Performance of Vegetable Oils and their Monoesters as Fuels for Diesel Engines*

Gerhard Vellguth

Institute for Basic Research in Agricultural Engineering
(Bundesfonschungsanstalt fur Landwirtschaft)
Braunschweig, Germany

ABSTRACT

Vegetable oils can potentially be used as fuels for diesel engines. But in direct injection engines, such as are used in agricultural tractors and trucks, some difficulties with vegetable oils – even with fully refined oils – have been noticed, so that long-time operation is impossible. Engine tests are made to evaluate some modifications to these oils. The result is that the former problems do not occur with derivatives of vegetable oils after transesterification with ethanol or methanol if the injection is advanced.

INTRODUCTION

Vegetable oils were some of the first fuels, and were used when Rudolf Diesel developed the self-ignition internal combustion engine at the end of the last century. During the further development of diesel engines, petroleum fuels were exclusively used, because, for instance, they were more readily available and cheaper. But in the last decade conditions began to change. The high consumption of petroleum for fuel and chemicals on the one hand, and the limited nature of this source of energy on the other, brought awareness of its exhaustibility and led, for political and commercial reasons, to an enormous increase in prices. Therefore in many countries, and notably in oil-importing and agricultural countries, fuels from renewable materials that are not unlimited but inexhaustible sources of energy have been tested.

Some properties of vegetable oils mark them out as being an important fuel for diesel engines. A former study[1,2] showed that in the German Federal Republic less than one-fifth of the agricultural area must be planted with rape to produce the required fuel for the total agricultural area. Since the area of rape fields and the yield per hectare has increased,[3] the balances of mass and energy have improved. Nevertheless in Germany, as in several other countries, vegetable oils, in comparison with the total need of diesel fuel, can only substitute for a small part of the energy requirements and can only be used as an emergency fuel. So for such countries at this time it is preferable to adapt the fuels to the engines and not to develop special engines for the fuels.

FUEL PROPERTIES OF VEGETABLE OILS AND DERIVATIVES OF VEGETABLE OILS

Properties

If fuels are to be used in the existing engines, some requirements are necessary with regard to their fuel properties: the kinematic viscosity, the self-ignition response and the net heating value, the gross heating value and the density.

The viscosity must not be too high so that the fuel will be sufficiently fluid to allow it to be used for filling up and to flow through the fuel system (filter, injection pump and nozzle). Figure 1 shows that the kinematic viscosities of the best disposable oils are quite similar to each other, but substantially higher than that of diesel fuel. Therefore, without aids, these vegetable oils are usable only down to about 0°C. At lower temperatures heating devices are required. Blends of diesel fuel and vegetable oils have viscosity values between the values of the clean components in relation to the proportions of the mixture.

Improving the viscosity by blending with ethanol or methanol is possible; but it becomes practically useless because these mixtures give unstable solutions. Solubilizers can help to stabilize the solution – but other disadvantages have been observed, such as decreased self-ignition and higher costs.

The derivatives of vegetable oils, called monoesters, have lower kinematic viscosities than the oils themselves. The viscosity of the methyl and ethyl esters of rapeseed oil is between that of the summer and winter quality of diesel fuel (Fig. 1). Monoesters are able to give stable solutions in a wide range of proportions in the case of both diesel fuel and vegetable oils, and also with alcohols.

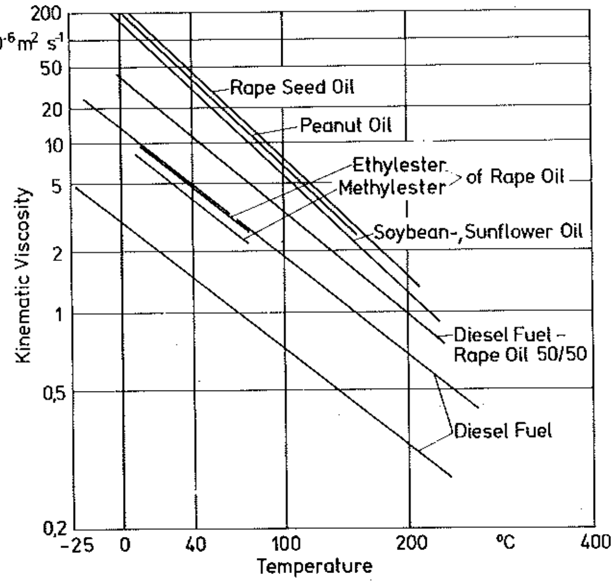

Fig. 1 Kinematic viscosity of diesel fuel, vegetable oils and esters vs. temperature.

Since they can be solubilizers, it is possible for monoesters to influence the viscosity of blended oils.

The self-ignition response, expressed by the cetane number, is good. For diesel fuel, according to the German standard DIN 51 601, the value has to be not lower than 45, and on the market CN = 51 is usual. These values will be reached or exceeded in general by vegetable oils. The cetane number of refined rape oil of food quality standard gave CN = 51.

