THE POTENTIAL OF RECOVERED VEGETABLE OIL AND TALLOW AS VEHICLE FUELS

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SUMMARY

The use of recovered vegetable oil (RVO) and tallow as vehicle fuels was investigated. Two options were considered; use in unprocessed form in specially adapted engines, and the production of biodiesel for use in unmodified engines.

Two vehicles were modified to allow the use of RVO as fuel. Their performance in terms of power and fuel economy was acceptable, but fuel filter blockage problems would need to be resolved and long-term effects on engine life investigated before this approach could be recommended.

Tallow with high free-fatty-acid content was esterified by a two-stage process that could be used in a simple plant and produce biodiesel of reasonable quality. High ester yields were obtained in laboratory and pilot-scale trials. Problems of layer separation remain to be resolved, and the process needs to be streamlined to allow a high throughput to be achieved.

In comparing the costs of these fuels with each other and with mineral diesel, allowance must be made for any differences in fuel economy and for the cost of engine conversion kits. Including these items, the use of RVO in a converted engine would have a slightly lower cost than its use as biodiesel. Biodiesel from tallow is likely to be more expensive than from RVO if either ester yield or plant capacity is significantly reduced.

INTRODUCTION

The recently enacted EU Transport Biofuels Directive requires Member States to set targets for the substitution of mineral fuels by biofuels (1). The Directive suggests an indicative target of 2% substitution by 2005, rising to 5.75% by 2010.

For Ireland to achieve a 2% substitution of road diesel, a production of about 35,000 t/annum of biofuel would be required. The most likely raw materials would be rapeseed oil, recovered vegetable oil (RVO), and beef tallow. RVO and tallow would have a lower cost than rapeseed oil, but their more variable and inferior fuel properties would limit their use options.

Irish RVO dealers estimate that about 7,000 t of RVO is collected annually at present. They also estimate that this could increase to 10,000 t if collection systems were improved and restrictions on dumping were tightened. Traditionally RVO has been used in animal feeds. This use is under threat throughout the EU, and is expected to terminate in Ireland by the end of 2004.

About 50-60,000 t per annum of beef tallow is produced by the rendering industry. Tallow from certain sources (all slaughtered herds and fallen carcasses, specific risk material from every slaughtered bovine) is banned from animal feeds.

Alternative uses for both these materials are desirable. The most likely use is as some form of energy: as an engine or heating fuel in unprocessed form, or converted to biodiesel for engine use. A number of rendering plants are using tallow to fuel very large boilers for process heat production. The use of these materials for energy purposes would contribute to the abatement of greenhouse gas emissions as well as removing undesirable organic pollutants from the waste stream. If used as vehicle fuels they would reduce air pollution by road traffic as well as providing some level of compliance with the EU Transport Biofuels Directive (1).

Research on the use of RVO and tallow as engine fuels in unprocessed form is at an early stage. A US evaluation of unesterified animal fats in unmodified engines indicated problems with carbon deposits and lubricating oil contamination (2). However, at least two engine conversion kits claiming to be suitable for use with RVO are now on sale.

Biodiesel based on rapeseed oil has now received widespread acceptance as a fuel for diesel engines. EU biodiesel production exceeded 1 Mt in 2002, virtually all from rapeseed oil (3). Experience with other feedstocks is still very limited. An EU Specification for biodiesel produced from any oil or fat was ratified in 2003 (4). Biodiesel has already been produced from RVO on a commercial scale in Austria (5). Sams, Tieber and Mittelbach (1996) have obtained biodiesel of mainly satisfactory quality from 40 RVO samples; engine performance and emissions on RVO ester were found to be similar to rape methyl ester (6). RVO quality might be expected to vary from country to country, depending on oil sources, cooking practices and collection systems. Oak Park trials have shown that RVO of acceptable quality can be produced from the material collected in Ireland (7).

