly leading to loss of power and excessive exhaust smoke. The cause was fuel containing a dispersion of finely divided solid fats and high melting point oils. Problems reported by others such as fuel acidity, injector fouling and fuel polymerisation were not experienced. On completion, the engine was found to have suffered extremely low cylinder head and cylinder bore wear and no acidity

was evident in the lubricating oil (pH 7.0). Fuel consumption was measured for all trials, country runs and city runs. Average speed was also measured for country runs. Measuring other variables such as vehicle condition, wind, temperature, power, torque and traffic conditions required more resources than were available. This was offset by using two principal routes with relatively constant journey times:—*Williamstown-Kilsyth-Brooklyn-Williamstown, 116 km city runs, twice per week in off-peak traffic; Williamstown-Bahgallah-Williamstown, 750 km country runs, approx 8 times per year.* Other variables such as vehicle performance (apparent power) and smoke emission, were noted in the trial log. [1]More recent trials as the odometer reading approached 300,000 km, assessed vehicle performance by logging the gear required and speed achieved when climbing two 'test hills'.

## 2.1 Fuel

Standard diesel fuel in Australia complies with Fuel Standard (Automotive Diesel) Determination 2001. This permits up to 10 mg/kg sulphur and requires a minimum Cetane Index of 46, a viscosity range of 2.0–4.5 cSt at 40 °C, a minimum flash-point of 61.5 °C and maximum PAHs of 11 % mass/mass. Australia also has a biodiesel fuel standard but unlike Europe (Fontaras et al. 2007) does not yet have a vegetable oil fuel standard. 50/50 vegetable oil/diesel fuel was the basis for all formal trials performed. The purpose of using additives was to assess whether they would improve performance. Principal examples used were a range of industrial grade perfumes, formulated as additives for disinfectant, detergent and bleach formulations. Perfumes consisted of complex proprietary mixtures of both natural and synthesised fragrances. Examples are eucalyptus oil, terpineol, 2-phenoxy ethanol, 2-octanol- 2, 6 dimethyl acetate, benzyl benzoate, and 6-acetyl-1,1,2,4,4,7-hexamethyltetraline. The blending technique was to mix 10L each of diesel fuel and decanted waste vegetable oil in a calibrated container. For trials involving an additive, 2L was added to the 20L blend. Additive blends were therefore 45.5 % WVO, 45.5 % diesel fuel and 9 % additive. The mixed fuel was filtered using Nital 9 monofilament filter cloth. The fuel gauge was calibrated by draining the tank and noting gauge readings following addition of a series of 10L increments. The calibration graph is presented at Fig. 1. Fuel consumption was measured either by filling the fuel tank with a measured amount and running until empty or more commonly, by adjusting for the fuel gauge reading at the start and finish of a run and adding any fuel additions made during the trial. Some trials with additives were grouped together for the purpose of analysing results.

[1] Full trial log available

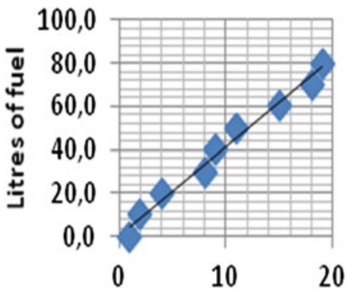



**Fig. 1** Gauge reading (1–19 = empty to full)

## 2.2 Results

The suppliers of WVO purchased cooking oils comprising Canola (six sources), Sunflower (two), a Canola/Sunflower blend (one) and Cottonseed (one source). Their calorific values are Canola 34–36 MJ/L, Sunflower 37 MJ/L and Cottonseed 42 MJ/L[2] (Wakil and Ahmed 2012; Tamilvendhan and Ilangovan 2011; Sustainable Energy Ireland 2004). Slightly lower values for vegetable oils compared with diesel fuel (37–42 MJ/L), might lead to higher fuel usage than diesel fuel for the same energy consumption. Here-following, trial duration and fuel consumption are presented for each type of fuel used.

