VEGETABLE OILS AS SUBSTITUTION FOR DIESEL OIL
Test results obtained on a Diesel Engine with direct injection

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INTRODUCTION

In April 1983, the Ethiopian Herald published an article on tests using vegetable oils as fuel for diesel engine driven lorries in Brazil [1]. In this context, it may be of interest to know that similar laboratory tests with different vegetable oils as diesel engine fuel had been conducted during the last three years in the Faculty of Technology, Addis Ababa University. These tests were carried out in order to obtain data about the behaviour of diesel engines if vegetable oils are used as alternative fuel. The tests were sponsored by the Ethiopian Science and Technology Commission (ESTC) after learning of reports of such tests made in Brazil, South Africa, USA and other countries*.

Due to the steep increase of price of crude oils from which Diesel oil is produced and due to the scarcity of hard currency in many countries to buy crude oil, a number of agencies are conducting worldwide tests with vegetable oils as substitute for diesel oil. However, test results are scattered** and many of these tests conducted by manufacturers of engines are still in the experimental stage and, thus, results of these tests are unavailable.

USED VEGETABLE OILS

The Faculty of Technology has conducted tests using sunflower-, cotton seed-, rape-seed- and noug-oil as alternative fuel. These oils were used in their natural state — hereafter referred to as 'non-esterified' — and in an esterified state (esterification = chemically transforming the vegetable oil into methyl ester and glycerol).

All mentioned vegetable oils, non-esterified and esterified, are miscible with diesel oil in any proportion. The mixture of sunflower oil with diesel oil seems to be the most stable one. No separation of the two components had been noted even after weeks of storage. The other vegetable oil-diesel oil mixtures did show separation to a certain extend after few days if not steered. However, all hereafter reported test results are obtained with unmixed fuels.

Some properties of the used vegetable oils are given in Table 1 and compared with the properties of diesel oil. Great differences exist between non-esterified vegetable oils and diesel oil as far as the kinematic viscosity is concerned. For instance, the kinematic viscosity of the non-esterified sunflower oil is about 6 to 10 times higher than that of the diesel oil. One result of the esterification process is that the viscosity is reduced to values which also occur with diesel oil. Similarly, the noteable differences between non-esterified vegetahle oils and diesel oil with regard to the flash point as well as to the proportions of fractions with higher boiling points are reduced due to esterification.

High kinematic viscosities, high flash points and high proportions with high boiling points of the non-esterified vegetable oils seem to increase the tendency of carbon deposits on the injection nozzle and in the combustion chamber. This is mentioned in many publications [2], [3] and [4]. However, the severity of difficulties encountered in field tests seems to vary.

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**An extensive list of concerned literature is with the author and could be made available to interested parties.

Table 1: Properties of vegetable oils in comparison with Diesel oil

Fuel		Non-esterified				Esterified		
		Diesel oil	Cotton-seed oil	Noug oil	Sunflower oil	Cotton-seed oil	Noug oil	Rape-seed oil
Density at 15.6°C	kg/m³	840	920		927	882	886	880
Destilation:								
Initial Boiling Point, IBP	°C				200	66	66	65
recovered at 300 °C	%-Vol				10	5	5	5
at 357 °C	%-Vol	87 min.			56		87	50
Final Boiling Point, FBP	°C	390 max.			360	350	359	382
Flash point	°C	66 min.	330	205	322	70	68	64
Viscosity, kinematic, at 40°C	10^{-6} m²/s (or cSt)	2.0—5.5			32	4.7	5.1	5.6
Carbon residue	%-weight	0.1 max.			0.22	2.2	1.4	3.75
Ash content	%-weight	0.01 max.			0.004	0.014	0.014	0.01
Cetane number		about 50			about 40			
Higher Heating Value HHV	kJ/kg	45400	41500	39200	37700	39100	39600	39700
	kJ/ℓ	38100	38200		34900	34500	35100	34900

TEST ARRANGEMENT

The tests were carried out on a 4-stroke, 4-cylinder Diesel Engine, type OM 314 of Mercedes-Benz make, without pre-chamber but direct fuel injection into the cylinder room. This type of engine is normally used as drive for lorries. In this case, however, the engine was mounted stationary for testing on a brake rig which allowed to measure torque, engine speed, fuel consumption and exhaust temperatures. Furthermore, the exhaust smoke at the outlet of the exhaust pipe could be observed, see Fig. 1.