Cetane numbers of monoesters, on an average, are above those of vegetable oils. For ethyl ester and methyl ester of rape oil cetane numbers of 54 to 55 were measured. A sample of ethyl ester, which was cleaned ("washed") in a laboratory, reached more than CN = 65. A mixture of this sample with diesel fuel (CN = 51), half and half, had CN = 60. According to these CN values, the monoesters of rape oil can be iginition improvers for distillates of less ignition response or for alcohols. It was possible to start a small one-cylinder, direct injection diesel engine fuelled with a mixture of 75% ethyl ester and 25% aqueous ethanol (~ 190 proof) at a temperature of 10°C without any ignition aid, and it ran normally.

The energy content, another important property of fuels, was determined by calorimetric measurement of the gross heating values. The specific heating values of the different vegetable oils are nearly the same. They range from 39.5 to 40.5 MJ/kg (Table 7 in [1]). For the ethyl and methyl esters of rape oil, 39.4 and 40.6 MJ/kg respectively were evaluated. The gross heating values by this procedure are about 12% below the average value of diesel fuel (45.0 MJ/kg). But for utilization in diesel engines the specific net heating values of the fuels are decisive. (The specific net heating value is the specific gross heating value diminished for the heat content of the combustion water). The specific net heating values of vegetable oils and esters are approximately 37.2 MJ/kg, with a variance of less than 2%; while for diesel fuel, it is approximately 42.4 MJ/kg.

The density of vegetable oils is 0.91-0.94 g/cc at 15°C (Table 7 in [1]), while the density of the ethyl and methyl esters of rape oil is 0.87 and 0.88 g/cc respectively. In comparison to the density of diesel fuel (0.81-0.86 g/cc) the densities of vegetable oils are about 10% higher, and for esters about 5% higher.

Consumption and Load

The injection pumps of diesel engines dose the fuel volumetrically. If we assume that the thermal efficiency is the same, the maximum load with different fuels depends on the volumetric heating value.

The above values result in a volumetric net heating value of 35.4 MJ/L for vegetable oils and 32.6 MJ/L for the monoesters of rape oil. The difference in the volumetric net heating value of vegetable oils and diesel fuel is only about 3%, and between the esters and diesel fuel the difference is about 10%. With the same adjustment of the injection pump, a reduction of the reachable load in these quantities must be expected.

By changing the adjustment of the injection pump to a higher fuel flow, the same load is possible as with diesel fuel, but corresponding to this the volumetric consumption is higher. Measuring fuel consumption and load with rape oil as fuel for agricultural tractors with direct injection, this fact was confirmed for a natural-aspirated engine, while for a turbocharged engine the fuel consumption was less than was expected[1,2]. Other research institutes and engine manufacturers have obtained similar results, even when other vegetable oils – such as soybean, sunflower or peanut oils – were used. These results were arrived at on the basis of short-term tests.

Problems in Long-term Operation

In Germany, nearly all agricultural tractors have direct injection (DI) diesel engines. If these engines run over long periods of time with vegetable oils or mixtures of diesel fuel with a high content of vegetable oils, troubles with deposits on several engine parts arise. They cause a decrease of load even after a short time – after a few hundred or sometimes after only a few engine hours – and finally the engine breaks down.

For example, Fig. 2 shows a 4-orifice nozzle after 50 hours operation with fully refined rape oil. Unburned or partly burned coked rape oil produces thick, hard deposits forming trompets around each orifice. This affects spraying, the formation of droplets and the air-fuel mixture, so that the combustion becomes worse and worse as more deposits arise.

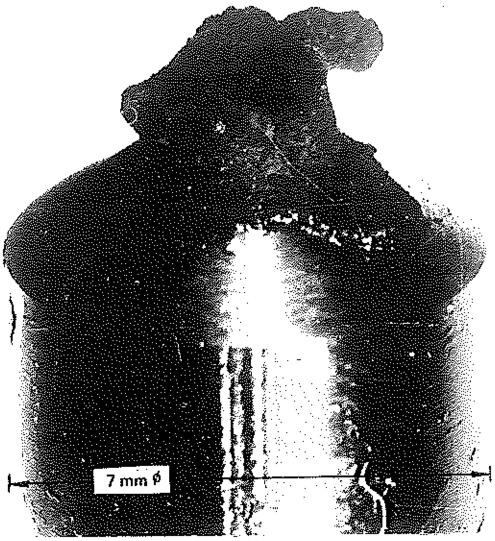

Fig. 2 Nozzle deposits after 50 hours operation with fully refined rape seed oil; one-cylinder direct injection engine.

The piston (Fig. 3), was also operated for only 50 hours at 3/4 of miximum load with fully refined rape oil. The deposits on the piston top are black, thick and hard, and at the edge fill the clearance in the top dead center position so that they are pressed together at each stroke. Deposits in the upper piston ring groove and on the piston ring give the severest problem of engine operation when using vegetable oil as a fuel. The piston ring sticks in the groove, and consequently the compression decreases and the combustion deteriorates. Subsequently deposits grow and the load decreases.