### 2.2.1 All Trials

Figure 2 and its key above, show that of the 30 trials performed, the most tested fuel was the 50/50 blend. Figure 3 shows that the lowest fuel consumption was achieved using 50/50 blend with Citrus perfume (8.6L/100 km). Second lowest was the 50/50 blend with lemon perfume (9.4L/100 km) and one of the straight diesel fuel runs was fifth best (10.1L/100 km).

| | |
|---|---|
| *Diesel* | *Conventional diesel fuel alone* |
| *50/50* | *50 % waste vegetable oil and 50 % conventional diesel* |
| *IPA* | *50/50 blend with isopropyl alcohol* |
| *WKR* | *50/50 blend with white king regular perfume* |
| *Brn Euc* | *50/50 blend with brown eucalyptus perfume* |
| *Citrus* | *50/50 blend with citrus perfume* |
| *Lemon* | *50/50 blend with lemon perfume* |
| *Lem/Euc* | *50/50 blend with lemon or eucalyptus perfume* |
| *Euc* | *50/50 blend with eucalyptus perfume* |
| *D + Euc* | *50/50 blend with eucalyptus perfume or straight diesel* |
| *Et/EtAc* | *50/50 blend with ethanol and ethyl acetate* |

[2] Details of WVO types and suppliers available on request

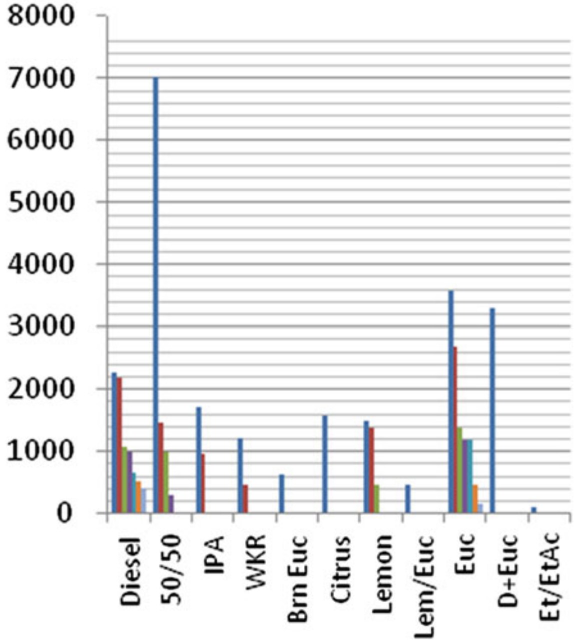



**Fig. 2** Trial distance (km) for all trials versus fuel type

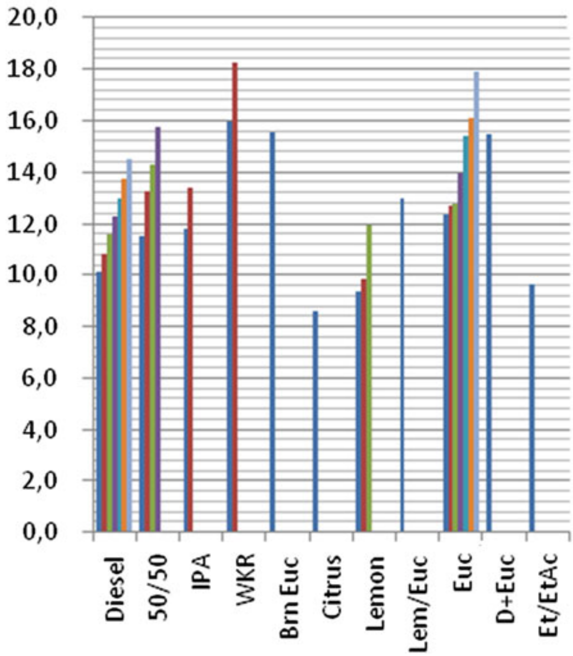



**Fig. 3** L/100 km versus fuel type for all trials

### 2.2.2 Country Runs

The range of average speeds achieved for outbound and return runs is similar (outbound 66.6–92.0 km/hr; return 64.6–90.6 km/hr). Broadly speaking, outbound runs were against the prevailing westerly wind and the vehicle was more heavily laden whereas return runs were with the wind and the vehicle was more lightly loaded. The route had few built-up areas, constant very limited traffic, substantially no road works and very few traffic lights. Average fuel consumption for outbound runs was 17.3L/100 km and return, 15.3L/100 km indicating that to achieve similar journey times, more fuel was consumed outbound. There was no diesel control outbound and so comparisons have been made with the 86/14 diesel/WVO blend. Figures 4 and 5 show fuel consumption versus fuel type. The best outbound fuel was 50/50 blend with lemon perfume (12.2L/100 km). Second best was 50/50 blend with citrus perfume (14.1L/100 km) and third best was 50/50 blend with IPA (16.0L/100 km). Worst performing was one of the blends with eucalyptus perfume (20.4L/100 km), followed closely by the 86/14 diesel surrogate, one of the 50/50 blends and a WKR blend (18.7L/100 km). Return runs showed 50/50 with lemon perfume to fare best (12.0L/100 km). Second was citrus blend (12.3L/100 km). Third and fourth were a 50/50 blend and a lemon blend (13.3 and 13.4L/100 km). Diesel was fifth at 13.9L/100 km.