Because of the very high kinematic viscosity of the vegetable oils at room temperature it was initially felt necessary to preheat the fuel before it enters the fuel system of the engine. An one meter long single pipe heat exchanger to be heated by hot water circulated and controlled by a thermostat had been arranged for this purpose. But this arrangement had not been used as all the tests could be conducted without preheating of the fuel and without noting adverse effects while running the engine. It may, however, be assumed that starting of the engine would have been facilitated if preheated fuel had been injected during the starting phase. But as the simple, above mentioned preheating arrangement was installed before the relatively large fuel filter which remaining unpreheated fuel would reach first the injection nozzle this arrangement would not have helped the starting procedure.

TEST RESULTS

As stated in [8] the first trials using vegetable oils as fuel for the investigated engine encountered certain severe starting and running difficulties. It has, however, to be mentioned that in all the later tests such difficulties were not experienced again and that especially quiet running was not only obtained with esterified oils but also with the non-esterified oil. In retrospect it cannot be stated why the first trials did encounter the afterwards not any more noted difficulties.

Because of the initial difficulties the change over to vegetable oils was done in the following tests with mixtures of sunflower oil and diesel oil increasing step by step the percentage of the sunflower oil. Running the diesel engine with 100% non-esterified and non-preheated sunflower oil proved so possible. For the following and below discussed tests only 100% esterified or non-esterified vegetable oils had been used.

A summary of the results of these tests is given in Table 2 which allows a comparison with diesel oil tests.

Out of the tested non-esterified vegetable oils, the sunflower oil seems to be the most suitable substitute for diesel oil. The tests with non-esterified sunflower oil produced about 5% lower maximum torque and maximum brake power. The minimum specific fuel