With regard to tallow, one US trial has shown that water content and FFA (free fatty acid) level had a big effect on the yield of biodiesel (8). Earlier Oak Park work has shown that low yield is the limiting problem with tallow esterification (7). Lower grades of tallow have high FFA (free fatty acids) content, and the esterification of this type of material is normally carried out with acid catalysts under pressure (9,10). However, acid catalysed-esterification does not yield biodiesel-grade methyl ester and would require equipment that is not used for biodiesel processing at present. An esterification process for high-FFA tallow that could be carried out with equipment used in existing biodiesel processing plants would boost the economics of small-scale biodiesel production.

In summary, research to date suggests the following:

- The possibility of using RVO in modified engines is worthy of further investigation. Given its high melting point, tallow would not be suitable for this application.

- Most of the RVO collected in Ireland could be used as a biodiesel feedstock in conventional single-stage plants. Tallow presents a more difficult problem; an esterification method is needed that would give a high ester yield and be suitable for use in small-scale plant.

The overall objective of the present work is to identify the most appropriate fuel uses for RVO and tallow, and their associated costs and benefits in comparison with mineral diesel. To allow this evaluation to take place, work was carried out under the following headings:

1. Evaluation of the use of RVO in unprocessed form in vehicle engines fitted with proprietary conversion kits.

2. Evaluation of two-stage tallow esterification in the laboratory and in a pilot-scale plant.

3. Comparison of the costs of these alternative uses.

ADAPTATION AND EVALUATION OF VEHICLE ENGINES WITH RVO AS FUEL

Introduction

While there is some information available on the use of virgin vegetable oil in adapted diesel engines, there is very little on the use of either RVO or tallow. With a melting point of 35-40^{o}C, the use of tallow in vehicle engines would always be difficult. RVO on the other hand might be expected to present fewer problems as a vehicle fuel. Trials were therefore carried out to evaluate this option.

Method

Oil samples for the trials were taken from 20-tonne batches of RVO that had been collected from caterers in small (20-50 litre) containers. After steam injection and coarse screening, settled water was drained off and RVO samples were removed for the trials.

Two vehicles were chosen for adaptation; a Toyota Dyna 100 Pick-up Transporter, with a 2400 cc indirect-injection naturally-aspirated engine, and a Peugeot 306, with a 1905 cc indirect-injection naturally-aspirated engine.

To provide a guideline on the amount of fuel heating that might be desirable for the RVO, its viscosity was measured at temperatures from 20 to 80^{o}C using a U-tube viscometer.

In each vehicle, a 30-litre biofuel tank was fitted with a copper coil through which the engine coolant was circulated to heat the tank contents (Fig. 1). In addition, the fuel and coolant lines to the tank operated as counter-flow heat exchangers to ensure that the fuel remained warm until it reached the fuel filter. Solenoid valves switched the fuel supply from mineral to biofuel.

Trials were carried out to compare the performance of the vehicles running on virgin vegetable oil, RVO and mineral diesel. Two performance characteristics were measured: fuel economy and power output. Practical operation and maintenance problems were also noted.

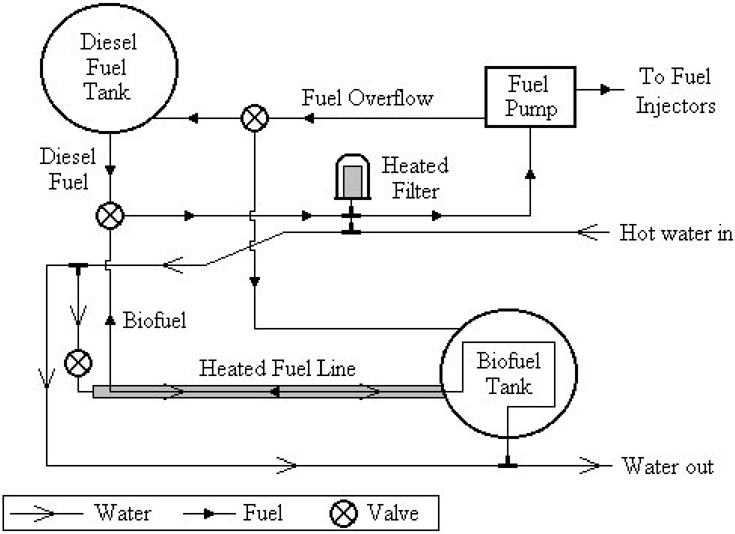

Fig. 1: Vehicle fuel supply adaptation to allow the use of oils and fats as fuels

Fuel economy was measured by driving the vehicles unladen around an 85-km public road circuit and measuring fuel consumption either by topping up or draining the fuel tank. Six runs were made in random order with each fuel. Power was measured on a Sun Road-a-Matic rolling-road dynamometer at University of Limerick.

