Vegetable oils as substitutes for diesel oil[1]

José Israel Vargas[2]

Introduction

The establishment of the transportation structure in Brazil based on a road network led to a dependence on liquid fuel. Despite the effort to alter this picture it is expected that for the next 20 years there will be no significant change on the pattern of mass transportation. The present fleet of more tan 8 million vehicles is expected to reach about 30 million by the end of this century.

Liquid fuel demand for ordinary spark-ignition carburetor type engines (OTTO cycle) can be met by the gasoline and alcohol production as already discussed during this SYMPOSIUM. The forecasted alcohol production of 10.7 million cubic meters will permit a mixture of at least 10 % in the gasoline and to feed a fleet of more than 2 million alcohol powered cars. The total fuel demand for OTTO cycle vehicles will grow from 16.7 in 1981 to 18.8 million cubic meters in 1985 (Table 1).

The popularity of diesel engines increased because they are built in a simpler and more rugged design and utilize cheaper fuel, giving higher thermal efficiency. This means more economical consumption for a given load to a certain distance. These technical advantages in addition to the low diesel oil price rapidly increased its demand in Brazil. It is expected that such demand will grow from 19.4 in 1981 to 25.7 million cubic meters in 1985.

Because of the Brazilian fleet characteristics and because of dependence of imported petroleum there is a strong effort in promoting an equilibrated substitution of the diesel oil coupled with other alternative energy program. Since diesel oil is the fraction to be replaced, attempts are being made to use vegetable oils as fuel for diesel engines in addition to modification of the cracking structure at the refineries.

Vegetable oils present comparable characteristics to diesel oil concerning viscosity, setting point, carbon residue and cetane number (Figure 1). The calorific value varies according to the species but they are close to the heating value of the diesel. On the volume basis very small differences can be detected (Table 2). These characteristics made

Table 1. Liquid fuel demand in the period 1980–1985 (10^6 m^3).

Liquid fuels	Years				
	1981	1982	1983	1984	1985
OTTO cycle (Gasoline Equiv.)	16.7	17.2	17. 8	18.3	18. 8
Diesel cycle	19.4	20.8	22.3	23.9	25.7
Fuel oil	21.5	22.6	23.0	24. 3	26.9

[1] Trabalho apresentado no 2º Simpósio de energia do Hemisfério Ocidental.

[2] Secretário de Tecnologia Industrial do Ministério da Indústria e do Comércio à época.

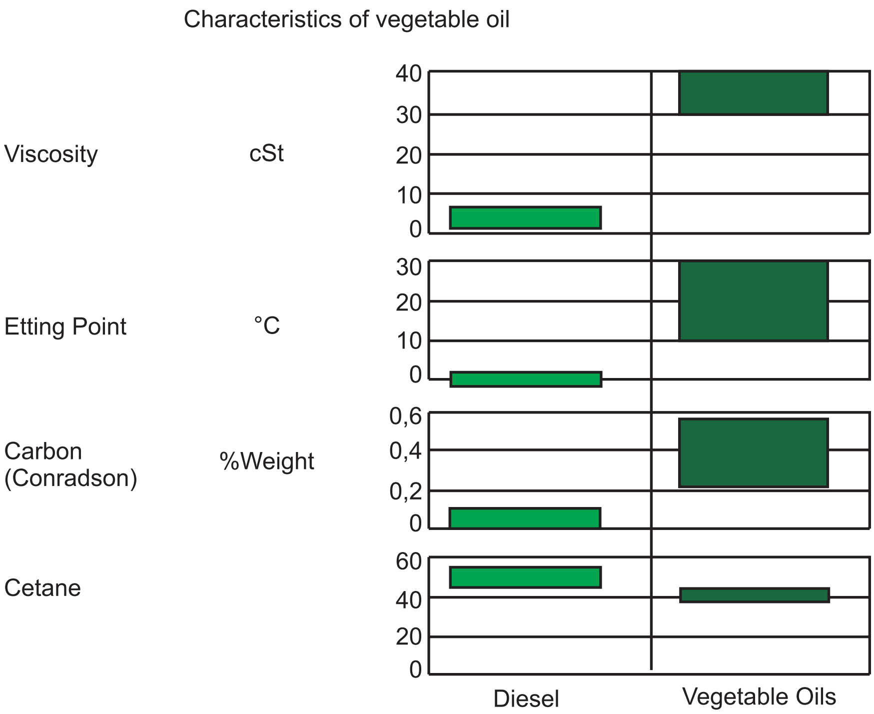

Figure 1. Comparison between vegetable oils and diesel oil.

Table 2. Calorific value of some vegetable oils.

Oil	Calorific value		Difference to diesel	
	Kcal/kg	Kcal/L		
Diesel	10,200	8,400	-	-
Peanut	8,844	8,057	86.7	95.9
Soybean	8,812	8,125	86.4	96.7
Cotton	8,759	8,050	85.9	95.8
Babaçu	8,435	7,769	82.7	92.0
Castor beans	8,342	8,000	82.7	95.2
Coconut	8,680	7,869	85.1	93.7
Sunflower	9,100	8,281	89.2	98.6
Rapeseed	9,236	8,405	90.5	100.0
Palm	9,104	8,330	89.2	99.2
Joannesia princeps	8,439	7,737	82.7	92.0
Játropha pohliana	8,449	7,130	84.9	82.8

vegetable oil as the best renewable energy source to substitute partially or totally for diesel oil.

Use of vegetable oil on diesel engines

The first mention about the possibility of using vegetable oil in diesel cycle engines was done by R. Diesel himself in the introduction remarks of the work "The Diesel Engines" written by A. P. Chalkley (1911). R. Diesel pointed out that in 1900, the OTTO Society exhibited during the Universal Exhibition, in Paris, a small Diesel engine which ran on vegetable oil without any modification. The French Government requested such study in order to use the peanut oil produced in large quantities in the French Colonies.