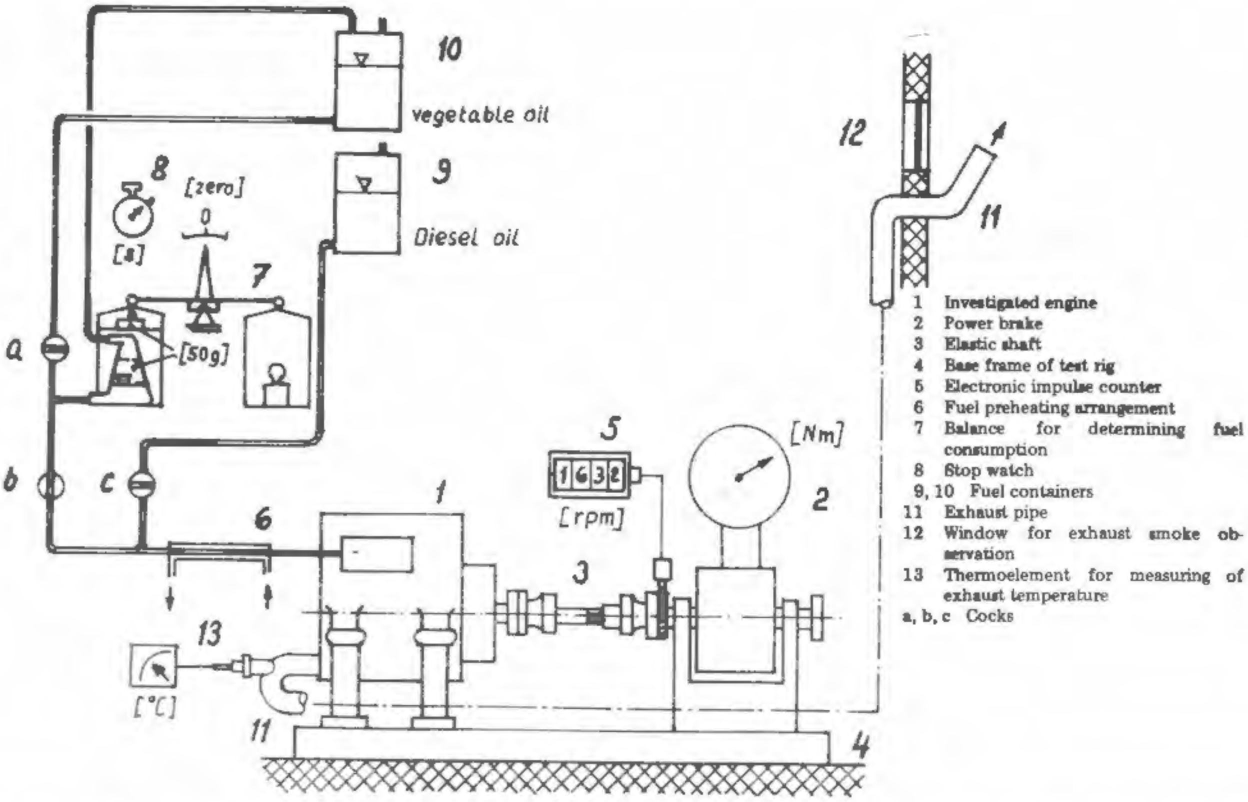

Table 2. Performance, consumption, starting behaviour and smoke levels of the Daimler-Benz Diesel engine OM314 run with vegetable oils in comparison with diesel oil

Fuel		Non-esterified				Esterified		
		Diesel oil	Cotton-seed oil	Noug oil	Sunflower oil	Cotton-seed oil	Noug oil	Rape-seed oil
max. torque T_{max}	Nm	205.5	198	199.5	198	206.8	204.5	207.6
	%	100	96.4	97.1	96.4	100.6	99.5	101.0
max. brake power N_{max}	kW	42.2	40.0	40.4	40.3	42.0	40.1	42.0
	%	100	94.9	95.6	95.5	99.5	95.0	99.5
specific fuel consumption for max. brake power	g/kWh	280	313	299	320	314	not measured	310
	%	100	111.8	106.8	114.3	112.1		110.7
min. specific fuel consumption for speed n = 1600 rpm	g/kWh	239	296	299	300	285	301	280
	%	110	123.8	125.1	125.5	123.8	125.9	117.2
Cold-starting behaviour		immediate after 1s	end of 6th trial	during 13th trial	end of 4th trial	after 13s	after 13s	after 12s
(each trial means 15 s running of starter motor, 15 s intervals between trials, engine temperature about 22° C)								
Smoke observations (only visual observation of the smoke at the outlet of the exhaust pipe)		For the above mentioned full-load tests the exhaust smoke of tests with vegetable oils was slightly less than with diesel oil. But for no-load running stronger exhaust smoke was observed with the vegetable oils.				Smoke observation was made only for the esterified Rape-seed oil: notably less smoke than with diesel oil. Especially, full-load running at 1300-1500 rpm produced no smoke with Rape-seed oil while diesel oil produced quite heavy smoke also for these speeds.		
		While the exhaust smoke of diesel oil is dark, the exhaust smoke of the vegetable oils, non-esterified and esterified, is bluish-white.						

consumption in (g/kWh) for the speed of 1600 rpm, Fig. 2, had been measured about 25% higher compared with that of diesel oil. It may be assumed that this difference of the fuel consumption approximately is the same for all torques and speeds as this engine is concerned, see Fig. 4. The higher specific fuel consumption of sunflower oil can mainly be explained with the lower heating value of sunflower oil which accounts according to Table 2 to about 17%. The remaining difference would indicate that the combustion of the sunflower oil in this engine had not been as complete as that of the diesel oil. In spite of this, the exhaust smoke was in general less with sunflower oil than with diesel oil.