Results

The viscosity of the RVO used in the trials was substantially higher than that of virgin rapeseed oil at low temperatures and might be expected to lead to pumping and atomisation problems (Fig. 2). However, at temperatures above 50^{o}C the difference in viscosity became very small. With the kit fitted to the Peugeot, the biofuel was heated to 65-70^{o}C in the tank. With the Toyota, somewhat lower temperatures (50-55^{o}C) were achieved. This was considered adequate to facilitate pumping and filtration.

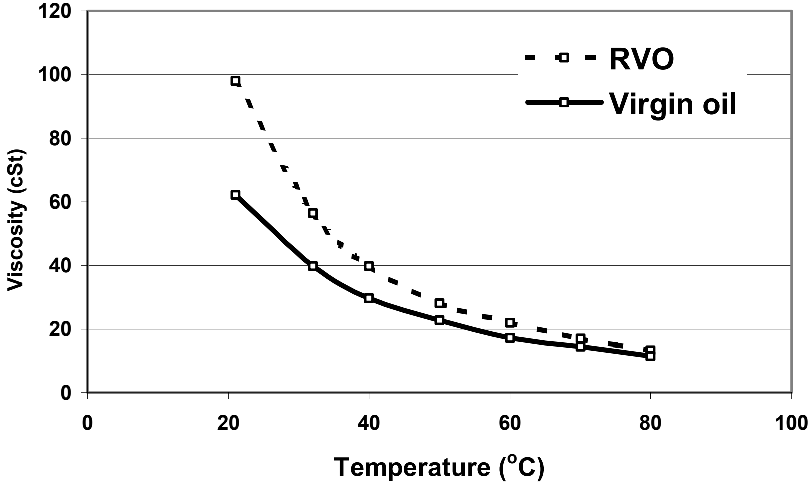

Fig. 2: Viscosity of RVO and virgin rapeseed oil used in trials

In the fuel economy measurements with the Toyota Dyna, the average speed for each circuit was 71 km/h. The results of this test showed a significant 12% decrease in fuel economy with the vegetable oil and RVO compared with mineral diesel (Table 1). There was no significant difference between vegetable oil and RVO.

Table 1: Fuel economy of Toyota Dyna 100 with vegetable oil and mineral diesel

Fuel	Unused veg. oil	RVO	Diesel	SED (sign.)
Fuel economy (km/l)	12.57	12.46	14.03	0.134 (0.001%)

With the Peugeot 306, the average speed for each circuit was also 71 km/h. The results of this test showed significant 8% and 11% decreases in fuel economy with the unused vegetable oil and RVO, respectively (Table 2). The difference between unused vegetable oil and RVO was not significant.

Table 2: Fuel economy of Peugeot 306 with vegetable oil and mineral diesel

Fuel	Virgin veg. oil	RVO	Diesel	SED (sign.)
Fuel economy (km/l)	20.43	19.85	22.26	0.176 (0.001%)

In dynamometer tests with the Toyota Dyna, higher power was measured with virgin vegetable oil than with mineral diesel (Fig. 3). The most likely explanation for this result is a higher injection pressure and fuel throughput due to a lower leakage loss with the more viscous fuel. A similar result was obtained in a German trial (11). There was a slight decrease in power with RVO.

In dynamometer tests with the Peugeot 306, there was very little difference between diesel and virgin vegetable oil, but a reduction in power was measured at high speeds when running on RVO (Fig. 4).