Despite the potentiality of vegetable oil as fuel in the Diesel engine it was not used in large scale. Soon after the first World war the matter was raised again. Tests made using palm oil and cotton oil in a semi-Diesel engine confirmed the efficiency of vegetable oils although some difficulties were pointed out (Mathot 1920). The amount of residues after combustion of pure vegetable oil was high, but it could be prevented with proper maintenance. About the same time tests were carried out by the Congo General Co., to evaluate the performance of a Drott engine (semi-Diesel) using palm oil. Results revealed that consumption was proportional to the heating value (cit Mensier 1952). During some years Rouston engines were set to run on 1ocally produced palm oil. No major problems were detected.

Cautier (1931, 1933) undertook an extensive evaluation of vegetable oils as alternative for Diesel oil. Two engines of 300 HP and 600 HP were tested using palm oil, peanut oil and castor beans oil as fuel. The main conclusion was that the thermal efficiency was higher for vegetable oils than Diesel oil; consumption was proportional to the calorific value; minor modifications were necessary and no detectable effect on the engines was found after a 80 hours test.

Schmidt (1932) tested oils from soybean, peanut and palm oil on a small Mercedes Benz Diesel engine. Although no major problems were detected, difficulty was experienced at starting which could be overcome by starting on Diesel oil. Due to the higher viscosity of the vegetable oil proper atomization was not obtained causing imperfect combustion. The high viscosity could be reduced by mixture with 20 to 30 per cent of Diesel (Tu and Ku 1936). Similar results were obtained by Howes (1936) and Hubner and Egloff (1936) for peanut, coconut, soybean and palm oils.

Manzela (1935) tried peanut oil in a 2-cycle engine on a 12 HP engine running at 52O rpm. Among his main conclusions it should be stressed that: operation with peanut oil offers no difficulty; fuel consumption was higher than that for Diesel oil at normal load and lower at reduced loads; thermal efficiency was always high for peanut oil; and ignition was somewhat retarded but the maxim pressure was lowered.

Gaupp (1936, 1938) carried out similar tests using oil of soybean, sesame, peanut , palm and sunflower in a 4 stroke, two cylinder Mercedes Benz engine, compression rate of 14-5:1,speed 750 rpm and an output of 25 HP. The consumption was 12 % to 15 % higher than when using diesel oil. Conclusions were similar as in previous work and engines should start on diesel oil; the vegetable oil should be filtered and heated. Tatti and Sertori (1937), likewise, found that at temperatures below 10 °C the viscosity of the peanut oil was high, rendering a difficult atomization. Oxidation of the oil injected on the combustion chamber would form a carbon deposit on the cylinder wall. Walton (1937} reported the need of pre-heating several vegetable oils. Fuel consumption was 10 per cent higher than Diesel oil in a 3.000 miles road test. No particular damage was noticed in the engine, but pump elements suffered from poor filtration. It was reported a cleaner exhaustion and that Diesel knock was practically eliminated. The amount of sludge produced by vegetable oils was inversely proportional to the iodine value.

Judge (1941) based on these experiments recommended vegetable oils (peanut, cotton, soybean and palm) as substitute for diesel oil. Field test using a 10 ton truck powered with a Gardner engine indicated that pre-heating vas necessary and Diesel oil should be used at starting. Consumption in a 3.000 miles road test was 10 % higher than diesel oil. Hamabe and Nagao (1941) reached similar conclusion using soybean oil in a 10/11 B.H.P. single cylinder diesel engine.

Twelve vegetable oils from native or cultivated species in India have also been tested (Aggarwal et al 1952). Peanut oil did not present any problem at starting while Karany, cotton seed, rape, coconut and sesame required a slight warming. Castor beans, kapok and mahua showed difficulty at starting, and motoring became necessary. Combustion was complete for all tested oils, with exception of castor beans. The maximum loss of power was 13 per cent for castor beans oil, whereas for cotton seed oil such loss was practically nihil. In Brazil, the interest for vegetable oils as substitute for Diesel oil initiated in the twenties (CARVALHO, 1936). A series of tests was carried out with cotton seed, babaçu and castor beans oils (SÁ FILHO et al., 1980). In 1943, a Technical Commission prepared a report about the use of vegetable oil as fuel. Evaluation tests were conducted with a truck powered with a Hercules engine using cotton seed oil. After 1.200 km road test, a light carbon deposit was detected. Further tests with a Perkins engine using pre-heated cotton seed oil for 3.000 km revealed no such deposit. It was concluded that pre-heating was necessary to adjust oil viscosity and that injection pressure should be equal or superior to that established for Diesel oil (SÁ FILHO et al., 1980).

During the period 1976-1977 a large number of evaluations were carried out under request of the

Brazilian Government. Several vegetable oils were tested pure or in mixture with diesel oil. These results will be discussed ahead.

Blends diesel-vegetable oils

As already indicated, studies using pure vegetable oil as fuel for diesel engines have shown minor difficulties which could be eliminated by blending vegetable oils and diesel oil. The literature on blends of vegetable oils and diesel oil is very scarce. Although several studies have been carried out in Brazil, they have not been published. Tests carried out by the Instituto Nacional de Tecnologia and Centro Técnico Aeronáutico indicated that a mixture of 20 % of soybean resulted in a 1 % power loss and a 15 % increase in consumption. On the other hand using babaçu oil in the same mixture there was an power increase in also a higher consumption (Table 3).