Another problem follows. The sticking ring is not able to make an adequate seal, and so the vegetable oil fuel gets through the clearance into the crankcase. It contaminates the lubrication oil which leads to the formation of a tough, rubber-like coating on the engine parts and the walls of the case, and on the fuel pump and the valve steering camshaft and rods, as shown in Fig. 4. These parts were only cooled and lubricated by the luboil and have no direct connection to the combustion chamber. The coatings too can cause trouble or breakdown. The analysis of the luboil after 200 hours of operation with refined rape oil showed a rape oil content of 12.5%.

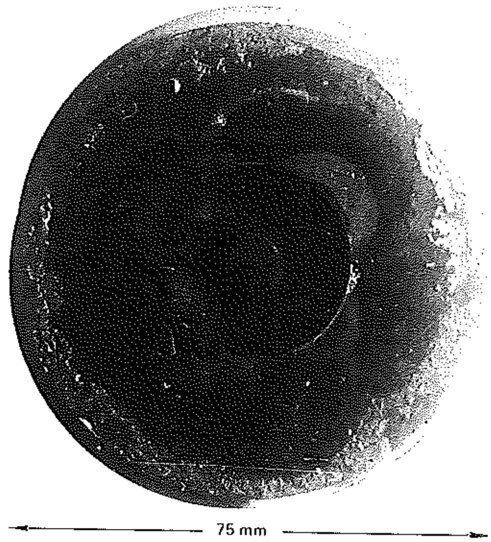

Fig. 3 Piston deposits after 50 hours operation with fully refined rape seed oil; one-cylinder direct injection engine.

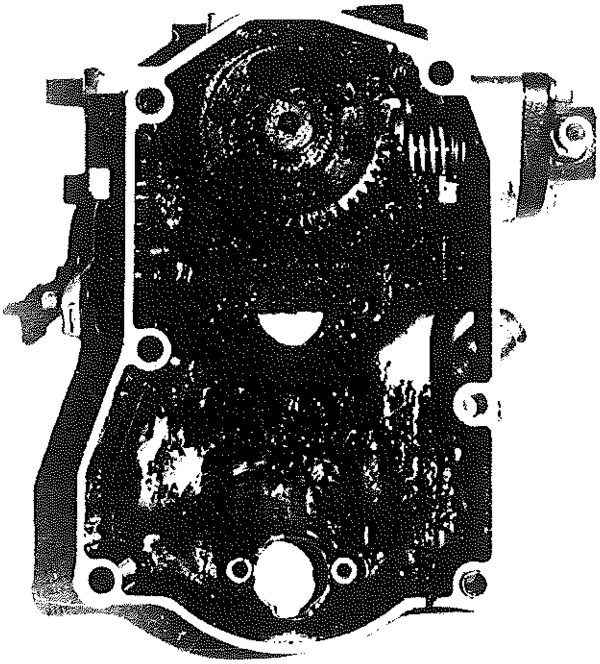

Fig. 4 Coating on engine parts after 200 hours operation with fully refined rape seed oil; one-cylinder direct injection engine.

In contrast to these problems with DI-engines, it has been reported that engines with pre-combustion chambers could be operated with vegetable oils almost without problems for more than a thousand hours, mainly if fully refined oils were used.

Selected Modifications to Improve the Behaviour of Vegetable Fuels

The use of vegetable oils as substitutes for diesel fuel requires that measures can be found to solve the problems of long-term operation. First of all, the problems of deposit build-up and ring sticking must be solved. The change in the lubrication oil seems to ensue from bad combustion, and therefore is of smaller interest at this point.

On this principle, two different solutions can be envisaged:

1. adaptation of the engines to the fuel, or
2. adaptation of the fuel to the engines.

Of course it is not excluded that one of these modifications will be complemented by a measure of the other. For the near future, and especially for the conditions of agriculture in the German Federal Republic, the second way – the adaptation of the fuel to the existing engines – has more advantages, because it allows the replacement of diesel fuel by vegetable oils suddenly and for a short term, and either as a total substitution or as a blend.

The modifications required to adapt the fuel can be:

1. The addition of chemicals (additives)
   – to improve the air-fuel mixture by decreasing the surface tension,
   – to improve the combustion by catalytic reaction, or
   – to dissolve and remove deposits.
2. A different mixture with other fuels – to get a better internal formation of the air-fuel mixture as a consequence of a lower viscosity of the blend, or to initiate better burning by easier burning components.
3. The extraction of imperfect or restrained burning components.
4. Preheating to diminish the viscosity for improving the internal formation of the mixture and combustion.
5. Chemical variation, i.e. the production of vegetable oil derivatives (e.g. methyl or ethyl esters), to reduce the size of the molecules and consequently to obtain an easier and quicker burning fuel with less tendency to coke. (For the process of transesterification, see the last section.)

Sometimes it is suggested that water should be added, and it is expected that the explosive evaporation in the hot combustion room causes better spraying of the fuel. Because the deposits more readily develop at cooler parts, like the cylinder wall and at the inlet valve, the injection of water with the successively cooler temperatures would not seem to be a promising measure.