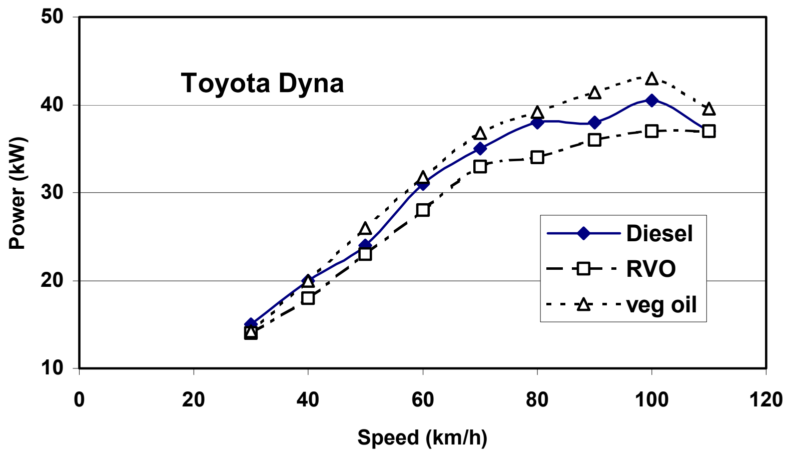

Fig. 3: Power performance of Dyna engine with RVO, unused vegetable oil and mineral diesel.

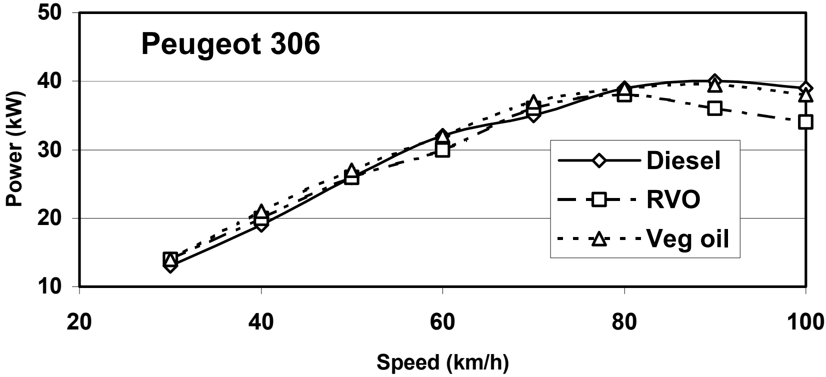

Fig. 4: Performance of Toyota Dyna with RVO, unused vegetable oil and mineral diesel.

In runs with RVO, both vehicles' fuel filters suffered from occasional blockages. This may have been caused by inadequate filtration of the RVO prior to use, by inadequate insulation of the fuel filters, or by some fuel constituents having a melting point higher than the fuel temperature with the existing heating systems.

Discussion

The reduction of about 10% in fuel economy with RVO would have a bearing on its evaluation as a vehicle fuel. The slight reduction in power requirement was scarcely noticeable in normal driving. Fuel filter blockage problems would have to be sorted out either by improvements to the preparation of the fuel or by improved engine conversion kits. The possibility of long-term engine effects from the use of RVO as a fuel still needs to be evaluated. A specification for RVO destined for vehicle fuel use would be necessary if this use were to become widespread.

TWO-STAGE ESTERIFICATION OF BEEF TALLOW

Introduction

The achievement of a high ester yield is one of the key factors in the economics of biodiesel production. The high FFA contents of the lower grades of tallow make it difficult to achieve high yields with a simple single-stage esterification process. Consequently, it was decided to examine a two-stage process in which base-catalysed esterification was followed by precipitation of the organic phase and acid-catalysed esterification. Initial laboratory trials were used to establish process parameters and compare yields from the simple and two-stage processes. This was followed by trials in a pilot-scale plant with 300-kg batches.

Method

High-FFA tallow samples for laboratory esterification were obtained from a local renderer. After unsuccessful pilot-scale trials with this material, the remaining trials were conducted with food-grade tallow.

In laboratory-scale single-stage base-catalysed esterification, tallow (120 g) was stirred vigorously with potassium hydroxide (1.8 g+ required amount to neutralise FFAs) in methanol (33.5 ml) at 50-55^{o}C for 1 hr (10). The methyl ester was allowed to separate for a minimum of 3 hr and after the removal of glycerol it was washed gently with water (2 x 100 ml), and dried to constant weight at 120^{o}C (12). Tallow with 16% FFA required 50% more methanol and, at the end of esterification, water (20 ml) had to be added to promote phase separation.