Several tests were carried out by diesel vehicles makers in the period 1976-77. The "Detroit Allison do Brazil" evaluated blendings of diesel with 10, 20, 30 and 40 per cent of palm oil or soybean oil in the Detroit Diesel 4-53 engine. Cycles of 1.500, 2.000, 2.500 and 3.000 rpm were used (Figures 2 and 3). Blends up to 30 % of vegetable oil did not alter fuel characteristics (Table 4). The performance analysis indicated that power was slightly higher for blends with 30 % of vegetable oil; torque was not affected whereas consumption was somewhat higher (Table 5). Similar results were obtained with a M.W.M. D-226-02 engine

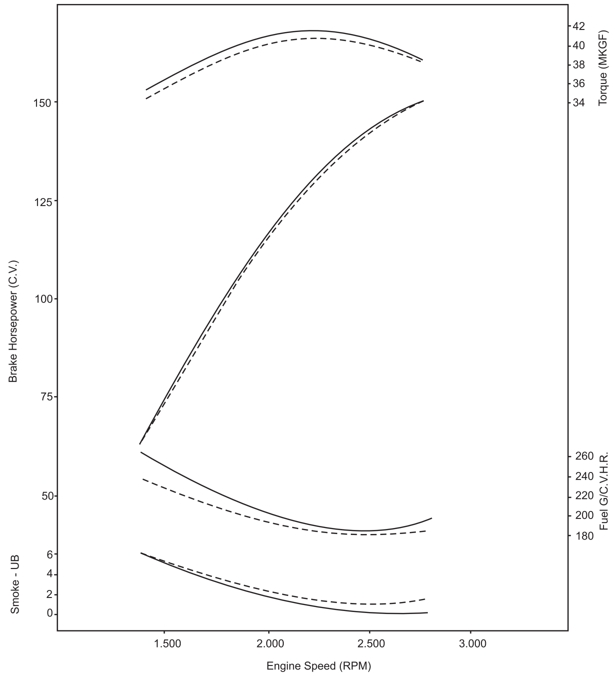

Figure 2. Performance of the engine using 70% diesel: 30% soybean oil blend (-) and 100% diesel oil (----).

testing different mixtures of Diesel oil and babaçu oil (Table 6). As expected, consumption increased with the increase of the percentage of babaçu oil. Power maintained practically non altered in mixtures with 25 % of babaçu oil. Smoke was reduced almost linearly with the increase of babaçu oil in the mixture. Oil performance of cotton seed, soybean, castor beans, peanut and babaçu oils blended with diesel oil were tested by the Mercedes Benz of Brazil. Castor beans oil, because of it viscosity proved not suitable to be

Table 3. Performance of engine perkins D 4203 running on Diesel oil or blend with soybean oil and babaçu oil.

Speed	Vegetable Oil Blended (20%)								
rpm	Power (CV)			Consumption (g/CV.h)			Smoke (UV)		
	0	Soybean	Babaçu	0	Soybean	Babaçu	0	Soybean	Babaçu
1200	32.0	30.7	32.1	218.7	232.8	224.6	6.4	6.3	6.0
1400	38.9	38.3	38.8	209.2	215.5	214.2	6.4	6.2	5.6
1600	44.3	43.2	44.1	202.5	212.8	209.0	6.0	5.6	5.4
1800	49.0	48.0	49.0	199.7	201.2	208.0	5.6	5.5	4.7
2000	53.8	53.5	53.7	196.0	207.6	207.9	5.1	5.2	4.4
2200	58.0	57.1	57.6	201.1	208.7	211.6	5.0	4.8	4.5
2400	61.4	61.2	61.3	203.2	209.7	209.9	4.3	4.8	3.8
2600	63.1	64.1	64.1	209.9	207.5	207.3	4.3	4.2	3.6

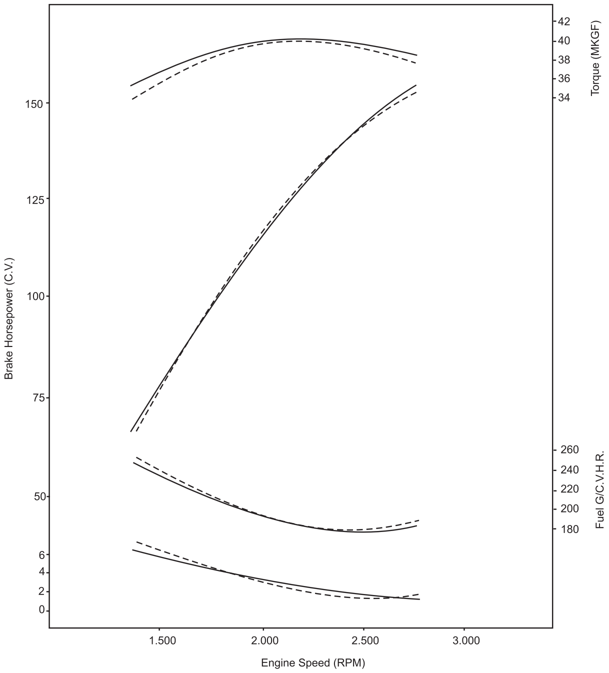

Figure 3. Performance of the engine using 70 % diesel : 30 % palm oil blend (-) and 100% diesel oil (----).

used in diesel engines. Babaçu oil required pre-heating in order to be used at temperature close to 20 ºC.

Among studies with mixtures of Diesel oil and vegetable oils, tests carried out by the Centro Técnico Aeronáutico deserve some consideration. Soybean, Croton seed and babaçu oils were evaluated in mixtures of 10,20 and 50 % at a compression rate of 16:1. The Croton oil, pure or in mixture, increased the engine power, whereas other oils revealed slight reduction in power and increase in consumption. Thermal efficiency was similar to the Diesel oil. Blends with 20 % of soybean oil or 20 % of babaçu oil confirmed previous experiences (Figure 4).

All carried out tests demonstrated the possibility of using mixture up to 30 % of vegetable oils with Diesel oil. Mixtures required only minor adjustment of the injector and of the amount of fuel injected. Long run tests were required in order to evaluate carbon deposits, durability and corrosion.

