Short note on Pure Plant Oil (PPO) as fuel for modified internal combustion engines

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Abstract:

This note contains a short summary of main characteristics of pure plant oil (PPO) as a fuel for internal combustion engine automotive applications.

The main conclusions are that:

- ✓ PPO does represent an option, which in some technical end environmental aspects are superior to other alternative fuels.
- ✓ On the other hand use of PPO entails a need for engine modifications as well as a need for a separate distribution infrastructure.

There is therefore little reason to see PPO as the primary fuel of the future. On the other hand PPO is a fuel, which does have its benefits, and therefore should be given equal treatment as compared to other CO_2 neutral fuels.

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Pure Plant Oil (PPO)

Fuel Characterisation

The interest in plant or vegetable oils originated in the late 70's and came from the agrarian sector, which is still one of its main drivers. Initially, it was believed to be possible to use these oils directly with a low processing level. Extensive testing by the engine industry has shown that unmodified engines, while operating satisfactorily, would quickly develop durability problems, due to problems with fuel injectors, piston rings and lubrication oil stability. For this reason the engine must be modified. Such modifications can at present be made by a number of facilities mainly in Germany. More than 5000 vehicles are presently using pure plant oil in Germany. [ELS] Nevertheless one can still find examples of claims that PPO can be used in any unmodified engine. As an example the TV program TopGear on BBC presented the claim in November 2002, but without showing any durability test of the concept.

The proponents of PPO point to many years of practical experience with the use of PPO in a wide range of modified engines and mention specifically a number of advantages of PPO over biodiesel:

- ✓ Processing is simple as the only steps are cold-pressing (<50°C) and filtering. Therefore the production can easily be decentralised and create jobs in rural areas. [FC1]
- ✓ De-central production allows a minimisation of raw material transport. As an example production of rapeseed oil yield around 1 t oil, 2 t protein feed and 4 t straw per ha. Thus large volumes needs to be transported, wherefore optimisation of this step is crucial for the overall energy balance. [FC1]
- ✓ Low overall energy consumption in optimised production. Fossil diesel 12%, PPO 13%, biodiesel 26%. Thus PPO is comparable to fossil diesel in this aspect. [FC2]
- ✓ According to the VwVwS (Verwaltungsvorschrift wassergefährdende Stoffe), which is the national German regulation on water hazard classification, PPO is harmless to groundwater (class NWG) which means that oil spills cause no harm to the environment. In comparison, biodiesel belongs to water hazard class WG1 like viscous crude oil, heavy fuel oil, and a number of other mineral oils and chemicals. [FC4]
- ✓ Modified engines can run on regular diesel, e.g. during a vacation to areas without PPO supply. [FC1]

In this light PPO represents an interesting option as a vehicle fuel.

Production paths

I theory a wide range of crops can be used for PPO production, but in reality only rape seed oil is being used. The production path is relatively simple as it consists simply in growing and harvesting the seeds, pressing the oil at low temperature and filtering the final product to remove impurities. Thus the production technology can be applied at almost any scale.

Production on a small scale in a decentralised structure will generally result in lower overall yield of oil, as cold pressing cannot extract all oil from the seeds. Typical yield values are around 77%, even though values above 87% can be found. For larger oil mills, using hexane solvent extraction, the yield is typically around 98% of total oil content in seeds. [BW] Using hexane extraction will increase the cost of processing, as the hexane used for extraction must be removed before the protein meal can be used as animal feed. It may thus be more economical to avoid this step in case the protein cake is to be used as feed stuff.

Production is constrained by availability of agricultural land in terms of total extent of useable land; in terms of competitions with other crops (food, etc.); in terms of crop rotation needs (rape can only grow every 5-7 years on the same land) and because of the Blair House Agreement limiting the area for oilseed production in EU.

For the German market a quality standard exists (RK-Qualitätsstandard), [LTV] which PPO must meet. This is not a problem for pure cold pressed rape seed oil, but may be a problem for some oils available in the market pressed at higher temperatures. Thus a larger scale adoption would require a market separation of the different oils, to ensure a consistent quality.

Market Position

PPO today represents a marginal niche in the transport fuel market. The majority of vehicles running on PPO are converted regular vehicles, and conversion equipment sets are available for many common engine models [VW]. Thus in theory most diesel engines can be converted to pure PPO operation, including advanced TDI versions, and as such the technology much be counted as available on a broad basis.

One of the main suppliers of conversion equipment (Elsbett in Germany) also sells an engine specifically designed for PPO operation. Additionally the tractor manufacturer Deutz-Fahr markets a tractor specifically adapted for PPO operation as part of a market introduction program.