In single-stage pilot-plant-scale esterifications, 300 kg of tallow was used with the corresponding amounts of methanol and potassium hydroxide; stirring was carried out by recirculation, and the glycerol layer was allowed to separate overnight. Excess methanol was removed by washing and residual water was removed by heating. Before esterification, tallow was heated to 40^{o}C.

In laboratory-scale two-stage esterification trials, the organic phase was precipitated from the single-stage reaction mixture by the addition of water (60 ml) and sufficient 3M sulphuric acid to lower the pH to $\leq$2.0. The mixture was heated to 80^{o}C, the water layer was removed, the organic phase was washed with warm water ($\geq$50^{o}C) (40 ml) until neutral and dried at 120^{o}C to constant weight. Part of the dried organic phase (30 g) was esterified by heating either with 3M hydrochloric acid (40 ml) or 16% boron trifluoride (40 ml) for 30 min, or with 20% sulphuric acid (8 ml) in methanol at 60-65^{o}C for 2 hours. The excess methanol was evaporated and the methyl ester was washed with water until neutral and dried at 120^{o}C.

In two-stage pilot-scale esterification, after acidification and removal of the separated aqueous phase, the organic phase was heated to 80^{o}C and washed with two volumes of water. It was then esterified (without drying) by stirring with 20% sulphuric acid for 2 hours at 60^{o}C. The reaction mixture was left to cool for 1 hour, the separated layer was removed, the methyl ester was washed with two volumes of water and dried at 120 ^{o}C for 5 hours.

To determine the methyl ester and fatty acid content of the glycerol phase, glycerol from base-catalysed esterification (20 g) was acidified (pH $\leq$2.0) with 3M sulphuric acid after adding water (40 ml), and the precipitated organic phase was removed by washing with hexane (3 x 40 ml). The hexane extract was washed with water (2 x 40 ml) which in turn was washed with dichloromethane (2 x 40 ml), the combined organic layers were evaporated to dryness on a steam bath, and the residue was dissolved in ethanol (50 ml). Half of the solution (25 ml) was used to determine the FFA content (mmoles) by titration with 1.0M potassium hydroxide, and the remaining half was saponified, and the methyl ester content (mmoles) was determined from the saponification titre (13). The fatty acids available for esterification (mmoles) in the raw tallow and the mmoles of methyl ester in the product were also determined by saponification, and the results were used to calculate the material balance of esterifications.

Results

The tallow in the laboratory trials had FFA contents from 10 to 20%. Biodiesel grade methyl ester was obtained from tallow up to 16% FFA in yields over 50% with small modifications to the single-stage base-catalysed esterification process (Table 3). Esterification of tallow with 11% FFA was carried out simply by adding extra potassium hydroxide to neutralise the FFAs. However, when tallow with 16% FFA was used as starting material, the methyl ester did not separate completely from the reaction mixture unless 50% extra methanol was used and water was added at the end of esterification. At 20% FFA content, 100% extra methanol had to be used to obtain good phase separation. If extra methanol was not added, the yields of methyl ester were reduced considerably, and if less than 90% of the FFAs were neutralised the esterification was not complete.

Table 3: Base-catalysed esterifications of tallow with high FFA content

FFA[1] content	(w/w)	11.2	15.8	15.8	15.8	15.8	15.8	15.8	20.0
Yield of ME[2]	(w/w)	53.5	41.8	41.3	53.4	53.4	55.6	55.6	34.5
Excess methanol	(%)	0	0	0	50	50	50	50	100
FFAs neutralised	(%)	100	100	100	75[3]	75[3]	90	90	100

[1]FFA= free fatty acid [2]ME = methyl ester [3]high triglyceride levels

The methyl ester yields obtained from high FFA tallow were relatively low (Table 3), but according to the material balance less than 3% of the yield loss could be attributed to the hydrolysis of triglycerides (Table 4). However, analysis of the glycerol layer indicated that methyl ester not recovered as product was dissolved in the glycerol phase (Table 4). Seemingly, FFA potassium salts help the dissolution of the product in glycerol, and previous work has shown that the amount of methyl ester in the glycerol phase increases linearly with the FFA potassium salt content of the same (14). Considering that less than 3% of the triglycerides hydrolyse during esterification, most of the solubilisation of the methyl ester must be due to the FFAs in the starting tallow which end up as potassium salts in the glycerol phase.