SYSTEMATIC TESTS

Test Stand

To evaluate the effectiveness of the different measures, the engine needs to be operated for a sufficient duration. The tests must guarantee the possibility of being reproduced, and should differentiate the result and the expense for the device and the maintenance, and they should aim to ensure that the fuel costs will be low.

Therefore, small one-cylinder diesel engines were used:

1. A diesel engine with direct injection:

   bore d = 75 mm diameter

   stroke s = 55 mm

   displacement V_H = 0.24 liter

   rated output P_N = 3.5 kW

   rated speed n_N = 3000 min^{-1}

   air cooled,

   2 equal engines alternately

2. A diesel engine with a pre-combustion chamber:

   d = 75 mm diameter

   s = 80 mm

   V_H = 0.353 liter

   P_N = 4.4 kW

   n_N = 3000 min^{-1}

   air-cooled,

   pre-combustion chamber designed as swirl-chamber.

The test scheme and a picture of the test stand are shown in Figs. 5 and 6 respectively. The load is varied by a generator with an adjustable resistance. Several sensors are installed to monitor the desired test conditions and to prevent accidents, e.g. fire and total breakdown of the engine. The temperatures, speed and load are recorded to compare and evaluate the tests and to reconstruct the reasons for unexpected stops.

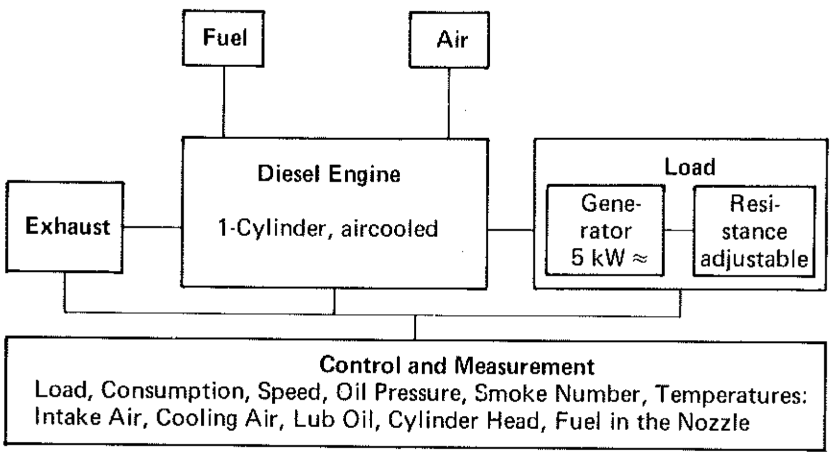

Fig. 5 Schematic diagram of the test stand to investigate alternative fuels.

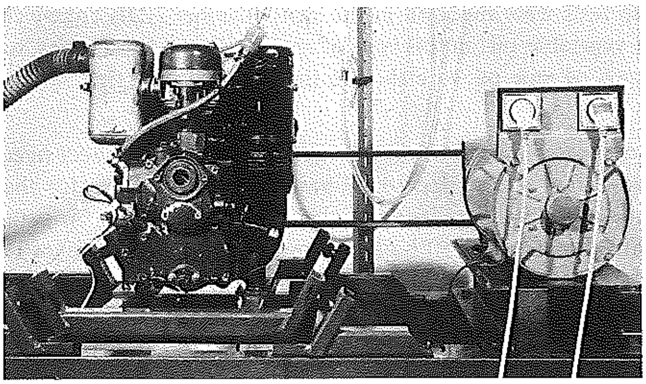

Fig. 6 Test stand with a small one-cylinder DI-diesel engine.

Because of the procedure to subjectively evaluate the results (see the following section) a new piston for each test run was required. Each time, a run-in with diesel fuel was made. At the end of this time, the fuel consumption and the BOSCH smoke number were determined to guarantee that the test engine was in faultless condition and that it would be possible to reproduce the results.

Subjective Evaluation

There is no standard method to provide the performance or the suitability of a fuel in engine tests, and therefore the method of evaluating the lubrication oil was modified. With the German standard, DIN 51 361,[4] the performance of different lubrication oils was examined, to determine whether the piston of a one-cylinder engine was clean after running it for 50 hours with a certain diesel fuel. The modification used for this evaluation consists of taking a certain well-known lubrication oil (BP Vanellus TS 30) and observing how different test fuels (vegetable oils in several variations) cause variations in the cleanness of the piston.

For the evaluation of the grade of cleanness, five sections of the piston must be inspected, and rated according to the procedure of the standard DIN 51 361. Instead of the continuous 50 hours of operation used for the standard tests, these tests were stopped at night, and it required five or six days to complete a given test so that the oils had time to build up resin if there was any tendency to do so.

Besides the cleanness of the piston, the daily measurement of the smoke numbers, and the quantity, thickness and consistency of the deposits on the nozzle, the piston top and the cylinder head gave indications for the success of the modifications of the fuel. Analysis of the lubrication oil was also made to differentiate the results. The fuel consumption for each day and for the total 50-hour period was measured, and the specific fuel consumption was determined. Yet these values are of less significance, because there were unavoidable differences in the run-in, the state of wear, and other influences.

