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ENERGY FARMING UPDATE — THE BIO-OIL OPTION.

GRAEME R. QUICK
Director of Agricultural Engineering, Agricultural Engineering Centre, Roy Watts Road, Glenfield. N.S.W. 2167.

ABSTRACT

Renewable fuels from crops are one class of alternatives for our diminishing fossil fuel reserves. Liquid fuels from crops are discussed, with particular emphasis on the potential for vegetable oils as replacements/extenders for diesel fuel.

An overview of the situation and the problems with using vegetable oils as fuels for diesel engines are discussed. The primary constraint is still cost and the second is the lack of warranty from engine manufacturers if these non-conventional fuel alternatives are used.

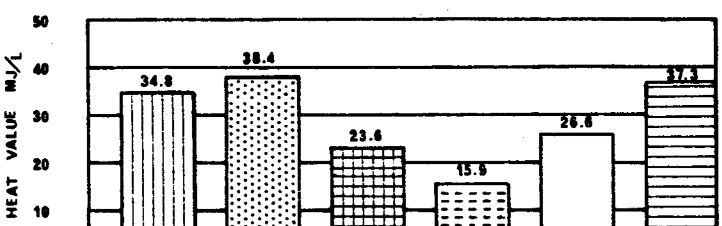
INTRODUCTION

Australian broadacre agriculture is dependent on the diesel engine. Changes in the fuel situation — changes in price, availability or quality of diesel distillate — directly affect the rural economy. Farmers have experienced traumas in all three of these areas and some regard renewable fuel alternatives such as ethanol or bio-oils as the answer to their energy problems, even to the extent of considering producing their own fuel, although they would not contemplate processing their own mutton, molasses or marmite.

A 'state of the art' seminar on Vegetable Oils as Diesel Fuels was held in Peoria, Illinois, Oct. 1981. At this USDA-sponsored seminar many new programs on the subject were reviewed and unpublished results were summarised, including work being undertaken by certain engine manufacturers. Pertinent findings from the seminar are reported in this paper.

Those features which make alcohol fuels attractive for use in spark-ignition engines — high octane rating particularly — militate against their sole use in unmodified compression ignition engines. Aside from this, the energy density of fuel alcohols is from one half to two-thirds that of the same volume of diesel fuel, Figure 1.

Figure 1. Fuel energy density spectrum of selected fuel on volumetric basis. Figures quoted are higher calorific values.



Bio-oils, on the other hand, have energy densities over 90 percent of that of diesel fuel. The term Bio-oils is coined for oils of recent biological origin, as distinct from fossil-derived hydrocarbons. Bio-oil fuels thus could come from plant foliage or latex-derivatives, or from the oilseeds which are of primary concern at this meeting, as well as from animal fats and algal sources. Of all these, oilseed crops are the nearest to being a substitute or extender for diesel fuel, in terms of potential for expansion in production agriculture, ease of extraction and cost. Palm oil and the Chinese tallow tree have been identified overseas as the most productive in terms of energy yield per unit land area — oil yields as much as five times that of sunflower are considered possible (e.g. 188 GJ/ha for palm oil vs say 38 GJ/ha for sunflower oil) — but these crops are not a component of Australian agriculture. In an emergency, sunflower, soybean, cottonseed, safflower, rapeseed, linseed and peanut oils would be the prime candidates as diesel engine fuels, roughly in that order of crop availability.

A comparison of the pertinent fuel-related properties of sunflower oil is shown in the table.

Properties	Diesel Fuel: Australian Automotive Distillate	Sunflower Oil: Crude Degummed
Gross heat value MJ/kg	45.93	39.38
Specific gravity	0.835	0.925
Viscosity @ 37.8°C mm^2/s	3.90	34.7
Cetane number (Typ.)	47 — 48	28 — 37
Flash point °C	55 — 77	215.5
Cloud point °C	−0.6	−6.6
Carbon residue %	0.15	0.42
Ash weight %	0.01	0.04
Distillation 90% point °C	335.0	355.0
Sulphur %	0.25 — 0.29	0.12
Copper strip corrosion	No. 1	No. 1B

1. Short-term engine performance on bio-oils:

Over forty bio-oils have been evaluated in short-term diesel engine tests since a diesel-cycle engine was first demonstrated running on peanut oil at the Paris Exposition in 1900.