Table 4. Characteristics of blends with different proportion of palm oil and soybean oil

Performance	Palm Oil %					Soybean Oil %				
	0	10	20	30	40	0	10	20	30	40
Consumption 2.800 rpm (g/ CV. H)	148.36	151.61	150.38	152.97	151.58	151.25	146.92	150.22	152.35	153.13
Torque 2.200 rpm (hk/m)	40.98	40.97	40.62	41.09	40.49	41.13	41.43	41.44	41.54	41.46
Power 2.800 rpm (CV)	26.48	28.28	27.24	27.08	28.65	27.83	26.13	28.55	29.21	29.11
Smoke 1.400 rpm (BOSCH)	6.40	6.00	6.20	6.20	6.50	5.50	6.50	6.30	5.80	6.10

Table 5. Performance of mixture of palm oil and soybean and diesel oil.

Vegetable Oil %	Palm Oil			Soybean		
	Density (g/cm²)	Viscosity (SSO)	Flash Point (°C)	Density (g/cm²)	Viscosity (SSO)	Flash Point (°C)
0	0.830	35.8	62	0.828	-	57
10	0.834	38.7	62	0.836		59
20	0.842	42.4	63	-	-	-
30	0.850	47.4	64	0.856	45.5	62
40	0.860	54.1	66	0.866	51.5	65
50	0.868	62.7	68	0.872	56.1	68
60	-	-	-	0.884	65.6	70
100	0.908	196.0	260	0.920	163.7	330

Table 6. Performance of different mixtures of diesel and babaçu oil.

Performace	rpm	Percentage of Babaçu oil					
		0	15	20	25	50	100
Power (CV)	1000	15.6	15.5	15.4	15.4	15.3	14.9
	1400	23.0	22.8	22.5	22.4	22.4	21.7
	1800	29.7	29.5	29.5	29.3	29.2	28.1
	2200	33.9	33.9	33.2	33.0	32.8	30.6
	2800	36.4	37.0	36.4	36.4	36.1	33.6
Consumption (g/CV.h)	1000	182.4	185. 5	187.3	188.7	197.2	211.6
	1400	176.0	181.2	182.9	185.1	191.0	209.7
	1800	171.1	180.5	181.8	182.6	188.2	204.9
	2200	170. 8	177.7	179.2	181.8	189.5	212.8
	2800	197.3	202.3	206.1	206.0	213.7	234.9
Smoke (Boch)	1000	5.1	4.9	4.6	4.3	3.4	3.5
	1400	4.7	4.5	4.5	4.0	3.4	3.3
	1800	3.3	3.4	3.2	2.4	2.6	2.4
	2200	2.1	2.5	2.2	2.1	2.0	1.2
	2800	4.0	3.6	3.6	3.4	3.6	1.5

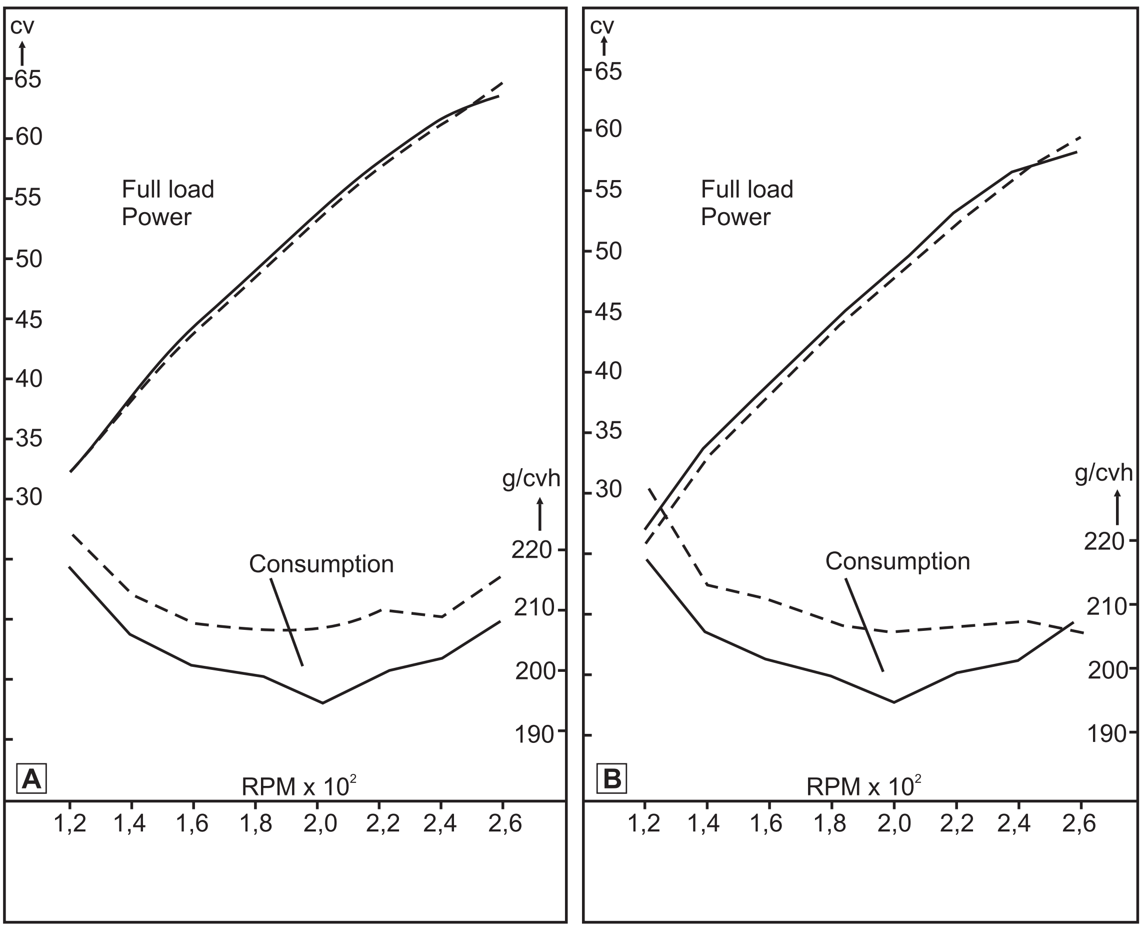

Figure 4. Blends of diesel oil : 20 % soybean (A) or 20 % babaçu (B).