Tests and Results

The different tests may be related to three series. In the first series, the selected modifications to improve the behaviour of vegetable fuels in DI-diesel engines were tested. In the second series, some of these tests were repeated in the swirl-chamber (IDI) engine to check the reported better behaviour of vegetable oils in this type of engine. In the third series, tests were made, especially with monoesters of rape oil, to elaborate the results of the first series concerning monoesters.

Tests with the selected modification of vegetable oils in the direct injection diesel engine – First, a test with diesel fuel was started to get basic data as reference for the other tests. Then a test with refined rape oil (edible quality) provided the starting point for evaluating the improving effect of the modifications. After 50 hours of operation, the cleanness was bad (Fig. 3), about half the circumference of the upper piston ring was stuck, and it broke when it was disassembled. There were heavy, black deposits on the piston, on the nozzle (Fig. 2), and on other parts of the combustion chamber. (For special values and details see Table 1 in [5].)

The addition of additives gave no better results. The first additive ("Renomix") is said to be a flow and ignition improver and a cleaner for diesel engines; but in the test the piston cleanness was worse. About 3/4 of the circumference of the ring was stuck, and there were more deposits than was the case without the use of this additive. The second additive ("V2") kept the fuel oil house-heatings free from soot. With this additive the test was stopped after only 30 minutes because the desired load could not be reached and the temperature of the lubrication oil increased to 140°C. Due to this experience, further tests were made at 3/4 full load.

Repeating the basic diesel fuel test followed by the rape oil test at the new load range brought similar results to those previously described. Tests with fully refined soybean and peanut oil showed no important differences from the tests with rape oil. There were only small differences in the consistency of the deposits, and after running with soybean oil the upper ring did not stick.

The question as to whether certain components of the vegetable oil cause the problems, and whether it is possible to run an engine with crude or partly refined oil, can be answered clearly. With crude rape oil the test was stopped after 5 hours, and with crude, degummed oil it was stopped after 6 hours. After such periods of operation, the piston ring was already sticking.

Mixtures with good burning components do not solve the problems, but they extend the operational time prior to their occurence. With a 50:50 mixture of diesel fuel and rape oil, the piston ring had no clearance after 50 hours, but was not yet sticking.

Great success is expected by warming up the oil to get the same viscosity as diesel fuel. Therefore this test was carefully prepared. A temperature sensor was mounted in the fuel flow inside the nozzle holder at a distance of 50 mm from the top of the nozzle, and the temperature of the diesel fuel at this point was determined to be 82-84°C. From Fig. 1 it can be seen that vegetable oils must be warmed up about 100 degrees to have the same viscosity as diesel fuel. This temperature was obtained by using an electric heating coil installed around the injection tube immediately before the nozzle holder. But this test gave negative results. The fuel consumption rose, smoke numbers were high, piston cleanness was very low, and the piston ring was sticking all around. A repetition of the tests using peanut oil resulted in deposits forming on the nozzle, which prevented the engine from starting again at the beginning of the third test day (after 23 hours of operation).

Finally, the possibilities of changing the properties of vegetable oils by using chemical processes were examined. For several processes in food production, pharmaceuticals, cosmetics and chemicals, transesterification is a well-known process. A run with ethyl ester, i.e. with ethanol transesterified rape oil, brought positive results – the piston cleanness was as good as with diesel fuel, the upper piston ring was clean and gave no sign of sticking. The deposits were thin and loose as with diesel fuel. The smoke numbers were low at the beginning, but they rose day after day. Therefore the third test series was started.

The results obtained after modifications to improve the behaviour of vegetable oils may be summarized as follows:

- additives gave no improvement;
- three different vegetable oils with their different components made no significant differences;
- crude or partly refined oil is not sufficient; and even for a short-term run the oils should be fully refined;
- with mixtures, the problems are only diminished as the proportion of vegetable oil is diminished;
- pre-heating for a better viscosity does not give better results, and may even increase the problems;
- only the chemical changing of the vegetable oils, the diminution of the molecules by transesterification with ethanol or methanol, seems to be successful.

Tests with a pre-chamber diesel engine – Reports about harmless or nearly harmless long-term operation with vegetable oils in diesel engines with a pre-combustion chamber prompted the decision to perform tests under the same conditions as with the direct injection engine. The main results were:

1. The engine could be started with crude, degummed rape oil when the normal ignition aid was used. But the crude oil caused several deposits on the nozzle and gave rise to alternating exhaust temperatures after only a few hours.
2. With refined rapeseed, peanut and soybean oils, the results of other research findings with pre-chamber engines were confirmed. The behaviour in forming deposits in the combustion chamber, the piston cleanness (Fig. 7) and the ring sticking was much better than in the DI-engine. But there were signs of a build-up of deposits on the inner-

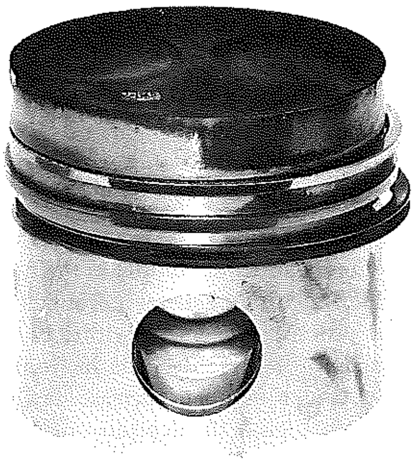

Fig. 7 Piston after 50 hours operation with fully refined rape seed oil; one-cylinder engine with pre-combustion in a swirl-chamber.