Out of the three used non-esterified vegetable oils the least difficulties were encountered with the sunflower oil as far as cold starting was concerned. Starting with non-esterified noug oil was most difficult in spite of the fact that the flash point of noug oil is considerably lower than that of the sunflower oil. Starting with all the non-esterified vegetable oils, however, was much more difficult than with diesel oil or even with esterified vegetable oils. The battery of the starter motor was, hence, subject to high strain.

As far as the tests with esterified vegetable oils are concerned, see Table 2, Fig. 3 and 5, the cold starting behaviour was improved strongly while max. torque, max. brake power and specific fuel consumption were not much influenced by the esterification of the vegetable oils.

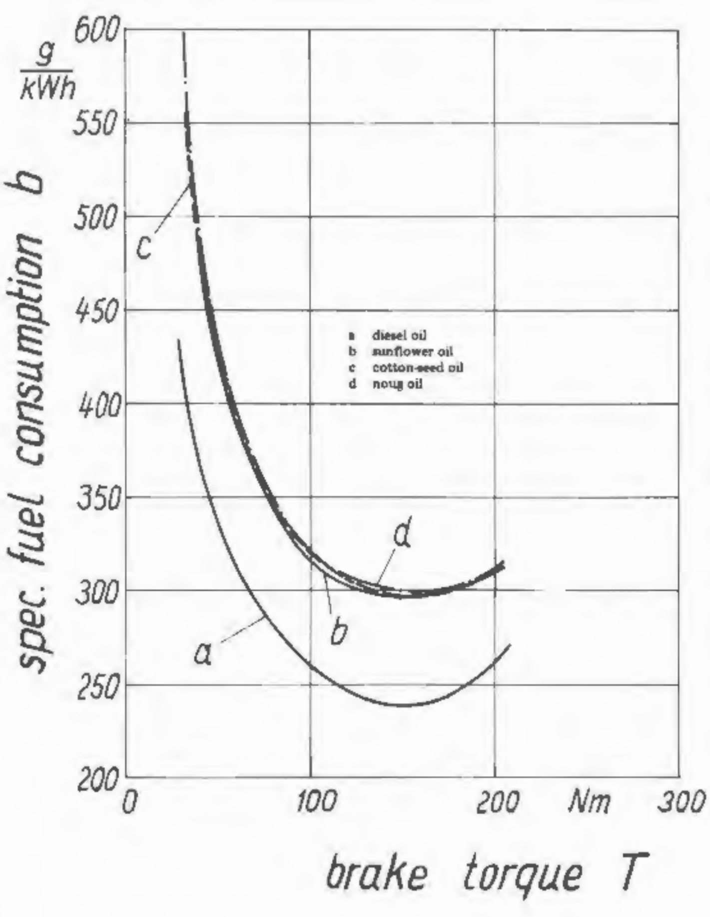

Fig. 2 Specific fuel consumption as function of the brake torque at 1600 rpm. Comparison between non-exterified vegetable oils and diesel oil