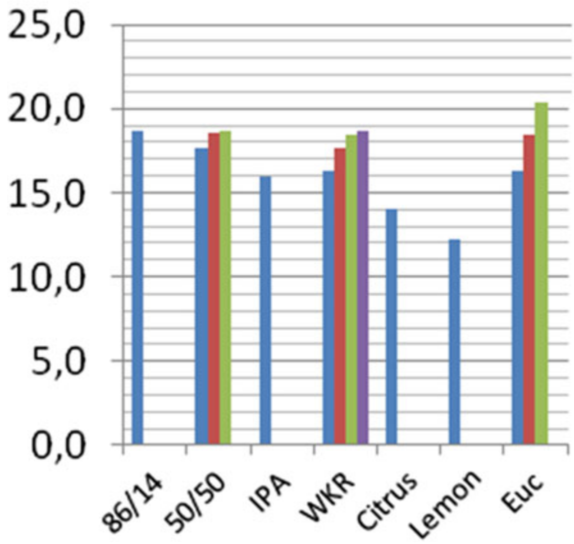
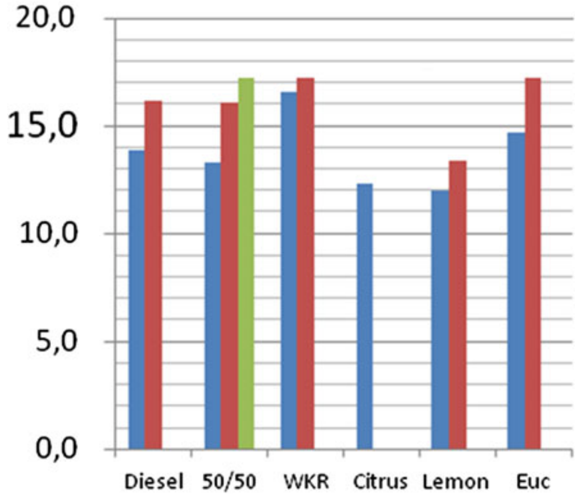



**Fig. 4** L/100 km versus fuel type for outbound country runs

**Fig. 5** L/100 km versus fuel type for return country runs




### 2.2.3 Statistical Analysis

For sets of more than four results for the experimental fuels (except for D + 86/14 vs. lemon for combined country runs), two-sample *t* test findings at 95 % confidence level are reported in Table 2. Results are presented in six blocks, (a) all trials, (b) outbound country runs, (c) return country runs, (d) all country runs, (e) all outbound versus all return country runs and (f) all city runs. There was insufficient data for two of the return country runs. For all trials, 50/50 blends containing eucalyptus perfume performed significantly worse than diesel fuel. Conversely, 50/50 blends containing citrus or lemon perfumes performed significantly better than diesel fuel. An equally important finding, is that there was no significant difference between diesel fuel and the most tested experimental 50/50 diesel/WVO blend. Country runs saw no significant differences apart from between all outbound runs and all return runs where the impact of the different prevailing conditions is borne out. Notwithstanding this, one of the best performing experimental fuels, 50/50 blend with lemon perfume when assessed for all country runs, was close to presenting a significant difference (t-stat [2.5] not > t-critical [2.8] and P two-tail [0.06] not < alpha [0.05]). This run showed significant difference at the lower, 90 % confidence level. City runs showed no significant differences between fuel types.