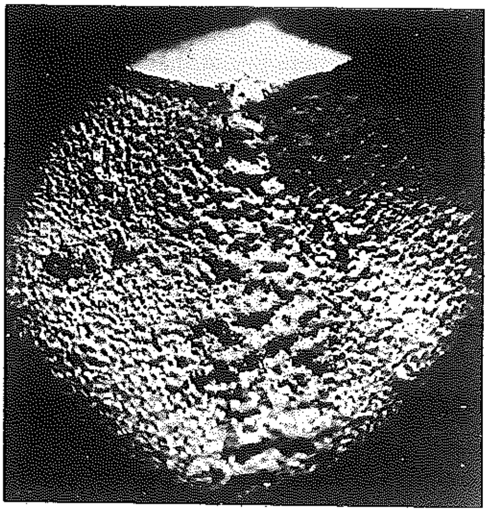

Fig. 8 Deposits in the swirl-chamber after 50 hours operation with fully refined soybean oil.

side of the piston ring and in the ring groove, and also on the nozzles and in the pre-chamber (Fig. 8). Also, pre-chamber engines will not by any means be without problems when they are operated with vegetable oils over long periods of time.

3. With a mixture of diesel fuel and methyl ester of rape oil the engine was cleaner than with pure diesel fuel. The transesterified oils are promising not only in DI-engines but also in IDI-engines, where they are better than the refined oils themselves. They could be used as alternative fuels for diesel fuel in both types of engines, which would be more advantageous from a logistic point of view than the use of two different fuels. (For special values and details see Table 2 in [5].)

Tests with ethyl and methyl esters of rape oil in the engine with direct injection – The transesterification could be easier and cheaper if measures were taken with regard to purity of the esters, i.e. if the surplus of alcohol needed for total transesterification need not be separated again, or if a certain quantity of untransesterified oil could remain for a lower input of alcohol. Both conditions caused trouble (Table 1).

Impure esters caused rising smoke numbers, bad piston cleanness and deposits on the nozzle. With the alcohol surplus, the tests were stopped prematurely because of the knocking of the nozzle needle. With a residue of untransesterified oil in the ester, the piston ring stuck after the 50-hour period of operation. Consequently the esters should be pure.

In practice it may be unavoidable that esters become mixed with diesel fuel, either to extend the stock of diesel fuel or by the residuals of diesel fuel in the fuel system. Therefore, such mixtures must be evaluated. The 50:50 mixture of diesel fuel and ethyl esters was used without problems, and showed the expected piston cleanness, as with diesel fuel, and the piston ring was clean and free. There was a build-up of loose deposits in front of the injection nozzle in the shooting channel which made the smoke numbers increase day after day, so that after only 37 hours the nozzle had to be taken off to push the deposits out of the channel. After that the run was continued without any trouble up to the end of the 50-hour test.

To remove the difficulties, which also appeared with the pure ester (100% ethyl ester) in the

Table 1. Results of Lubrication Oil Analysis after Tests with Monoesters of Rape Oil; One-Cylinder DI-Engine.

Fuel	Oil Drain Period [h]	Viscosity at 100°C [m^2/s]	Insolubles [% by Weight]	Breakdown of Antiwear-Additives [%]	Ester Contents [%]
Ethylester (EE)	50	11.4	0.4	– 18	2.5
EE/Ethanol 90:10	50	8.54	0.7	– 54	9.8
EE/Rape Oil 50:50	50	11.7	0.6	– 15	2.2
DK/EE 50:50	50	10.8	1.4	– 18	2.2
DK/EE 50:50 (4° advanced)	50	11.9	0.2	± 0	0.4
Methylester (ME) (4° advanced)	50	–	0.9	– 4	0.8
ME (4° advanced)	100	11.6	0.2	– 17	0.9
ME (4° advanced)	150	11.6	0.6	– 19	1.0
ME (4° advanced) (after 300 h run)	150	11.8	0.3	– 19	1.3

first test series, the following point was considered: if a good combustible material is not totally burned, either the needed oxygen is missing or there is not enough time for it to mix completely with the oxygen. Because there is enough air available, the time was extended by advancing the injection timing by about 4 degrees of the crankshaft beyond the normal timing for diesel fuel given by the manufacturer of the engine.

Subsequently, the specific fuel consumption and the smoke numbers improved, the piston cleanness was better than with diesel fuel, the piston ring was free and very clean, the deposits on the nozzle were as little as those produced using diesel fuel, and the orifices were free. In the combustion chamber, thin loose crusts could be found, which could be said to be a dusty covering.