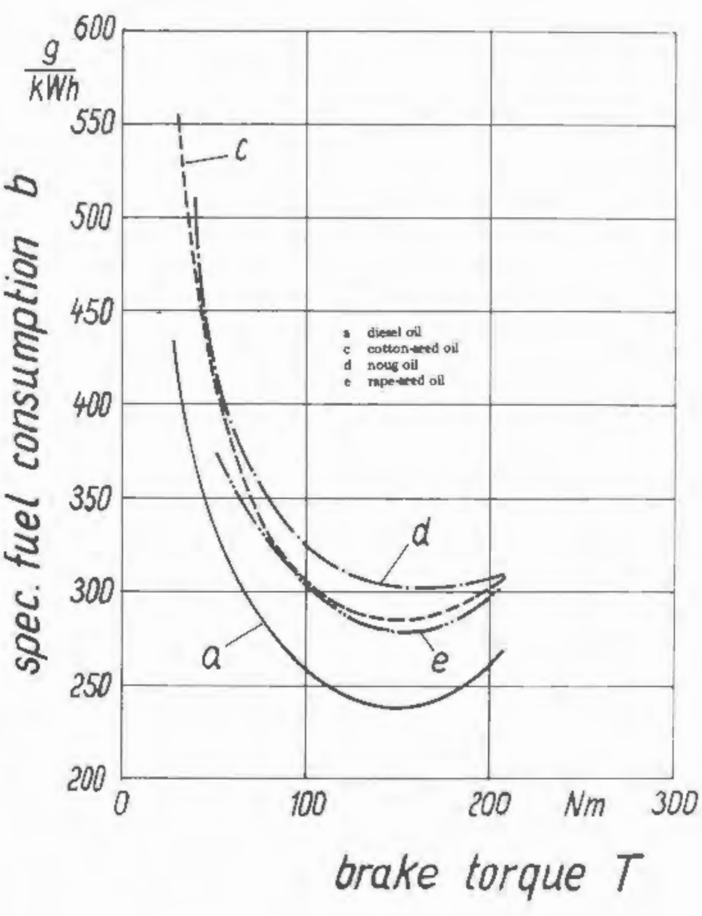

Fig. 3 Specific fuel consumption as functions of the brake torque at 1600 rpm. Comparison between esterified vegetable oils and diesel oil