Environmental Performance

The scientific literature on environmental performance of PPO vehicles is somewhat sketchy, and seems for a large extent to be relatively old. Quite a few studies were reported 15-20 years ago, generally concluding that PPO operation was not feasible. Most of these studies were however conducted on unmodified engines, and as such not comparable to modern modified engines. In a recent report from a Finnish study on raw mustard seed oil (MSO) on a 4.4.litre agricultural DI diesel engine, that did not test durability but emission values, reports that the engine, which had been modified with larger injector nozzle bores and a slight timing change performed almost equal to the original engine (BMEP=13bar, P=25.7kW/l, Md=100Nm/l, ç=42%). In terms of emission values wet exhaust HC and NOx were lower with MSO than with diesel; some increased CO emissions were reported for low loads up to medium speed and high loads at lowest speed. However, despite lower or equal smoke no. the MSO fuelled test shows considerably higher ultrafine particulate counts (<100nm). Japanese studies on PPO and blends do indicate problems with PPO from oxygenation of lubricant due to the water content. [EN]
In a test on a modified engine (VW Golf 1.6D) carried out by EMPA in Switzerland the result was a significant reduction (20-60%) of all emissions as

compared to fossil diesel, except for CO_2, which was identical. Very few details are available, however, wherefore it is not possible to fully evaluate the test. As an example it is not possible to see if the quoted emission for fossil diesel are in the modified engine or in a comparable unmodified engine. [FC3]
In a test conducted by MAN B&W on a marine engine it was concluded that the performance showed better efficiency but higher NOx emission compared to Marine Gas Oil. It was hypothesised, however, that figures would be comparable in case a number of modifications to injection nozzle configuration and pressure be made. There is, however, no test of these modifications available.

One environmental aspect often mentioned in connection with diesel fuels is the relatively high NOx values encountered. To address this problem catalytic processes can be applied. This requires, however, a low sulphur fuel, if the catalyst is to have a reasonable lifetime. This is one of the reasons for the increasing interest in low sulphur fuel. In this context PPO is a brilliant fuel, as it has very low S content. Typically PPO has 5-10 ppm sulphur, and as such meets any suggested future limits for future fuel.

Consumption Paths

The consumption path is equal to the path for ordinary diesel fuel, except for the need for some modification of the engine. Modifications cost in the range from 1500 to 6000 Euro [FC1] [VW], depending on engine type, workshop, etc. and are as such a significant extra cost for the vehicle owner (Some workshops offer a do-it-yourself course at a somewhat lower price). In large-scale OEM production the cost should be only slightly higher than a regular diesel engine due to the need for preheating equipment for the fuel (the author of [FC3] estimates an additional cost of less than 300 Euro). An engine modified for PPO use can run on fossil diesel, as the general working of the engine is the same. It is to be assumed, however, that the modifications made to injection nozzles, etc. affect the combustion characteristics away from the optimum point for fossil diesel. Fossil diesel therefore represents a bridging solution while driving in areas without access to PPO, but should not be seen as a normal driving situation for the vehicle.

The distribution system for PPO is less developed than the system for fossil diesel. In the most well developed market (Germany) there are around 109 refuelling points, several of these however, with limited opening hours (e.g. tied to the opening hours of a workshop doing engine modifications). Additionally there is a network of suppliers selling PPO in bulk (e.g. 1000 litres) allowing users to have a large tank at home to fill up from. [VW2].

Thus using PPO is today much less convenient than using traditional products. It must therefore be assumed that conversion is attractive mainly for drivers:

- ✓ who can benefit from lower prices of PPO via large driving needs;
- ✓ or who are "early adopters" of the technology for more idealistic reasons.

Well to Tank Information

None of the major well to wheel studies [ANL], [GME], [IEA], [ECO], etc. contain any estimation of the performance of PPO. The reason for the omission is not reported. Bearing in mind, however, that conversion of plant oil to biodiesel is responsible for up to 50% (25-50% [IEA]) of the energy used in the fuel production chain indicates that a potential for improved efficiency by running on PPO should be present. In a note from one of the plant oil promoting organisations [FC2] the energy balance of rape seed oil is calculated based on a model published by the Danish Energy Ministry.

Source	Well to tank energy consumption in MJ/GJ delivered to tank	Comment
[FC2]	Credit ~ 40-90 Some credit ~ 57-125 No credit ~ 144-229	2000; Based on calculations with EMBIO model of Danish Energy Ministry Credit ~ full credit for all by-products Some credit ~ credit for straw used in CHP
[IEA]	No credit ~ 300-415	1999, Formally the report does not present the calculation, and the figures given are the figures for the feedstock production step for biodiesel.

