VEGETABLE OILS AS ALTERNATIVE FUEL FOR NEW GENERATION OF DIESEL ENGINES. A REVIEW

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Abstract: *One of the primary incentives for expanding the production and use of biofuels worldwide is the potential environmental benefit that can be obtained from replacing petroleum fuels with fuels derived from renewable biomass resources. The use of straight vegetable oil in diesel engines is one of the available alternatives, but its use in existing vehicles usually requires modification of engine or fuel system components. The increased viscosity, low volatility, and poor cold flow properties of vegetable oils lead to severe engine deposits, injector coking, and piston ring sticking. The paper presents a literature review on vegetable oils as alternative fuel for diesel engines.*

Keywords: STRAIGHT VEGETABLE OIL, DIESEL ENGINES, VISCOSITY, ALTERNATIVE FUEL

1. Introduction

The utilization of biofuels in diesel engines is not a recent practice [1]. The original diesel engine that Rudolph Diesel designed ran with vegetable oil. He used peanut oil to fuel one of his engines at the Paris Exposition in 1900. In 1911, Dr. Rudolf Diesel was quoted as saying: "The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which will use it" [2].

First generation biofuels for diesel engines are produced from vegetable oils. After more or less deep purification, they can be used directly as fuel in diesel engine and are still currently used in some limited applications [1]. Renewable and alternative energy sources are becoming more demanding and necessary due to increases in crude oil prices and exhaust gas emissions due to fossil fuels throughout the world [3].

Vegetable oils have their own advantages: first of all, they are available everywhere in the world. Secondly, they are renewable as the vegetables which produce oil seeds can be planted year after year. Thirdly, they are "greener" to the environment, as they seldom contain sulphur element in them. This makes vegetable fuel studies become current among the various popular investigations. So does the evaluation of the performance of diesel engines when fuelled with vegetable oils. A number of investigations have been made, and the test results have proved that vegetable oils are feasible substitutes for diesel fuel [4].

The main problem of using vegetable oils in diesel engines is the high viscosities of such fuels [5-9]. Chemical and thermal methods are the two techniques to reduce viscosities of vegetable oils. The thermal method uses preheating of fuels, which increases the temperature and reduces viscosity [10]. Chemical methods can be divided into dilution, pyrolysis, transesterification and micro-emulsion [8,9]. Fuel blending has the advantages of improving the use of vegetable oil fuel with minimal fuel processing and without engine modifications [4].

Vegetable oils possess almost the same heat values as that of diesel fuel. But a major disadvantage of vegetable oils is their inherent high viscosity. Modern diesel engines have fuel-injection systems that are sensitive to viscosity changes. High viscosity may lead to poor atomization of the fuel, to incomplete combustion, to coking of the fuel injectors, to ring carbonization, and to the accumulation of fuel in the lubricating fuels [11,12].

2. Composition of vegetable oils

Fats and oils (lipids) consist of 95-98% triglycerides. Minor constituents present in oils include free fatty acids, mono- and di-glycerides, phospholipids, tocopherols, sterols, natural colouring agents as well as more or less volatile odorous compounds. Triglycerides are composed of a glycerol molecule esterified with three similar or different fatty acid molecules. Some twenty fatty acids are found in nature and their numerous possible combinations with the three alcohol functions of the glycerol produce a wide variety of triglycerides and therefore of oils [1].

Generally, biomass-derived feedstocks for the production of liquid biofuels can be classified into the following three categories according to the source, i.e. triglyceride-based biomass, starch- and sugar-derived biomass, and cellulosic biomass. A variety of liquid biofuels can be produced from triglycerides based biomass such as vegetable oils, animal fats, waste cooking oils and microalgae oils as shown in Figure 1 [13].

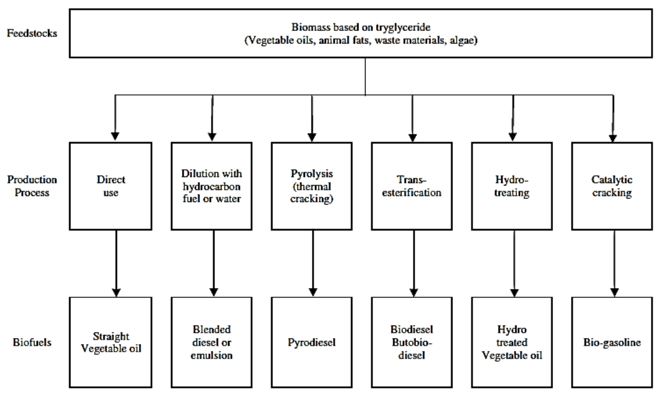

Fig. 1 *Overview of feedstocks and production process for liquid biofuels from triglycerides-based biomass [13].*

3. Direct use of vegetable oils in diesel engines

3.1. Some characteristics of vegetable oils

Vegetable oils first developed as fuel for direct use, after more or less deep purification [1].