Requeriments for vegetable oil

Studies of vegetable oils as a substitute for diesel oil reported in the literature have indicated a set of characteristics which need to be considered. Main points to be established are the flash point, density, viscosity, setting point, calorific value, chemical constitution and carbon residues. Results so far reported for more than 20 vegetable oils could be grouped according to the engine performance in order to give a better insight of the consequences of using vegetable oil as substitute for diesel.

Startability

All available reports point out to the importance of the temperature when the tests were made. This temperature effect on startability is small in tropical countries. It has been demonstrated that vegetable oils differ greatly in the setting point. The difficulties found in startability of pure vegetable oil can be overcome by using mechanisms to ensure proper fluidity by pre-heating. Differences were found for the same oil according to local temperature due to differences between engines and fuel in injectors. Startability presented no major problem where diesel oil was added to vegetable oils.

Smoothness of Running

Most of the tested vegetable oil gave a smooth running; castor beans and coconut oils, however, presented defective operation. Probably the difficulty was caused by the higher viscosity of the castor beans oil and by the high setting point of the coconut oil. As already pointed out pre-heating with exhaustion fumes could eliminate the roughness of running.

Studies are need concerning the roughness of running due to ignition problems. The lag phase is longer for vegetable oil than for diesel oil. However even in cases which the lag was longer the operation was smooth, due probably, to the progressive way in which the pressure takes place.

Nature of Exhaust

The combustion for all but the castor beans oil was complete. The completeness of combustion was clearly indicated by the colorless exhaust (Figure 5).

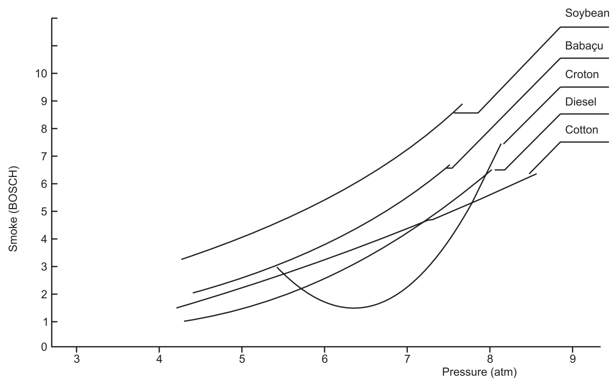

Figure 5. Smoke for different vegetable oil.
Source: CTA/STI

Power Output

Heating value differences of vegetable oils indicate that they will develop less power than diesel oil. Reported differences lead to a 0 to 37 % reduction in power. A great portion of the power loss can be recovered by appropriate adjustment of operating conditions such as injection timing, pre-heating and suitable injector. Factors connected with engine design, such as the shape of the combustion chamber, may also have considerable effect and the problem needs full investigation. Likewise attention to preliminary data indicates that high H/C ratio favors fuel combustion.

Specific Fuel Consumption

As expected, all studies with vegetable oils reported that consumption was higher than that of Diesel oil. There was a good correlation between calorific value and consumption. However the consumption values are lower than expected because of the more efficient combustion (Figure 6).

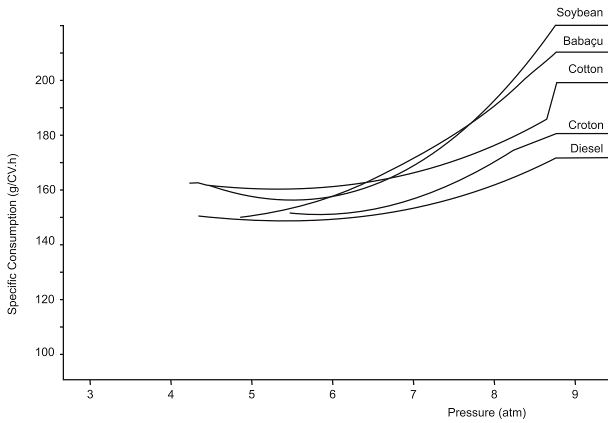

Figure 6. Specific consumption of vegetables oils.
Source: CTA/STI

The variation in consumption reported in the literature should be explained in terms of differences in the engine and in the fuel injector. In general, vegetable oil consumption was 10 % to 15 % higher than that of diesel oil.

Brake Thermal Efficiency

The brake thermal efficiency is a good indicator of fuel performance since it expresses the net power output in terms of the total energy input. In no case the thermal efficiency of the vegetable oils was lower than that of diesel oil. A few examples like cotton (Aggarwall, 1952) or peanut oils (MANZELA, 1941) gave higher thermal efficiency. In brief, it can be stated that without any appreciable change in design it is possible to get similar or superior thermal efficiency to that obtained by diesel oils.

Carbon Residues

Diesel oil may vary according to the possibility of forming carbon deposit. Carbon may start to be formed on the fuel injection nozzle leading to reduction of power output and smoky exhaust. Aggarwall (1952) indicated that more deposits are formed when the engine is running on vegetable oils than on Diesel oil. However the amount of deposit was not high enough in order to prevent efficient operation. Additional data (MANZELA, 1935; GAUPP, 1937; WALTON, 1938) revealed small deposit in long test using larger engines, but it is not serious problem.

Corrosion

Corrosion has been reported in some works, whereas in other no meaningful difference was noted (AGGARWALL, 1952). Besides the attack to cooper (MANZELLA, 1966; TATTI; SERTORI, 1937) no other serious corrosion effect was noted even using oil with high acid value. More detailed studies in the area are required.