The main problem – the deposit building up from combustion – seemed to be solved with these measures; so then the problem of lubrication oil contamination by mixing with the fuel remained. The lower viscosity of the ester as compared to the luboil leads to thinning, and therefore may cause deficient formation of lubricating film and increased wear – which happened during the first tests with ester, as the oil analysis shows in Table 1. With the advanced injection timing and the subsequent improvements of the combustion, the values of the oil analysis were improved. The viscosity value was kept, the deactivation of the antiwear additives dropped to zero and the ester content in the lubrication oil was less than a fifth of the former value. All findings are quite normal as compared with that of diesel fuel under normal conditions, and better than the acceptable limits.

A long-term test with methyl esters of rape oil was run with planned intervals until the first oil drain after 150 hours, and then an oil change after a further 150 hours. Neither the intermediate investigations of the oil nor the analysis of the two drained oils showed any problems. Accordingly the crankcase and the other case with engine parts (Fig. 9) were clean after draining the oil, and did not have coatings. The cleanliness of the piston (Fig. 10) after 300 hours was better than with diesel fuel after 50 hours. The piston ring was free and clean, deposits on the nozzle caused no trouble and the deposits on the other parts of the combustion chamber after 300 hours were equivalent to that of diesel fuel after 50 hours.

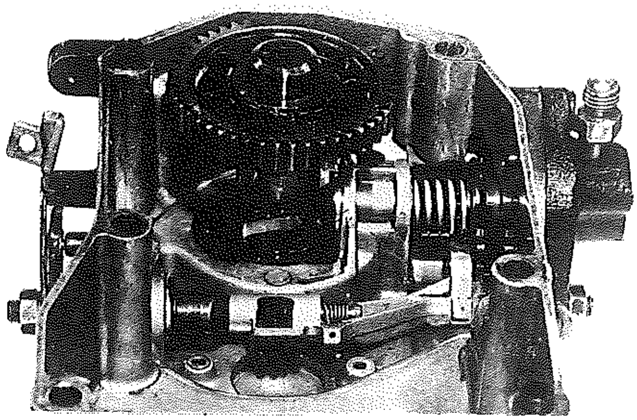

Fig. 9 Engine parts after 300 hours operation with methylester of rape oil; one-cylinder DI-engine.

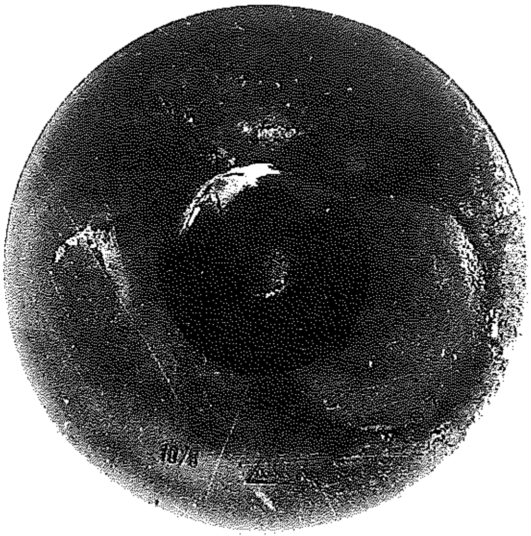

Fig. 10 Piston after 300 hours operation with methylester of rape oil; one-cylinder DI-engine.

Conclusions

From the results of the three test series, the following deductions can be made:

– crude vegetable oils are not useable as fuels for diesel engines;
– refined vegetable oils in long-term runs are useable in pre-chamber engines with restrictions, but they are not suited for direct injection engines;
– the problems with vegetable oils in direct injection engines can be solved by transesterification to methyl or ethyl esters and simultaneous adjustment of the injection timing, if high demands regarding the purity of the esters are guaranteed.

TRANSESTERIFICATION OF VEGETABLE OILS

Vegetable oils consist of about 97% triglycerides, with the other 3% distributed among di- and monoglycerides, free fatty acids and fat accompanying substances, which will be mostly removed with the refining.

A triglyceride (Fig. 11) is a compound, in which 1 molecule of glycerine – a trivalent alcohol – is estered with 3 fatty-acid molecules. For the most part, these three are different. Transesterification is the change of the trivalent glycerine molecules against 3 molecules of monovalent alcohols – methanol or ethanol. Each alcohol molecule then forms with the fatty-acid residue 1 molecule of monoester. In most vegetable oils, fatty acids with 16 and 18 C-atoms predominate. These triglycerides have molecular weights of 850 to 900. The methyl or ethyl esters have less than 300, and this is much nearer to that of diesel fuel (with about 200). With transesterification, the kinematic viscosity decreases – in the case of rape oil to about 1/10, so that with a value of 6 to 8 m^2/s at 20°C it lays in a range which is between that of diesel fuel of summer and winter quality respectively.