The oil most frequently produced in Europe, rapeseed and sunflower, are composed of fatty acids with carbon chains (18 carbon atoms) including three chains globally longer than those of the hydrocarbons found in diesel. These oils have high molecular weights, about 0.88 kg/mole, density above 910 kg/m^3, and low volatility. On heating, they generally crack at temperatures in the region of 300°C [1]. The main characteristics of vegetable oils appear in table 1 [14].

The usage of vegetable oils as diesel fuel depends on world market prices for mineral products and is therefore of special interest at present only for countries with a large excess of vegetable oil production [15]

It is essential to measure three characteristic parameters to ensure that the fuel used is indeed pure vegetable oil and to confirm the vegetable origin: density, viscosity and iodine value [16]

The density specification is suitable for excluding material other than vegetable oil, or for detecting mixtures of vegetable oil with other liquids (petroleum products, glycerol, etc.). The density of vegetable oils is slightly variable between 900 and 960 kg/m^3 [16].

Table 1: *Main characteristics of vegetable oils [14].*

Vegetable oil	Viscosity at 40°C (mm^2/s)	Carbon residue (% w)	Cetane number	GCV (kJ/kg)	Ash content (% w)	Sulphur content (% w)	Iodine value (I/g oil)	Saponification value (mg KOH/g oil)	CFPP (°C)
Cotton	33.7	0.25	33.7	39.4	0.02	0.01	113.2	207.71	
Poppy	42.4	0.25	36.7	39.6	0.02	0.01	116.83	196.82	
Rapessed	37.3	0.31	37.5	39.7	0.006	0.01	108.05	197.07	+20[a]
Sunflower	34.4	0.28	36.7	39.6	0.01	0.01	132.32	191.7	+15[a]
Sesame	36	0.25	40.4	39.4	0.002	0.01	91.76	210.34	
Flax	28	0.24	27.6	39.3	0.01	0.01	156.74	188.71	
Palm	63.6 (30°C)		42				35-65		
Jatropha	49.9 (38°C)		40-45						
Castor	29.7	0.21	42.3	37.4	0.01	0.01	88.72	202.71	
Soya	33.1	0.24	38.1	39.6	0.006	0.01	69.82	220.78	+11[b]
Peanut	40	0.22	34.6	39.5	0.02	0.01	119.55	199.8	
Hazelnut	24	0.21	52.9	39.8	0.01	0.02	98.62	197.63	
Walnut	36.8	0.24	33.6	39.6	0.02	0.02	135.24	190.82	
Almond	34.2	0.22	34.5	39.8	0.01	0.01	102.35	197.56	
Olive	29.4	0.23	49.3	39.7	0.008	0.02	100.16	196.83	
Wheat	32.6	0.23	35.2	39.3	0.02	0.02	120.96	205.68	
Corn	35.1	0.22	37.5	39.6	0.01	0.01	119.41	194.14	
Diesel	2-4.5		47						0 to -20

[a] *Source: Valenergol*
[b] *Source: USDA*

The straight vegetable oils (SVO) viscosity is much higher than that of diesel fuel: it increases with the carbon chain lengths [7,17]. SVO high viscosity causes (i) a decrease in injection rate due to head losses in fuel injection pumps, filters and injectors, (ii) poor fuel atomisation and vaporisation by the injectors, which leads to incomplete combustion inside the combustion chamber [18,19,20]. This results in lower thermodynamic efficiency and an increase in soot emissions and particle matters.

Viscosity is a rapid indicator of fuel quality before use, especially if the nature of the feedstock is not well known, or if the oil could have been deteriorated or polymerized during storage [21].

As shown in Figure 2, for a typical heavy fuel viscosity of 180 cSt at 50°C, it is necessary to heat the HFO (heavy fuel oil) to between 114°C and 125°C to reach the appropriate viscosity, while SVOs require only 67°C to 78°C to achieve the same viscosity [16].