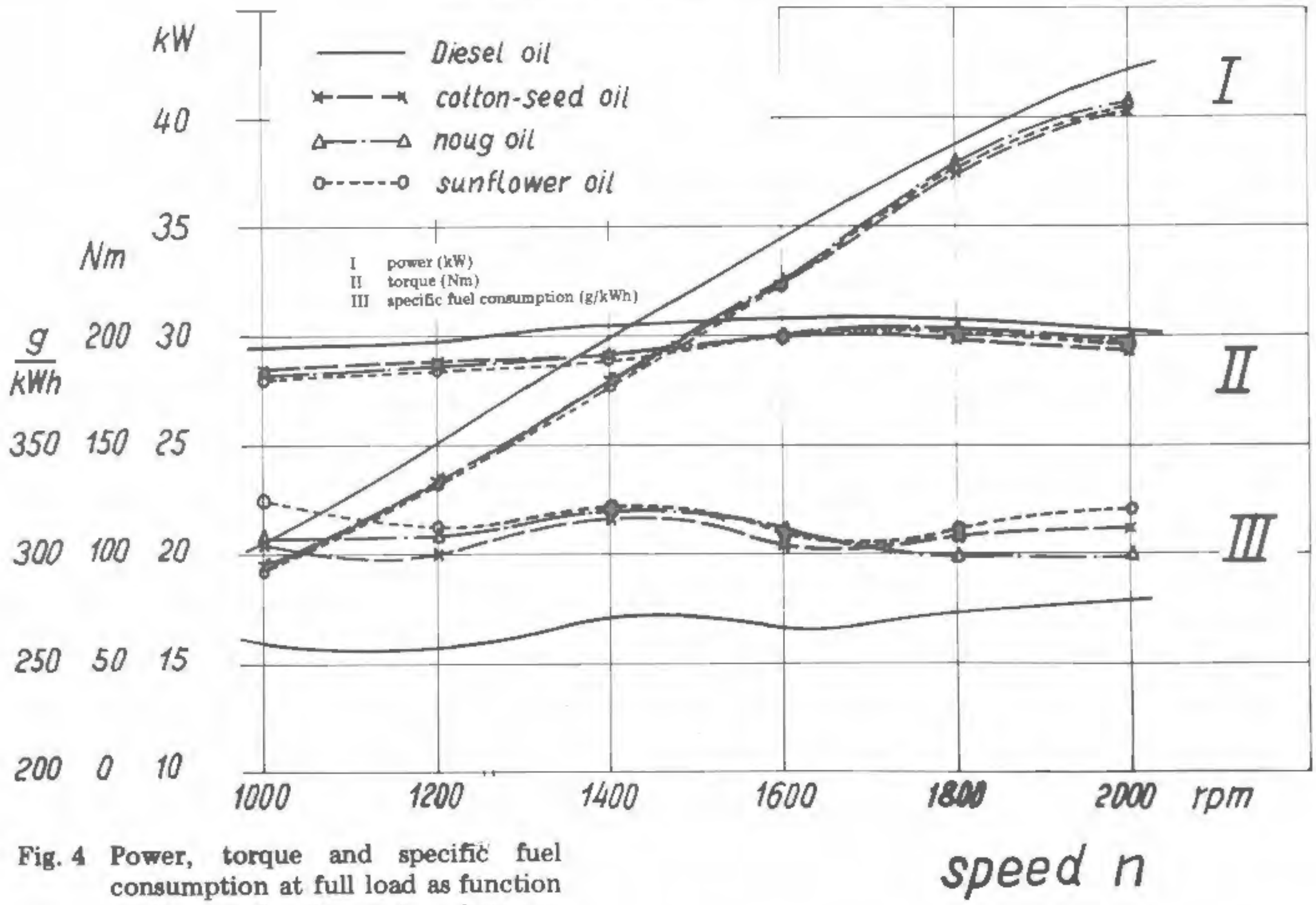

Fig. 4 Power, torque and specific fuel consumption at full load as function of the speed. Comparison between non-esterified vegetable oils and diesel oil