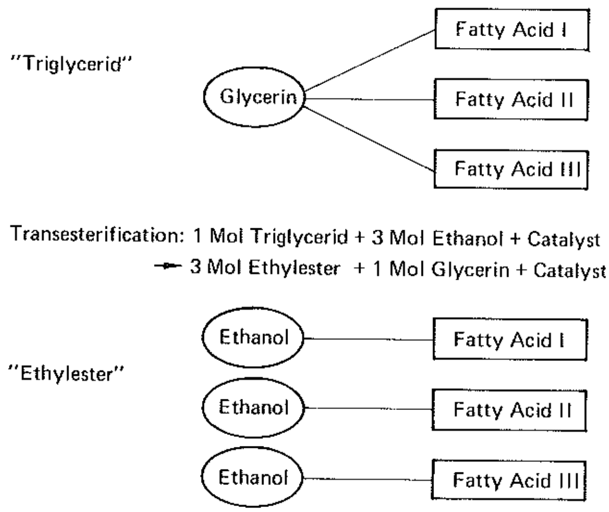

Fig. 11 Scheme of transesterification of vegetable oil.

Transesterification can be effected with methanol or ethanol, according to the equation in Fig. 11. Alkali metals, e.g. sodium, are qualified as catalysts. The processing in principle is simple: to produce 100 kg of ethyl ester 0.13 kg of sodium must be dissolved in 26.3 kg of ethanol, and then must be intensively mixed in a reaction chamber with 105 kg of fully refined rape oil. To accelerate the reaction, it is heated up to 60-80°C for some hours and then cooled. During a resting interval it separates, and after that a glycerine-water mixture and an ester-alcohol mixture can be drained off. Pure glycerine is a resource for many products, and therefore it must be separated from the water. This separation is expensive, and it is profitable only in industrial processing which uses greater quantities. The ester-alcohol mixture must also be separated, and the ester must be dried and filtered to make it pure enough. The total amount of time required for a charge may be 2 to 3 days.

Large-size industrial transesterification is realized as a continuous flow, working pressureless at 70°C or at a pressure of up to 90 bar and a temperature of 240°C.

This method has been tried in different countries to process the oil and the transesterification "on farm." The idea is to expel the oil with tractor-driven screw presses. By this process the output of oil is much lower because, when expressing, the residual content of oil is 4 to 10%. On the other hand, in the oil mills with pressing and extraction the residual content of oil is only 0.5%. As a reaction chamber for the transesterification, the tanks for spraying plant protection agents are usable. But if the crude expressed oil is taken without refining, then the efficiency of the catalyst is affected. The transesterification runs slower, is incomplete, and gives a smaller output. The impurities and accompanying fat substances appear in the esters, and impure esters causes engine problems – clogged fuel filters, sticking nozzle needles, and breaks as a consequence of deposits on the piston rings and valves. It remains to be seen if "on farm" conditions can be provided which are suitable to ensure sufficient purity of the ester.

SUMMARY

Vegetable oils seem to be usable as fuels for diesel engines, as some of their properties show and as has been confirmed in short-term tests to determine fuel consumption and power. But in long-term operations with direct injection diesel engines, some problems arise with deposits, ring sticking and changes in the lubrication oil, which after a relatively short time lead to troubles and breakdown. With pre-combustion chamber engines the behaviour of vegetable oils is better; but nevertheless it is expected that long-term operation will not be possible without difficulties.

Tests with selected modifications of oils showed that only transesterification is useful in solving the problems involved. In addition, the injection timing has to be advanced.

Transesterification is a relatively simple process, but because of the required purity and the utilization of glycerine, industrial processing is preferable.

It remains for the results to be proved in agricultural practice. Consequently a tractor with 100% methyl ester of rape oil as fuel has been on duty since November 1982. As of June 1983, no problems had arisen – except dilution of the lubrication oil, which required oil draining after 150 hours. This might be caused by the greater combustion room and lower speed as compared with the test engine, so that another evaluation of the optimum injection timing has to be made.

REFERENCES

[1] Batel, W., M. Graef, G. J. Mejer, R. Möller, F. Schoedder (1980), Pflanzenöle für die Kraftstoff- und Energieversorgung. *Grundl. Landtechnik Bd.* 30, Nr. 2, S. 40/51.

[2] Schoedder, F. (1981), Rape seed oil as an alternative fuel for agriculture. *Beyond the energy crisis. Third International Conference on Energy Use Management*, Berlin, Oct. 26-30, 1981, Vol. III, p. 1815-1822.

[3] Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten der Bundesrepublik Deutschland 1981 (1981), Hursg.: Bundesmin. Ernahrung, Landwirtschaft und Forsten 25. Jg. Munster-Hiltrup: Landwirtschafts-Verlag.

[4] DIN 51 361 (1977), Teil 2: Prüfung von Schmierstoffen; Prüfung von Motorenschmierölen im MWM-Prüfdieselmotor, Verfahren zur visuellen Büerteilung der Kolbensauberkeit. Berlin/Köln: Beuth-Verlag.

[5] Vellguth, G. (1982), Eignung von Pflanzenölen und Pflanzenölderivaten als Kraftstoff für Dieselmotoren. *Grundl. Landtechnik Bd.* 32, Nr. 5, S. 177-186.