Table 4: Material balance of six base-catalysed esterifications

Yield of ME	(w/w)	51.8	55.7	55.6	55.8	55.8	55.3
FFAs in tallow	(m/m)	11.1	16.6	16.6	16.6	15.6	16.6
FFAs from hydrolyses	(m/m)	2.8	1.8	2.4	2.3	2.7	2.5
FFAs in glycerol	(m/m)	13.9	18.4	19.0	18.9	19.4	19.2
Yield of ME	(m/m)	51.8	57.1	56.3	57.0	56.5	56.2
ME in glycerol	(m/m)	32.6	21.3	21.8	22.4	22.7	22.9
Material accounted for	(4+5+6)	98.3	96.8	97.1	98.3	98.6	98.8

In order to recover the methyl esters dissolved in the glycerol phase and to esterify tallows with FFA content above 16%, the possibility of two-stage esterification was examined. This involved the separation of the organic phase from the base-catalysed esterification mixture, which was esterified again with an acid catalyst. The separated organic phase contained only FFAs, methyl ester and traces of glycerides. Optimum conditions were established for the esterification of the isolated organic phase with methanolic hydrochloric acid, boron trifluoride and sulphuric acid and the yields of methyl ester based on tallow were above 90% (w/w) (Table 5). Somewhat higher yields and lower acid values were obtained with boron trifluoride and hydrochloric acid than sulphuric acid, but they also required far more catalyst and methanol, hence these processes would be more costly.

Table 5: Total esterification (base- and acid-catalysed) of tallow with high FFA content

FFA in OPH[1] (w/w)	17.5		17.5		20.5	
Acid catalyst	20% H_2SO_4		16% BF_3		3MHCl	
Volume of catalyst (ml)[2]	8		40		40	
Yield of ME (w/w)	94.2	94.4	96.3	95.7	98.1	98.1
Acid value of product	1.5	1.4	0.95	0.95	0.69	0.63

[1]OPH = organic phase [2] per 30g OPH

The ester-specific properties of the products were within the EU draft specifications except that the acid values of the methyl esters from the total esterifications were slightly above the specified maximum (1). In addition to the somewhat high acid values, methyl esters obtained from tallow have been found to have pour points as high as 15°C. This arises from the high proportion of saturated fatty acids in tallow, and is not related to the FFA content or to the esterification process. This suggests that tallow methyl ester could only be used in blends of 10% or less with mineral diesel, and in this application the measured acid values would not present a problem.

Initial pilot-plant-scale trials of the two-stage process with high-FFA tallow were unsuccessful, mainly because suspended matter in the starting material made phase separation very difficult. In the laboratory, suspended material was filtered with kieselguhr (1% w.w), but pilot-scale filtration facilities were not available. Greater success was achieved with high-grade material; a yield of 92% was achieved, in comparison with 72% from conventional single-stage esterification. However, the two-stage process in its present form is very time-consuming, mainly because of the increased number of phase separations and washings that are required. Further work is required in the laboratory to streamline the two-stage process.

Discussion

This work has established the following:

- Biodiesel grade methyl ester can be obtained from high-FFA tallow.
- Base-catalysed esterification of this material gives uneconomical ester yields.
- High yields of methyl ester can be obtained with a combination of base- and acid-catalysed esterifications.
- The two-stage process used in these trials was slow, and gave poor phase separation with unfiltered commercial high-FFA tallow. These problems would have to be resolved before it could be used on a practical scale.