Compression-ignition engines run well initially on most of these fuels. Engine torque and power characteristics can be very close to, or even in some cases may exceed, the performance of the same engine on diesel fuel. Considering that sunflower oil has about 5% less energy than diesel fuel, this result becomes explicable only when it is discovered that the bypass flow from most diesel engine fuel systems is dramatically reduced on vegetable oils. Normally bypass flow is used to lubricate and cool the injectors. With the much more viscous bio-oils, bypass flows as little as one-third to one-tenth that of distillate have been observed. This is probably one reason why fuel consumption on the vegetable oils in such engines is higher. Fuel injection systems vary considerably between makers and even within makes and models, so that variations in performance of even similar engines on different load cycles on vegetable oils have been recorded.

2. Long-term operation:

Sustained operation, however, on vegetable oils as straight fuel substitutes in unmodified **direct** injection engines can cause injector fouling, leading to a train of events that if left unchecked can result in premature engine failure.

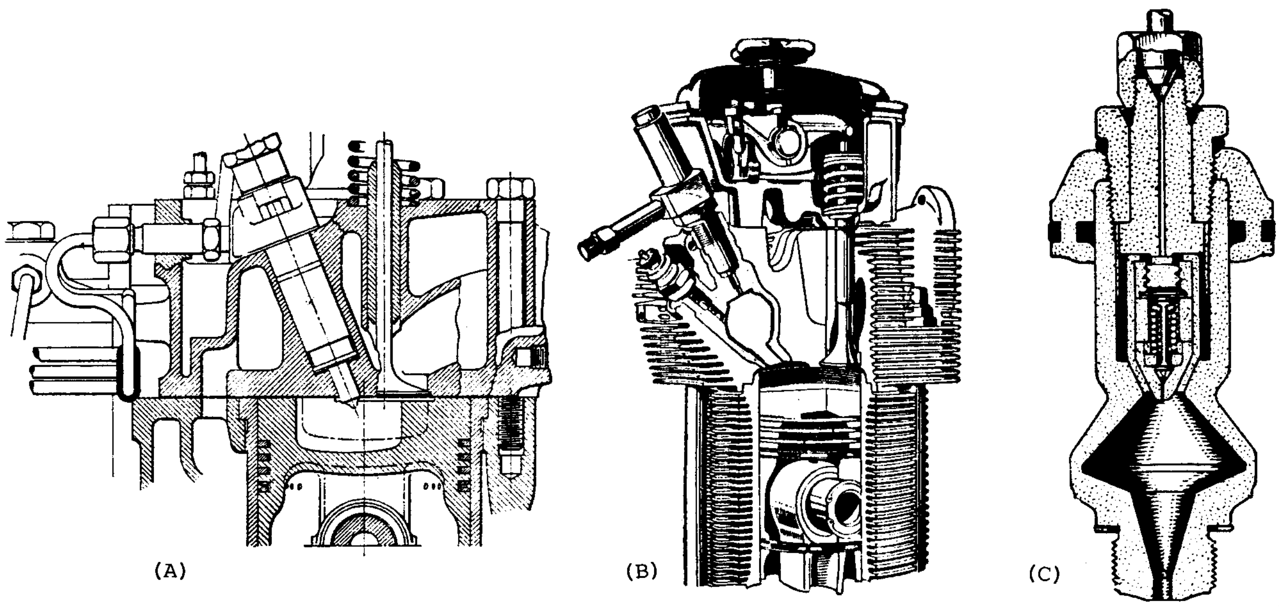
Problems with injector-coking can occur in well under 100 h in a direct injected engine on straight sunflower oil. Blending the vegetable oil with distillate will extend this duration, but coking and/or ring-sticking eventually ensues. With a blend ratio of 20/80 SFO/Distillate 1000 h of operation has been recorded.

Direct-injection types of diesel engines are used as prime-movers in the greatest majority of modern tractors and farm machinery. Indirect-injection engines are the other class of diesel engines in use. The results of tests just starting to come in on this class of engine indicate that **indirect injection** engines **do not** have problems with such fuels as soybean, rapeseed or sunflower oils.