Transfusion of vegetable oil into fuel

The studies carried out aiming at the improvement of the production of light fuel from petroleum led to the development of great progress in cracking and the use of catalysers.

The expansion of such researches allowed the development of the industry to produce fuel from shale or lignite. The progress obtained in the cracking of petroleum brought great interest in using the vegetable oil as raw material in the production of light fuel. Thermal or catalytic cracking decomposes the fatty acids into hydrocarbons. Subsequent cracking of these hydrocarbons is somewhat similar to petro1eum cracking. The cost of the process has limited its use (CHANGE; WAN, 1947; LOURY, 1945; MENSIER, 1945; 1947).

The vegetable oils may also be converted into ester with improved performance in diesel engines. The vegetable oils are composed mainly of triglycerides. The reaction of these glycerides with mono alcohol in presence of sulphuric acid form an fatty acid ester. The alcohol used can be ethanol or methanol.

Such product can be used directly in the diesel engines without any modification. After a 20.000 km test the consumption was 5.3 % higher on weight bases than diesel oil (MENSIER, 1952).

Preheating was not needed, neither corrosion nor carbon deposit was detected.

Selected oil crops

Among the favorable features of the carburant vegetable oil it should be stressed the great number of oil species adapted to diverse ecological conditions and the existence of annual or perennial, cultivated or native species. These characteristics will give high flexibility in any alternative fuel program because it will permit the production of raw material in different ecological and socio-economical conditions.

The selection of the species to be included in a such a program will have to consider that:

1. vegetable oils will be used mainly in mixture;
2. any vegetable oil can be used alternatively;
3. the participation of each species will have to be considered in terms of space and time;
4. the capacity of production of reproducing material will determine the number of species;
5. industrial transformation presents no major difficulty.

A. Species for immediate use

Annual crops will prevail among the species to be selected in a short run program. A sensible increase in oi1 production can be achieved using the known annual species, particularly, those species for which agricultural technology and seeds are available. Other annual species should be better evaluated before being included in a large scale program.

1. Peanut (*Arachis hipogeae*)

Several wild species of the genus Arachis occur in Brazil and Bolivia. From the economical standpoint only the species hipogaea is commercially grown. Three types are known namely, Virginia, Spanish and Valencia. The Virginia type, not cultivated in large scale in Brazil, has a long cycle (140 - 160 days) conditioning high productivity. The Spanish and Valencia types are commonly grown all over the country. The vegetative period is shorter (120 days) and they may be planted twice a year in most of the country. The so-called dry season planting usually presents lower yields than the October-November season planting. More than one million hectares has already been planted in the past, but today only 300.000 hectares are being cultivated, mainly in São Paulo. The oil average yield is of 500 kg/ha, although the available data indicate the possibility of obtaining more than 1000 kg /ha. More than 50 million hectares in the Center-west and Northeast regions have adequate ecological condition for planting peanut. Additional areas may become available, but due to high humidity during the vegetative growth efficient disease control will be necessary. Experiments in the cerrado area have given promising results.

Peanut is suitable to be grown by small farms. The available technology and equipments offer good possibility of being produced not only in small farm but also in extensive areas totally mechanized. Besides this high potential, in isolated area peanut can be consorted with crops like cassava or some perennial crops. Due to its short vegetative cycle peanut fits well as a second crop to be cultivated in the renewal area of sugar-cane plantation (roughly 20% every year) . The alcohol distilleries could be converted into energy farms by producing alcohol, vegetable oil and bagasse pellets for direct burning.

2. Sunflower (*Helianthus annuus*)

This oil crop is mainly grown in the USSR, Argentina. USA, and Australia. Its yielding potential is similar to the peanut although very little experience is available in the country. Many attempts have been done in the past to introduce the sunflower in commercial plantation but they failed despite the interest of the oil industry. One of the limiting factors was the leaf rust that attacked the susceptible varieties. At present new varieties and hybrids are available which increase the possibility of obtaining high yields.

The range of climatic conditions under which the sunflower can be cultivated is very large, Sunflower can be grown in area of peanut but it is more adapted to area with higher humidity during the growing season, 7 the area potentially favorable to plant sunflower covers almost 150 million hectares, The broad adaptation permit sunflower to be grown below latitude 20º South reaching the north region of Rio Grande do Sul. Sunflower can also be cultivated during the raining season or in the so called dry season in regions with adequate precipitation.

There is not reliable indication about the yielding potential in different areas. The small cultivated area has not yet allowed a proper demonstration of productivity in different ecological conditions. Values reported vary from 500 to 1000 kg of oil per hectare. Sunflower also fits for associated planting with crops like cassava. Early varieties could be planted in renewal areas of sugar-cane plantation.

3. Soybean (*Glycine max*)

The Brazilian experience with soybean gives support to any program aiming at a massive production of vegetable oil. The Brazilian average yield is comparable to the best productivity obtained for this crop in the world. In the State of São Paulo where agricultural technology and appropriate equipments are available, the average yield is more than 2 tons per hectare. Besides that, scientific development involved with knowledge of this species and its interaction with different ecological conditions is well advanced in the country. It is possible to make safe estimate of future progress in yield.

Oil yield (kg/ha) is low considering a 18 % oil content in the present varieties. It is possible that selection may improve the oil production per hectare. However the present yield of 360 kg of oil per hectare can be raised to 440 kg/ha in the next years.

Soybean potential is similar to that of sunflower. Since soybean demands low hand labor it is recommended particularly in the expansion of the new agricultural frontier. The successful introduction of soybean in the cerrado area confirms such broad potential of adaptation.

Soybean has also been cultivated in renewal area of sugar-cane plantation. Since sugar-cane is planted on March, early varieties are required to harvest on time.