COMPARISON OF USE ALTERNATIVES FOR RVO AND TALLOW

Introduction

This chapter contains estimates of the costs of using RVO and tallow in unmodified form as a vehicle or heating fuel, and converted to biodiesel for vehicle use. These costs are based on information brought forward from the trials carried out in the present work and from the literature, e.g. extractable oil content, yields, amount of reaction chemicals, recoverable methanol and energy requirements, as well as costs obtained from renderers, RVO collectors and equipment suppliers. The price of RVO after collection and cleaning was assumed to be €220/t (2003 price). The price of low-grade tallow suitable for esterification is assumed to be €200/t.

It is widely held that the economies of scale in oil extraction and bio-diesel production are substantial. This aspect was not analysed in this study, since the raw materials for a large-scale plant are unlikely to be available.

Use of RVO in vehicle engines

The assumed price of RVO is its 2003 price of €220/t or 20 cent/litre. The cost of conversion varies from under €1,000 (for a DIY kit) to over €2,000 (for parts and installation). The price has been falling and may be expected to fall further as the market develops.

The recovery of a conversion cost of €1,000 over a five-year period at 10% interest would amount to €264/yr. A vehicle driving 40,000 km/yr at a fuel economy of 15 km/litre would consume 2,667 litres of fuel. Therefore, the RVO price would need to be roughly 10 cent/litre lower than the mineral diesel price to allow the expenditure on engine conversion to be recovered.

In making comparison with mineral diesel, an allowance must also be made for some reduction in fuel economy. If the 10% reduction measured with the two vehicles in these trials is representative, the total cost of this reduction would amount to about 3 cent/litre.

The equivalent price of mineral diesel (i.e. before tax or distribution costs) would therefore need to be at least 33 cent/litre for the biofuel to be competitive. This price has rarely, if ever, been reached. Some subsidy would be needed, at least for an initial period, to allow RVO to compete with mineral fuel in diesel engines.

Biodiesel production from RVO and tallow

The following assumptions are made in this analysis:

- The biodiesel plant is to be set up adjacent to an existing RVO and tallow assembling company and can be supplied with RVO at a price of €220/t and tallow at €200/t.
- There already exists a collection, cleaning and storage facility for RVO adjacent to the proposed site for the plant.
- The glycerol by-product will be sold with minimal refining for €100/t.
- The capital cost estimate for this size and layout of plant is based on quotations from companies involved in the construction of biodiesel plants.

- The capacity of the plant is assumed to be 3,000 t/annum in conventional use, but reduced to 2,000 t/annum when used for two-stage esterification.
- Literature-based estimates have been used for fixed and variable running costs.
- It is assumed that a rate of return on investment of 20% per annum is required.

Total operating costs are estimated at from k€305-340 per annum. This includes all raw materials other than the feedstock oil, and is equivalent to 9.7-13.5 cent/litre of biodiesel produced (Table 6).

Table 6: Operating cost for 3,000 tonne esterification plant (2003 prices)

Capacity (t/annum)	3,000	2,500	2,000
No. of stages	One	Two	Two
Methanol	87,384	110,000	88,000
Potassium hydroxide	36,576	30,480	24,384
Sulphuric acid	0	13,125	13,125
Labour	95,904	95,904	95,904
Energy	39,960	33,300	26,640
Repairs, maintenance, insurance	40,000	40,000	40,000
Quality control & administration	30,000	30,000	30,000
Total operating costs	329,824	339,684	304,928
Operating cost €/t (ester)	109.94	135.87	152.46
Operating cost cent/litre (ester)	**9.70**	**11.98**	**13.45**

The capital cost of the proposed plant including site works is estimated at €1.09-1.18M. (Table 7). Assuming that a rate of return on capital of 20% is required, the annual cost of the investment is €0.22-0.24M. The annual equivalent of the total capital investment is estimated at 6.6-10.7 cent/litre of biodiesel produced.