Direct-injection (DI) engines dominate the market because they are more fuel efficient, the combustion chamber is more compact and cheaper to produce, DI engines are easier to start from cold and they usually have lower compression ratios. The injection system for such engines operates at higher pressure and the small bore multi-holed injector nozzles are more vulnerable to blockage and erosion.

The indirect injection (IDI) engine is not being ignored (Figure 2). These are preferred in the emerging automotive diesel market, probably because of their lower exhaust emissions, smoother running and higher engine speed capability. IDI fuel injectors are often single-hole type and more tolerant of a wider range of fuels. Tests of over 3000 h duration on straight vegetable oil fuels, without modification to the engine or the oil change frequency have been reported on Caterpillar and Deutz IDI engines running respectively on soybean and sunflower oils.

Figure 2. Direct and Indirect Injection diesel engine designs. (A) Ford DI, (B) Deutz IDI, (C) Caterpillar Prechamber IDI. (Prechamber & unit injector shown)



Conversion of an existing DI engine to the IDI type is possible, but would be quite expensive — usually requiring piston substitution as well as the changeover cylinder head.

Results for indirect injection engines running on vegetable oils while most favourable, have not been extensive enough yet to convince manufacturers that engine warranties should be extended to include this class of fuel in that type of engine. A major reason for this position is that there are no 'fuel' quality standards on bio-oils. There are at least five degrees of processing 'refinement' through which vegetable oils may be exposed, depending on the ultimate use for the oil, none of these are specifically related to fuel uses. Even spoiled edible oils have been used as fuel; a DI Blackstone engine was operated in Western Australia for 2000 h on spoiled rapeseed oil, but the injectors were routinely exchanged at oil change service intervals.

There is no strong evidence to conclude that refining vegetable oils to, say, edible standards (alkali refined and bleached etc) does anything to significantly extend DI injector life before the onset of coking, but the one factor common to all experimental work on these oils as fuels is the need for **filtering**. In all cases it is mandatory that bio-oils be filtered to diesel fuel 'standards' otherwise expensive engine fuel filters are likely to become plugged after very few hours of operation. A suggested desirable level of filtration is 4 micron.