**Table 2** T-Test Outcomes

| 1st variable | 2nd variable | L/100 km | | No of samples | | Significant ? [b] |
|---|---|---|---|---|---|---|
| | | 1st mean [a] | 2nd mean [a] | 1st | 2nd | |
| *All trials* | | | | | | |
| Diesel | All other | 12.3 ± 1.5 | 13.4 ± 1.1 | 7 | 23 | No |
| Diesel | Citrus/Lemon | 12.3 ± 1.5 | 9.9 ± 2.3 | 7 | 4 | Yes |
| Diesel | Cit/Lem/LemEuc | 12.3 ± 1.5 | 10.5 ± 2.3 | 7 | 5 | No |
| Diesel | IPA/C/L/Et-EtAc | 12.3 ± 1.5 | 10.6 ± 1.6 | 7 | 7 | No |
| Diesel | W/L-Eu/Eu/D-Eu | 12.3 ± 1.5 | 14.9 ± 1.4 | 7 | 11 | Yes |
| Diesel | 50/50 | 12.3 ± 1.5 | 13.7 ± 2.8 | 7 | 4 | No |
| Diesel | Euc | 12.3 ± 1.5 | 14.5 ± 1.9 | 7 | 7 | Yes |
| *Outbound country runs* | | | | | | |
| 86/14[c] | WKR | 18.7 | 17.8 ± 1.7 | 1 | 4 | No |
| 86/14[c] | All other | 18.7 | 17.2 ± 1.3 | 1 | 13 | No |
| 86/14[c] | All additives | 18.7 | 16.8 ± 1.7 | 1 | 10 | No |
| *Return country runs* | | | | | | |
| Diesel | All other | 15.0 ± 14.5 | 15.3 ± 1.8 | 2 | 10 | No |
| Diesel | All additives | 15.0 ± 14.5 | 15.1 ± 2.4 | 2 | 7 | No |
| *All country runs* | | | | | | |
| D + 86/14 | 50/50 | 16.2 ± 5.9 | 17.2 ± 2.2 | 3 | 6 | No |
| D + 86/14 | Lemon | 16.2 ± 5.9 | 12.6 ± 1.9 | 3 | 3 | No (Yes 90 %) |
| D + 86/14 | WKR | 16.2 ± 5.9 | 17.7 ± 1.1 | 3 | 6 | No |
| D + 86/14 | Euc | 16.2 ± 5.9 | 17.5 ± 2.7 | 3 | 5 | No |
| D + 86/14 | All other | 16.2 ± 5.9 | 16.4 ± 1.1 | 3 | 23 | No |
| D + 86/14 | All additives | 16.2 ± 5.9 | 16.1 ± 1.3 | 3 | 17 | No |
| *All outbound vs All return runs* | | | | | | |
| Outbound | Return | 17.3 ± 1.2 | 15.3 ± 1.5 | 14 | 12 | Yes |
| *City runs* | | | | | | |
| Diesel | 50/50 | 12.2 ± 1.4 | 13.2 ± 2.7 | 7 | 5 | No |
| Diesel | Euc/B Euc/D + Eu | 12.2 ± 1.4 | 13.3 ± 2.2 | 7 | 5 | No |
| Diesel | All other | 12.2 ± 1.4 | 13.0 ± 1.1 | 7 | 18 | No |
| Diesel | All additives | 12.2 ± 1.4 | 12.9 ± 1.4 | 7 | 13 | No |

[a] and [b] at 95 % confidence level
[c] Diesel fuel surrogate (86 % diesel, 14 % WVO)

## 3 Conclusions

- For all 30 trials inclusive of both city and country driving, (a) there is no significant difference between mean fuel consumption using 100 % diesel fuel and the 50/50 blend of WVO and diesel fuel, (b) 50/50 blends containing eucalyptus perfume performed significantly worse than diesel fuel alone and, (c) 50/50 blends containing citrus or lemon perfume performed significantly better than diesel fuel alone.
- Outbound country runs performed best using the 50/50 blend with low concentrations of lemon or citrus perfume and return runs performed best with the same perfume blends and the straight 50/50 blend. However, there is/are (a) no

significant differences between fuel types used in outbound runs or in fuel types used in return runs, (b) a significant difference in the mean overall fuel consumption outbound vs the mean overall fuel consumption in return runs consequent upon the different wind and vehicle loading conditions in the two groups and (c) a significant difference at the lower 90 % confidence level for the combined country runs between diesel fuel and the 50/50 blend containing lemon perfume.
- There is no significant difference between any of the fuel types for city runs.
- Fuel filter blockage was caused almost exclusively by suspended fats present in the waste vegetable oil used. These comprise higher melting point components of the vegetable oil blend used by the source fish-and-chip shop, hotel or restaurant, together with introduced fats from pre-cooked foodstuffs.
- Smoke emission is increased when the fuel filter is partially blocked, when the fuel injectors are worn and as the vehicle ages.

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