4. Rapeseed (*Brassica campestris*)

In the last few years there has been a growing interest on this species to produce edible oil. Experimental plantations have been done in the south of Brazil where ecological conditions favor rapeseed plants growth. Adapted to be planted from February to March, it has been indicated as crop to come after soybean or some other annual crops.

The productivity so far reported is good although it can be raised by the use of new varieties. Some varieties with high erucic acid content can not be cultivated for edible oil, but may be used for carburant oil. In Canada yield varies from 700 to 1000 kg of oil per hectare. Productivity from 500 to 800 kg/ha has been obtained in the south of Brazil. Despite its great potential further studies are required before its extensive use.

5. Other annual species

Several other species will have to be evaluated to confirm their potential in different ecological conditions. Among these species it is worth to mention sunflower (*Carthamus tintorius*), sesame (*Sesamum indicum*), and linseed (*Linum usita tissimum*). Some wild species can be found, which deserve further investigation.

B. Perennial crops

Several perennial crops are available with high production of oil per hectare. However, these species demands longer period of time to contribute to an oil program. Besides the well known species some very promising native species have been reported.

1. Palm Oil (*Elaies guineensis*)

The growth of palm oil production in the tropics is placing it among the most important oil crops in the international market. Its yielding capacity is the main reason for the increased production in some Asiatic and African countries. Oil productivity has been reported to reach 4 to 5 tons per hectare. Despite the possibility of growing palm oil in Brazil, although a few plantations have given high productivity.

More than 80 million hectares have optimum conditions for palm oil production. This area is mainly concentrated in the west Amazônia with smaller areas in the North of Pará, South Amapá and Bahia. For this reason any program considering the palm oil as source of vegetable oil should take into account the distance to consumer centers.

The best yielding planting material is the hybrid tenera obtained from the cross between psifera and dura. Ivory Coast and Malasia are among the most important seed producers. Each hybrid seed costs from 50 to 60 cents of US dollars. In a first stage of the program, seeds will have to be imported until locally developed hybrids can be produced. Tissue culture maybe used for rapid multiplication of the best genotypes.

These limitations make difficult a significant participation of palm oil in a program of carburant oil within a period of 5 to 10 years.

2. Coconut (*Cocus nucifera*)

Coconut may represent a dependable perennial oil crop in the Center-west, part of Amazonas and Southeast region comprising Rio de Janeiro and Espírito Santo. Requirements for humidity and luminosity are also met at regions favorable for palm oil. Despite its popular use, very little has been done in terms of agricultural management and variety development. Yield is usually high, reaching from 1.5 to 3.0 tons of oil per hectare. Restrictions presented for palm oil hold true for the coconut.

3. Macauba (*Acrocomia sclerocarpa*)

Macauba probably originated either from India where is called gru-gru or from Brazil. Its spontaneous distribution in the country has suggested that Brazil may be its center of origin or diversification. It is well adapted in the Center-west including Rio de Janeiro, North of São Paulo and South of Minas Gerais. A close related species *A. totae* is commercially exploited in Paraguai.

Like most of the palm trees, macauba requires from 4 to 8 years to initiate fructification. An adult palm fructifies almost the whole year. Experimental plantations have given productivity from 4 to 9 tons of oil per hectare. The range of productivity estimated from the available data indicates that macauba may play a role as an important palm oil in a carburant oil production program.

4. Babaçu (*Orbynia Martina*)

The native populations of babaçu covering more than million hectares represent a great potential for production of alcohol, coke and oil. Considering that 60 kg of oil maybe obtained as by-product of the transformation of the fruits collected in one hectare, almost one million tons of oil can be produced. Difficulties related to the collection and processing of the fruits recommend further studies before deciding about the participation of babaçu in an oil program.

5. Avocado (*Persa americana*)

The pulp of the avocado fruit gives a high quality oil used mostly in cosmetics or for human consumption. Yield of more than 5 tons of oil per hectare have been reported. The range of ecological conditions where the species can be grown deserves further investigation. The need of varieties with different production cycles must be stressed due to the short harvesting season within each variety.

6. Other perennial crops

There is a large member of species with potential for oil production. However it is difficult to forecast the participation each species without detailed studies of oil quality and productivity. Among these species the following could be indicated: piqui

(*Caryocar brasiliense*), pinhão (*Jatropa* ssp.), catieira (*Joannesia princeps*) , buriti (*Mauritia vinifera*) and many others.

Sugestion for carburant vegetable oil program

The launching of carburant vegetable oil program must also take into account the availability of other alternative energy sources to replace the main fraction of the petroleum. The PROALCOOL in Brazil led to increase the offer of light fuels required by the OTTO cycle. The price policy for liquid fuel conducted to a distortion of the fleet structure with a marked increase in diesel engine vehicles. For this reason it became necessary to alter the petroleum cracking route toward higher diesel production. Besides that, an adequate policy must be undertaken to prevent the growth of light trucks fleet using diesel engines.

Program of substitution

An balanced alternative program for liquid fuel can be established taking into account the following parameters:

1. growth of the diesel oil demand of 7.2 percent per year;

2. production of diesel will be altered from 29.3 to 36.4 percent;

3. demand of gasoline is obtained from the OTTO cycle engines demand subtracted by the alcohol production forecasted, divided by 1.15;

4. 1 liter of diesel or vegetable oil corresponds to 1.4 liters of gasoline; 1 liter gasoline corresponds to 1.15 L of alcohol.

Taking into account these factors it is possible to minimize the petroleum consumption using properly each one of the fractions. This optimization would be expressed by the equation:

$(\alpha_G^{P-G})/1.4 = D - \alpha_D P$

where P, D and G are the demand of petroleum, diesel and gasoline; αG and αD are the diesel and gasoline fractions in the cracking. Results are presented in Tables 7 and 8. Although the short period of analysis, it is possible to verify the evidence of keeping low the petroleum demand when vegetable oil is considered. The proposed increase in the production of vegetable oil is low compared to the experimental results. The value could be altered depending on the capacity to increase the vegetable oil production. This growth curve when extended to 1990 will represent 27 % of mixture in the diesel.