3. Viscosity not the sole cause of injector coking:

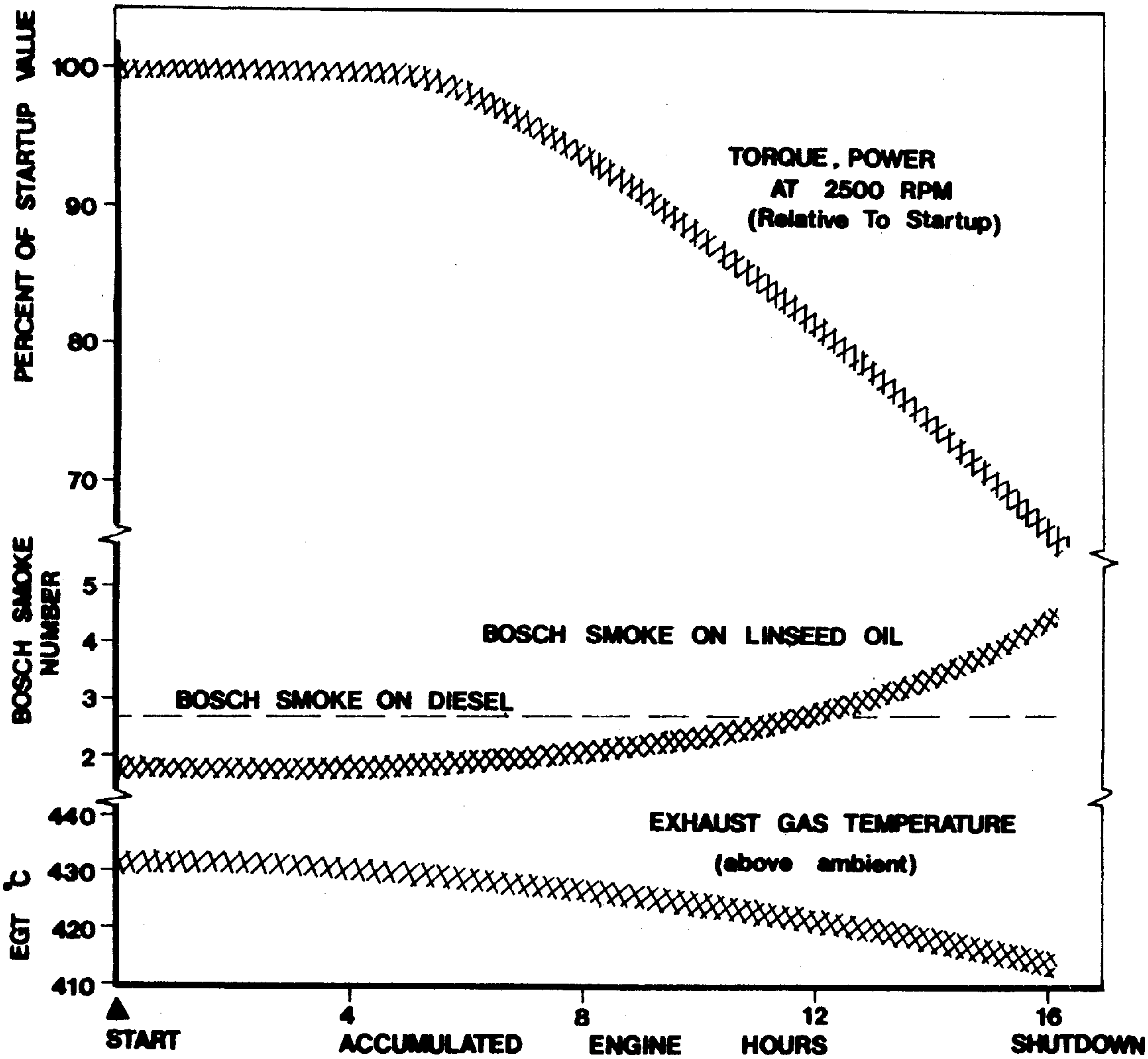
The injector-coking phenomena in DI engines has been designated by some researchers as a viscosity problem. With the exception of castor oil, the viscosity range of the candidate oilseed fuels in Australia is narrow. Thus any viscosity-related problem with vegetable oils would be expected to be common to them all.

Sunflower oil is typically about nine times as viscous as diesel fuel at the same temperature, and injector spray studies certainly have shown that there are quantitative differences in spray pattern from the more viscous oils, with streaming or hosing from the injector holes rather than the fine cone spray characterising diesel fuel injection.

N.S.W. Deparment of Agriculture engineers at Glenfield showed that two vegetable oils, rapeseed and linseed, of practically identical viscosity but differing 'reactivity', or film-forming propensity, showed a wide difference in tendency to injector coking in the same engine.

Linseed oil was selected as the most reactive commercially-available vegetable oil. The Glenfield tests on linseed oil involved monitoring enginer characteristics as performance declined, and established baseline data on this so-called "worst oil" which so seriously coked up the DI engine that no more than about 16 h of full-load operation was possible, and performance began to decline after just 7 hours, Figure 3. Rapeseed oil, rating around 100 on the iodine number scale (versus 180 for linseed oil) would run four to five times as long before performance was seriously impaired.

Figure 3. AEC Glenfield test data on a Lombardini 720 DI single cylinder engine logged over 16h running on raw linseed oil and loaded to maintain constant 2500 rpm at full governor setting.



It was concluded that the problem was **not** solely viscosity-related. Coconut oil (Iodine number 10) ought to be a very good fuel candidate just from this viewpoint. Unfortunately we do not have the climate for commercial coconut production in Australia, whereas in some Pacific islands even now coconut oil is a cheaper commodity than diesel fuel.

4. Esters:

As early as 1945, chemical modification to lower the viscosity of coconut oil for use as a fuel in North Africa established the potential for the technique of esterifying vegetable oils.

Trans-esterification using ethyl, methyl or butyl alcohols can lower viscosity substantially and alter boiling range of the vegetable oil esters to approach that of diesel fuel.

Volkswagen Brazil have reported very favourable on this type of fuel, pointing out that it fulfilled the following criteria for a new fuel candidate:

(1) compatibility with existing diesel engines

(2) miscibility in diesel fuel.