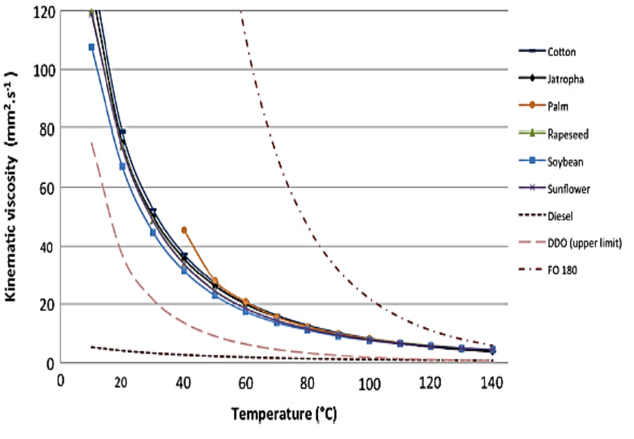

Fig. 2 *Temperature dependence of the kinematic viscosity of vegetable oil and different heavy fuel oils; DDO – distillate diesel oil; FO 180 – heavy fuel oil 180 [16].*

The iodine value is a measurement of the total unsaturation of vegetable oils, as well as an indicator of their susceptibility to oxidation [21]. Vegetable oils can be divided into four major categories depending on their iodine value: saturated oils (iodine value between 5 and 50), mono-unsaturated oils (50 and 100), di-unsaturated oils, also called semi-siccative (100 and 150) and tri-unsaturated oils called siccative (over 150) [16].

As shown in Figure 3, this parameter is specific to each oilseed, making it possible to check the nature of the biomass used. Although SVO viscosity increases with total unsaturation, the iodine value is not a parameter that can be used to draw conclusions

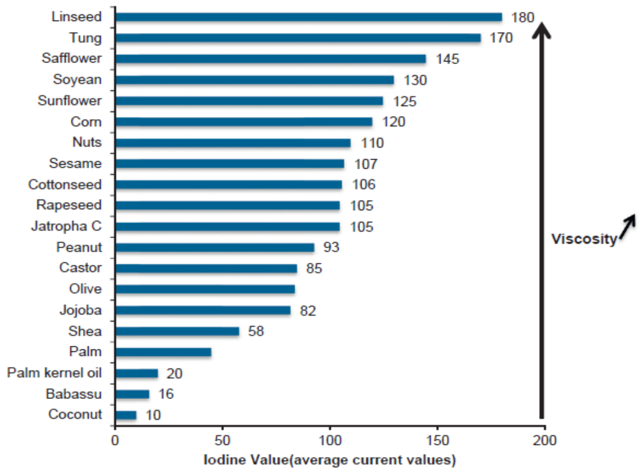

Fig. 3 *Mean iodine values of different vegetable oils viscosity increases with the degree of unsaturation)[16].*

about the quality of SVO or the potential presence of impurities [16].

As Figure 4 indicates, the viscosity of pure SVO is much higher than that of diesel fuel at normal operating temperatures. This can cause premature wear of fuel pumps and injectors and can also dramatically alter the structure of the fuel spray coming out of the injectors to increase droplet size, decrease spray angle, and increase spray penetration [22].

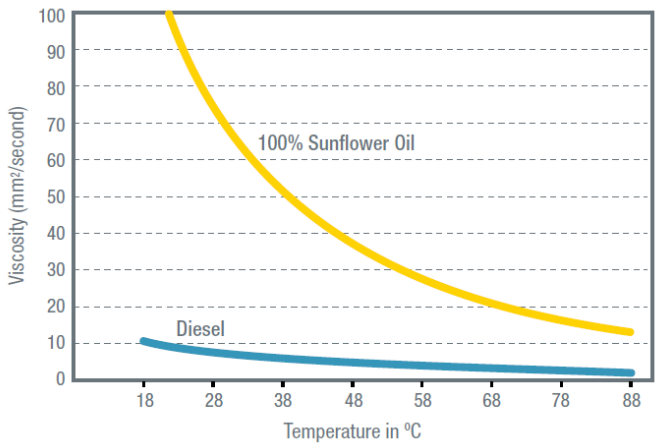

Fig. 4 *Impact of temperature on the viscosity of sunflower oil and diesel fuel [22].*

The cetane number reflects the ability of a fuel to self-ignite when compressed under standardized conditions [23].

Ash content indicates the content of minerals and oxides of an abrasive nature for the engine [16]. According to Espadafor and coworkers [24] ash constituents, such as vanadium, nickel, sodium, aluminum and silicon are harmful for the engine, and their presence merely increases engine wear and corrosion.