Economics of the substitution

At present time it is difficult to make a detailed

Table 7. Demand of petroleum and the production of liquid fuel a carburant vegetable oil program (10^6 m^3).

Liquid fuels		Years				
		1981	1982	1983	1984	1985
Gasoline	D	13.3	13.2	13.2	11.9	10.2
	P	14.2	13. 8	14 .0	13.0	13.6
	S	0.9	0.6	0.8	1.1	3.4
Alcohol	D	4 .0	4 .6	5.2	7.3	9.9
	P	4.0	4.6	5. 2	7.3	9.9
	S	0.0	0.0	0.0	0.0	0.0
Diesel	D	19.4	20.8	22 .3	23.9	25.7
	P	18.8	20.4	21. 8	23.1	23.2
	S	-0.6	-0.4	-0.6	-0. 8	-2.4
Petroleum		61.8	63.5	64.5	63.5	63.8

Table 8. Demand of petroleum and production of liquid fuel including vegetable oil (10^6 m^3).

Liquid fuels		Years				
		1981	1982	1983	1984	1985
Gasoline	D	13.1	13.2	13.2	11.9	10.2
	P	14.1	13.5	13.5	12.5	12.9
	S	0.8	0.3	0.3	0.6	2.6
Alcohol	D	4.0	4.6	5.2	7.3	9.9
	P	4.0	4.6	5.2	7.3	9.9
	S	0.0	0.0	0.0	0.0	0.0
Diesel	D	19.2	20.0	21.2	22.5	23.8
	P	18.7	19.8	21.0	22.1	21.9
	S	-0.6	-0.2	-0.2	-0.4	-1.9
Vegetable Oil	D	0.2	0.8	1.1	1.4	1.9
	P	0.2	0.8	1.1	1.4	1.9
	S	0.0	0.0	0.0	0.0	0.0
Petroleum	D	61.4	61.8	61.8	60.8	60.1

studies of the economical return of the substitution of diesel oil by vegetable oil. The price of the vegetable oil in the international market has been declining suggesting that in a long run this should be the tendency to be observed. On the other hand the price of diesel shall raise due to the increase of the petroleum price and because of the decision of the Brazilian Government to eliminate its subsidy. Considering that the diesel price in 1985 will correspond to 65 % of the gasoline price, it is expected that the existing price difference between diesel and vegetable oils will disappear by 1982 (Table 9).

Table 9. Estimative of the evolution of petroleum and diesel price.

Price US$	Years				
	1981	1982	1983	1984	1985
Petroleum (barril)	38	46	55	66	80
Gasoline (liter)	0.81	1.01	1.20	1.46	1.75
Diesel (liter)(1)	0.33	0.40	0.48	0.58	0.70
Diesel (liter)(2)	0.37	0.51	0.66	0.87	1.14

(1) 1. Diesel price = 0.4 gasoline price.
(2) Diesel price = increasing percentage of gasoline price (0.54 to 0.65) .

Vegetable oil cost is difficult to be estimated. The information available indicates that for 1981 the oil cost shall vary from 50 to 10% US$ for sunflower, soybean and peanut . These figures were established considering the current raw material price productivity of different oil crops. Further studies are required to define the oil quality need and the real cost of vegetable oil produced for carburant use.

Referências

AGGARWALL, J. S.; CHOWDBURN, H.. D; MUKHERJI, S. N.; VERMAN, L. D. **Bull of Indian Industrial Research**. [S.l.: s.n.], 1952. 34 p.

CARVALHO, J. B. M. **A Indústria de Óleos Vegetais e Seus Problemas**. [S.l.: s.n.], 1936. p. 85.

CHANG, CHIA-CHU; WAN, SHEN-WU. China's Motor Fuels from Tung Oil. **Industrial & Engeneering Chemistry**, Washington, D.C., v. 39, n. 12, p.1543-1548, 1947.

GAUPP. K. **Oil and Color Trade Journal.** [S.l.], v. 20, p. 249, 1938.

GAUPP, K. Automobile Tech. **Zeit**., v. 40, p. 203, 1937.

HAMABE, C.; NAGAO, T. **Chemical Abstracts**, Washington, v. 35, p. 4178, 1941.

HOWES, D. A. In: WORLD PETROLEUM CONGRESS, 2., 1937, Paris. **Proceedings**... [S.l.:s.n.], 1938. p. 78l

HUBNER, W. H.; EGLOFF, G. National Petroleum News, n. 26, p. 25, 1936.

JUDGE, P. High speed engine. [S.l.: s.n.], 1941.

LOURY, M. M. **La France Energetique**, n 11/12, p. 332, 1945,

MANZELA. **Energia Térmica**, v. 3, p. 153, 1935.

MENSIER, P. H. The utilization of palm oil as a motor fuel. **Olegineaux**, Paris, v. 7, p. 69, 1952.

MENSIER, P. H. La production de carburants a partir des oleagineux. **La France Energetique**, n. 9/10, p. 277-279, 1945,

SÁ FILHO, H. L. de; ROTEMBERG, B.; ALBUQUERQUE, S. F.; MENDONÇA, M. C. de; MEDEIROS, P. R. da S. **Energia**, São Paulo, v. 2, p. 51, 1980.

SCHMIDT, A. W. **Tropenplazer**. v. 35, p. 386, 1932.

TATTI, E.; SERTORI, A. **Energia Térmica**, v. 7, p. 59, 1937.

TU, C. M.; KU, T. **Journal of Chemical Engineering**, China, v. 3, p. 21, 1936.

WALTON, J. **Gas and Oil Power**, v. 33, p. 167, 1937.