Table 7: Capital costs for esterification plant (2003 prices)

Plant	One-stage	Two-stage	Two-stage
Capacity	3,000	2,500	2,000
Equipment/installation	944,000	1,038,000	1,038,000
Tanks, site works, etc.	150,000	150,000	150,000
Total capital costs	1,094,000	1,118,400	1,118,400
Real annual cost of capital (20%)	218,800	237,680	237,680
Total annual operating cost	329,824	275,184	275,184
Working capital (1/12 of total costs)	45,719	42,739	42,739
Annualised cost of working capital	5,715	5,342	5,342
Annual capital costs	224,515	243,022	243,022
Capital cost €/tonne (ester)	74.84	97.21	121.51
Capital cost cent/litre (ester)	**6.60**	**8.58**	**10.72**

The cost of RVO after assembly and cleaning is assumed to be €220/t. When capital, feedstock and operating costs are combined, the total cost of biodiesel produced from RVO is calculated as 36.1 cent/litre (Table 8).

For single-stage esterification of tallow, a feedstock cost of €200/t and an ester yield of 70% were assumed. On this basis, the cost of the biodiesel produced would be 38 cent/litre (Tables 7, 8).

For two-stage esterification, a yield of 90% was assumed, along with an additional cost for sulphuric acid and extra methanol and a reduction in plant capacity due to the extra steps in the process. If the capacity were reduced to 2,000 t/annum, this would outweigh the increased yield benefit, and the cost of the biodiesel would increase to 42 cent/litre (Tables 7, 8). At a capacity of 2,500 t/annum, the costs and benefits would be roughly in balance, with little change in the cost of the biodiesel.

Table 8: Total cost of biodiesel produced from RVO and tallow (2003 prices)

Material		RVO	Tallow		
Capacity (t/annum)		3,000	3,000	2,500	2,000
Process		1-stage	1-stage	2-stage	2-stage
Oil cost	€/t oil	220.00	200	200	200
Esterification yield	%	90.00	70	90	90
Nett oil cost	€/t ester	244.44	285.71	222.22	222.22
Glycerol yield	%	20	40	20	20
Nett glycerol value	€/t(glycerol)	100.00	80	80	80
	€/t (ester).	26.4	32	16	16
Oil cost nett of glycerol	€/t (ester).	224.44	253.71	206.22	206.22
	cent/litre (ester).	19.80	21.67	17.84	17.84
Capital cost	cent/litre (ester)	6.60	6.60	8.58	10.73
Operating cost	cent/litre (ester)	9.70	9.70	11.98	13.45
Biod. cost ex works	***cent/litre (ester)***	**36.10**	**37.97**	**38.40**	**42.02**

For a cost comparison with mineral diesel, an allowance for reduced fuel economy should be included. In past Oak Park trials, the reduction varied between 2 and 4% (7). A 3% reduction would add a total of about 1.4 cent/litre to the price. Therefore, the equivalent price of mineral diesel (i.e. before tax or distribution costs) would need to be at least 38 cent/litre for the biodiesel from RVO to be competitive. For tallow ester to be competitive, the equivalent price of mineral diesel would need to be over 40 cent/litre. The analysis also suggests that the costs of RVO as a fuel is slightly lower when used in modified engines than when converted to biodiesel.

Discussion

The use of RVO in modified diesel engines has potential. However, before it could be recommended, more information is needed on the long-term effects on engine life. Problems of fuel filter blockage also remain to be eliminated by improvements to the modification kits or better pre-cleaning of the RVO. A specification for RVO intended for vehicle use would be important.

Biodiesel production from RVO is a feasible option; a simple single-stage process should be adequate for most of the material collected, and the fuel quality should be of a fairly high standard. The main problem would be to procure sufficient volumes to achieve a reasonable economy of scale.

Tallow esterification presents more difficulties. On a small scale, the two-stage process would need to be streamlined to maintain plant capacity before it could be recommended.

At 2003 prices, when allowance is made for the cost of engine modification kits and reductions in fuel economy, the equivalent production cost (before tax and distribution) of mineral diesel would have to be at least 33 cent/litre for RVO to be competitive as a vehicle fuel. Biodiesel produced from RVO would require a mineral diesel price of 38 cent/litre. For tallow ester to be competitive, the diesel price would need to be at least 40 cent/litre. Since these were all well above 2003 diesel prices, some subsidy would have been required for the biofuels before they could be marketed at prices competitive with mineral diesel. Recent changes in the prices of diesel, RVO, tallow and glycerol are reducing the difference between the two fuels, but still not to the point of eliminating the need for a biofuel subsidy.

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