There is not explanation for the big difference between the two "no credit" scenarios. However, the [IEA] study may include other steps in the figures as well, and may as such represent an upper limit. Whether credits should be given for protein meal can be debated as a significant part of the production of PPO is actually a by product of protein meal production, where the meal is produced as feed for animals. It thus substitutes import of meal from other regions. As such one could argue that the real substitution is the energy consumption of this transport. The [FC2] figures represent a decentralised structure, where little transport of products is included. It is thus mainly suited to describe the niche market application. For large scale applications, it is assumed to be closer to biodiesel, however, with a slight advantage because of the lower processing need.

Tank to Wheel Information

No formal assessment is available. However, rape seed oil has an energy content 6% below that of diesel on a volume basis (similar to biodiesel). Indications are that the energy efficiency is similar. Claims that the combustion characteristics should be better due to higher oxygen content in fuel leading to a more efficient combustion, makes sense in theory. However, no scientific verification has been found. The study mentioned earlier on a marine engine indicated a more complete combustion (lower Bosch smoke number), under part load and full load conditions. However it is not known if these results would transfer well to an automotive engine with different load patterns. Additionally the durability problems, quoted by most opponents of PPO, have not been documented in the available literature if studies on unmodified engines are not considered.

Well to Wheel Summary

Using figures available in the study and assuming that all CO_2 released during combustion is recaptured during growth of plants, so that the only net emission is the emission related to planting, harvesting, pressing, etc. the following numbers can be found:

Source	Well to wheel greenhouse gas emission in g CO_2 equivalent/km	Comment
[FC2]	DI ~ 8-43 (4-20)	2002; Based on interpretation of results

As very little information is available the results should be seen only as indicative. However even so the results should warrant further analysis.

Conclusion

The limited information available here indicates an interesting option, which however, is not documented fully. The use of PPO, does however, require a separate distribution infrastructure. Additionally the use of relatively unprocessed products may lead to variations in quality of the oil causing problems for engines and/or environment.

References

The descriptions of the different fuels in this report are based on a number of published reports, papers, etc. Each reference has been given a shorthand letter code in order to make identification of the source easy. Codes are included below.

- **[ANL]** *Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – North American Analysis*. Report in 3 volumes prepared by Argonne National Laboratory, June, 2001. Report available at http://www.transportation.anl.gov:80/ttrdc/pdfs/TA/163.pdf
- **[BW]** *Production of vegetable oils in decentral plants and aspects of quality management - Investigation of plants in practice to optimise the process*. Bernhand Widmann. University of Munich, Center of Agricultural Engineering. Presented at Biomass for Energy and Industry, 10th European Conference, 1998.
- **[ECO]** *Well-to-Wheel Efficiency for alternative fuels from natural or biomass*. Ecotraffic publication 2001:85. Report available at: http://www.ecotraffic.se/sv/index.htm
- **[ELS]** *Homepage of Elsbett Technologie Gmbh*. Available at www.elsbett.de
- **[FC1]** *Homepage of Nordvestjysk Folkecenter for Vedvarende Energi.* Available in Danish at www.folkecenter.dk
- **[FC2]** *Note: Rape seed oil for transport 1: Energy balance and CO_2-balance*. Paper prepared by Jacob Bugge, Folkecenter for Renewable Energy. 2000. Available in English at http://www.folkecenter.dk/plant-oil/publications/energy_co2_balance.pdf
- **[FC3]** *Notat vedørende emissioner fra forbrændingsmotorer, plante olie sammenlignet med diesel.* Paper on emissions of PPO by Niels Ansø, Nordvestjysk Folkecenter for Vedvarende Energi. 2000. Available in Danish at www.folkecenter.dk
- **[FC4]** *WGK (Wassergefährdungsklassen):The German Water hazard classes*. Available at http://www.folkecenter.dk/plant-oil/WGK_ENG.htm
- **[GME]** *GM Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study*. Report in several volumes prepared by LBST Gmbh, Sept. 2002. Available at www.lbst.de/gm-wtw
- **[IEA]** *Automotive Fuels for the Future. The search for alternatives*. IEA 1999. Report available at http://www.iea.org/
- **[LTV]** *Quality Standard for Rapeseed Oil as a Fuel (RK-Qualitätsstandard).* LTV-Arbeitskreis Dezentrale Pflanzenölgewinnung, Weihenstephan. http://dec2.tec.agrar.tu-muenchen.de/pflanzoel/rkstandard.html
- **[VW]** *Homepage of Die Vereinigten Werkstätten für Pflanzenöltechnologie* contains a pricelist (pricelist.pdf) of all models, which can presently be converted. List available at: http://www.pflanzenoel-motor.de/
- **[VW2]** *Homepage of Die Vereinigten Werkstätten für Pflanzenöltechnologie* contains a list of refuelling points in Germany. Available at: http://www.pflanzenoeltankstellen.de/ Another site with a similar list is available at http://www.rerorust.de