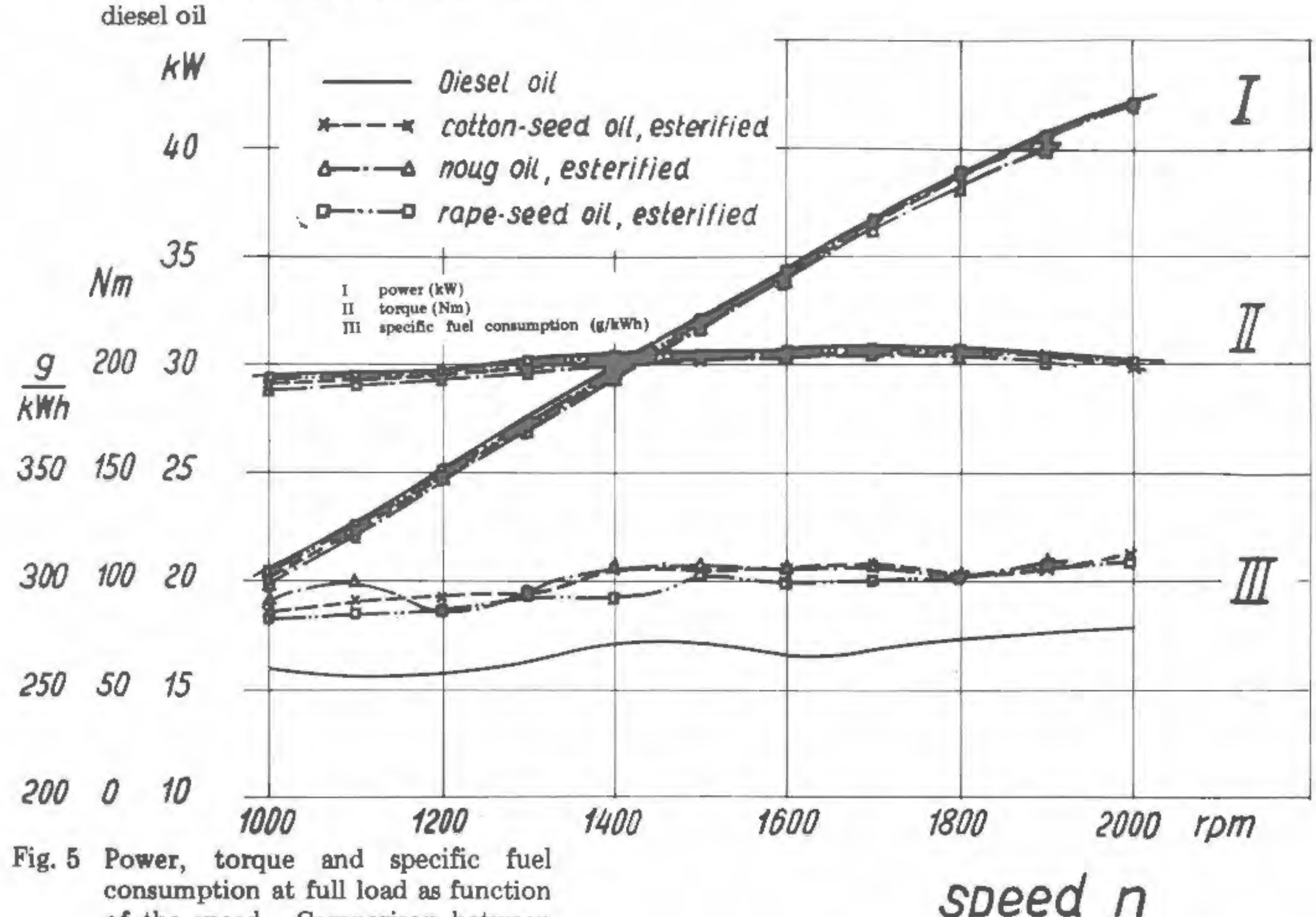

Fig. 5 Power, torque and specific fuel consumption at full load as function of the speed. Comparison between esterified vegetable oils and diesel oil.

FINAL REMARKS

The tests confirmed that the mentioned diesel engine could be run with 100% vegetable oil. The poor cold starting behaviour was the major draw back experienced with the non-esterified vegetable oils. This can mainly be attributed to the very high viscosity of the vegetable oils at room temperature. Thus, the oil injected through the cold injection nozzle does not atomize properly for starting. Improvements could be achieved either by an appropriate preheating of the fuel and/or of the combustion chamber — as for instance mentioned in [2] — or by dual injection systems using diesel oil or its mixtures with vegetable oils for starting or by decreasing the viscosity of the vegetable oils by means of chemical treatment like the esterification process.

All tests were run with an unaltered injection system. Pichinger, [2], found that advancing the injection timing — in his case at 6 degree crankshaft over normal setting — when running the diesel engine with vegetable oil had obtained increased max. torque and substantial lower specific fuel consumption.

It has to be mentioned also that according to Ref. [4] incomplete combustion of vegetable oils which may occur especially during idling or prolonged part-load condition may finally lead to catastrophic solidification of the lubricating oil of the engine. As countermeasure the authors of Ref. [4] recommend changing of the lubrication oil with 200 operating hours intervals.

But even if the substitution of diesel oil by vegetable oil is technically feasible, care has to be taken that the use of vegetable oil does not produce undue shortage of essential cooking oil. The use of non-edible vegetable oil would, however, eliminate this problem. For instance, castor oil which is already produced for other industrial purposes or the oil from the seeds of the neem tree may be considered. Castor oil may be of special interest as it is contrary to other vegetable oils soluble in alcohol in all proportions and at room temperature. Hence alcohol could be used as means of lowering the high viscosity of the vegetable oil [9], [10]. As the castor oil plant and the neem tree can be grown in tropical areas but also under semi-arid conditions their cultivation may also serve as soil conservation and may be an additional source for fire wood.

For an intended large scale substitution of diesel oil a proper strategy producing vegetable oils has to be worked out. The substitution of diesel oil by vegetable oil has to be seen in this wider context.

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