The cold properties of the oils, especially their Cold Filter-Plugging Point (CFPP) represent a further handicap. At low temperature, the resulting higher viscosity makes them virtually impossible to use and development of a special cold-starting technology is essential. Solutions include starting the vehicle with Diesel, or methods to warm up the fuel [1].

3.2. Impact on combustion

Vegetable oils cause serious damage to combustion systems, due to the formation of deposits, and downgrade the performance and emission quality, especially in direct injection engines. During the fuel vaporization and combustion process, due to the high molecular weights and low volatility of the oils, the molecules cracks, resulting in the formation of deposits. The high viscosity of the oils radically modifies the phenomena associated with spraying of the fuel and therefore the combusting timing, already disturbed by the low cetane number of these oils (about 30 to 40), well below the 51 limit imposed by Diesel standard EN 590 [25,26,27,28].

Vegetable oils contain significant amounts of oxygen. Its ignition characteristics are such as poor cold engine start-up, misfire, and ignition delay, and latter includes incomplete combustion, e.g. deposit formation, carbonization of injector tip, ring sticking, lubricating oil dilution and degradation, polymerization during storage [29].

Carbon deposits around the nozzle orifice, upper piston ring grooves and on piston rings are the main problems during the use of vegetable oil as fuel [30]. They are also biodegradable, non-toxic, and have a potential to significantly reduce pollution. Vegetable oils and their derivatives in diesel engines helps to reduce the emissions of sulfur oxides, carbon monoxide (CO), poly aromatic hydrocarbons (PAH), smoke, particulate matter (PM) and noise [31].

In addition, some of the difficulties mentioned above will be further amplified with improvements in diesel engine technologies (smaller injector nozzles, more injectors resulting in higher risk of clogging). Direct use of vegetable oils with technologies currently being developed will become increasingly critical [32].

3.3. Impact on emissions

Due to the need to adapt the combustion time, use of vegetable oils in diesel engines generally leads to higher CO, HC and PM. In contrast, due to their slower combustion and lower temperatures in the combustion chamber, vegetable oils reduce NO_x emissions . The emissions vary depending on the condition of the vehicle. The differences may increase with the mileage, the age of the engine technology and the degree of engine clogging [1].

Experiments have also been conducted on use of vegetable oils in mixtures. These tests were performed with 25/75 mixtures of sunflower or safflower oil in diesel. Performance with the fuel formulated using sunflower oil rapidly deteriorated due to deposits on injectors and piston add to gumming of the piston rings. Mixtures based on safflower oil did not generate any special problems [33,34,35].

Other isolated and endurance tests have been conducted [13] with various fuel formulations based on cotton oil and diesel, containing between 30% and 65% vegetable oil and with a 50/50 mixture of cotton oil and cotton oil ester. Although beneficial effects may be observed in the short term, serious problems of deposits, ash, wear and gumming appeared during endurance tests, in the longer term.

In the experiment [4], the tests have been carried out to evaluate the performance and gaseous emission characteristics of a diesel engine when fuelled with vegetable oil and its blends of 25%, 50%, and 75% of vegetable oil with ordinary diesel fuel separately. A Lister Petter T series diesel engine is selected for the study and is mounted on a test-bed. The engine is type TS2, 9.5 kW capacity, fixed speed (1500 rpm) with air-cooled and direct injection.

Figure 5 shows the comparison of the CO emissions of different fuels at different engine load. Within the experimental range, the CO emission from the vegetable oil and vegetable oil/diesel blends are nearly all higher than that from pure diesel fuel. Only on the point of engine full load, the CO emission of vegetable oil and vegetable oil/diesel fuel blends were all lower than that of diesel fuel. This is possibly due to two factors: (1) at the engine full load, the temperature in the cylinder of engine is higher, which makes the vegetable oil and it blends easier to atomize, a better air/fuel mixture and then a better combustion can be achieved; (2) the oxygen contents in the vegetable oil makes it easier to be burnt at higher temperature in the cylinder [4].