They also mentioned that the esters might be used to raise the cetane rating of low grade diesel fuels.

VW Brazil have successfully logged 1400 hours in static engine test cycles and 25 000 km in road tests on a VW Passat (1.6L IDI) engine, using peanut methyl ester. A significant point made was that the esters do not produce the carcinogen **acrolein** which can be a by-product of combustion of straight vegetable oils.

Some pertinent characteristics of Brazil vegetable oil methyl esters

Cetane Number	45 to 63	Could be used as a Cetane Improver for lower-grade diesel fuel.
Viscosity (Cst @ 37.8°C)	4 to 6	Compared with 1.6 — 6.0 for diesel fuel.
Cloud Point (°C)	+1 to +13	Compared with −5 for SFO −1 for diesel
Flash Point (°C)	164 to 267	Compared with 321 for SFO 55 to 77 for diesel

Note that the onset of crystalization may occur at temperatures above freezing, depending upon process control.

South African agricultural engineers have reported fairly satisfactory results with sunflower ethyl esters in direct injected engines running up to several hundred hours, but there were hints of trouble in the injectors with small quantities of the catalysts in the final product. The South Africans have developed simple technology for esterification, claiming that processing costs should not be 10% more than that of producing straight sunflower oil. US researchers, on the other hand, estimate the costs of esterification would be likely to add from 20 to 50% to the cost of the straight vegetable oil, and expressed considerable uncertainty about the future of the market for the by-product glycerol. A valuable commodity now, the glycerol market is only small and would be readily "swamped".

Caterpillar reported on a 200 hour satisfactory screening test with soy methyl ester in a DI engine but they had severe storage drum contamination, with rust coming all the way through the fuel system to even show up in the combustion chamber. Precise source of contamination was not known but was suspected to be due to attack of drums by the ester.

Some injector fouling was noted with rapeseed methyl ester (9% free fatty acid) and lube oil contamination was reported in Mercedes DI engine tests in Brazil.

Around one dozen US University groups and three engine manufacturers have commenced esterbased fuel test programs. While preliminary results were favourable, long term test reports are not yet available.

DISCUSSION

In this review of renewable liquid fuel candidates from agriculture, vegetable oils have been considered as the most likely short-term candidates as a substitute fuel for the diesel engines on which modern agriculture depends.

Short term tests have shown that torque and power output of a range of diesel engines operating on oilseed fuels equalled or were close to performance on regular diesel fuel. Fuel consumption was invariably higher. Sustained operation on vegetable oils as straight fuel replacements in unmodified direct injection engines eventually causes coking, all the faster with the more "reactive" oils, such as linseed oil. Filtering of the oils to diesel standards is essential, and chemical modification of the oils by such techniques as transesterification may overcome the injector-coking problem — a problem which is combustion-related. Some interesting avenues for improvement in long-term engine performance of direct injection engines have been explored but there has been no breakthrough that would give engine manufacturers sufficient confidence for them to endorse the use of this class of fuel substitute under warranty. Several indirect-injection engines have been successfully field proven in long term tests and their wider fuel tolerance capabilities demonstrated on certain of the vegetable oils. Vegetable oils could be used in an emergency as blends or modified and used as esters, bearing in mind that the engine warranty would be voided. The major obstacle is still cost.

CSIRO studies estimate the ex-plant costs of oils from linseed, rapeseed and sunflower at 44 to 59 cents per litre, compared with the excise-free wholesale cost of diesel distillate in rural centres of 29 cents per litre. Five million hectares of oilseeds could produce more than 20% of Australian diesel consumption, or most of Agriculture's diesel needs. This level of cropping could be achieved in Australia without reducing current crop production.

In view of the uncertainties in the continued availability and the price of petroleum-based diesel fuel, it is considered essential that research and development on oilseed fuels be continued in order that their production and use could be rapidly implemented should the need arise.

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"THE USE OF VEGETABLE OILS FOR ENGINE FUELS MAY SEEM INSIGNIFICANT TODAY. BUT SUCH OILS MAY BECOME IN THE COURSE OF TIME AS IMPORTANT AS PETROLEUM AND THE COAL TAR PRODUCTS OF THE PRESENT TIME"

1912

- Rudolf Diesel

Pioneer of the Age of Power