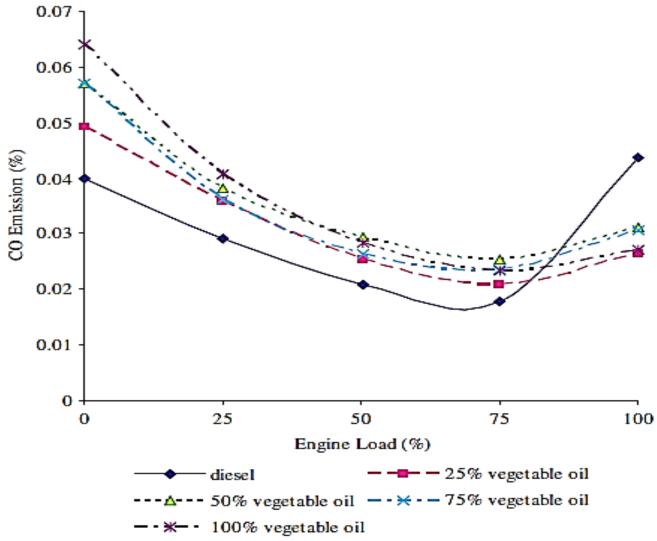

Fig. 5 *Comparison of CO emission versus engine power output for different fuels/oil blends [4].*

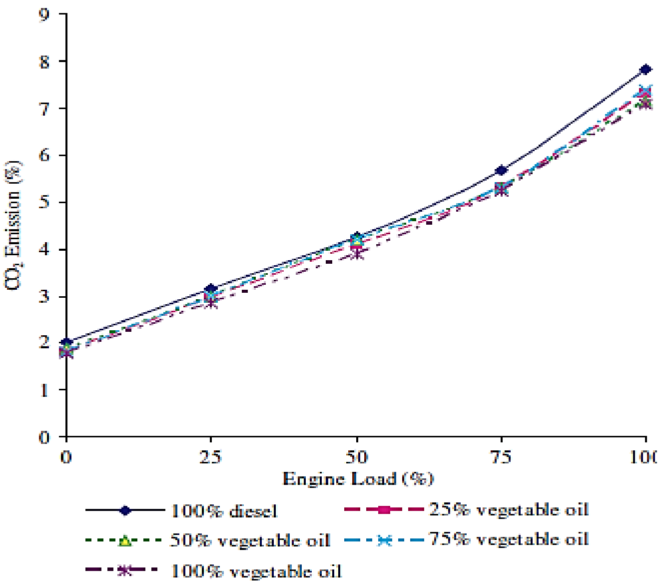

Fig. 6 *Comparison of CO_2 emission versus engine power output for different fuels/oil blends [4].*

In the range of whole engine load, the CO_2 emissions of diesel fuel are all higher than that of the other fuels (figure 7). This is because vegetable oil contains oxygen element; the carbon content is relatively lower in the same volume of fuel consumed at the same engine load, consequently the CO_2 emissions from the vegetable oil and its blends are lower [4].

Rakopoulos et al. [36] have evaluated the use of sunflower, cottonseed, corn and olive straight vegetable oils of Greek origin, in blends with diesel fuel at proportions of 10 vol.% and 20 vol.%, in a six-cylinder, turbocharged and after-cooled, heavy duty, direct injection diesel engine.

For the speed of 1500 rpm, for the neat diesel fuel, and the 10% and 20% blends of the four vegetable oils with diesel fuel, at the three loads, it can be observed that the NO_x emitted by all vegetable oil blends (Fig. 7) are equal or slightly higher than the ones for the corresponding diesel fuel case, with this increase being higher the higher the percentage of the vegetable oil in the blend [36].

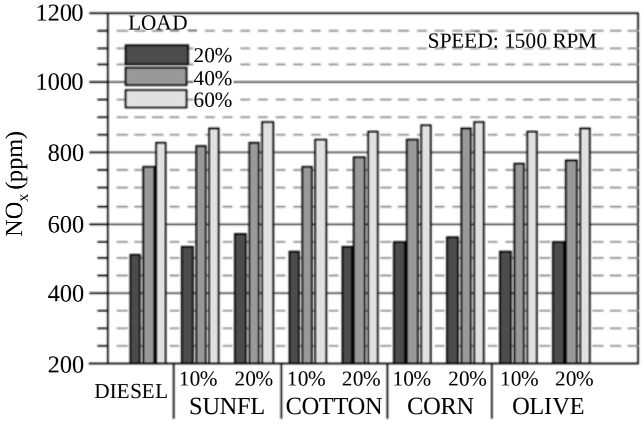

Fig. 7 *Emissions of nitrogen oxides (NO_x) for neat diesel fuel, and the 10% and 20% blends of the four vegetable oil with diesel fuel [36].*

In [4], the HC emissions of all fuels are lower at partial engine load, but increased at higher engine load (Fig. 8). This is due to relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at higher engine load. The HC emissions of vegetable oil and vegetable/diesel fuel blends are lower than that of diesel fuel, except that 50% of the vegetable oil with 50% diesel fuel blend is a little higher than that of diesel fuel [4].

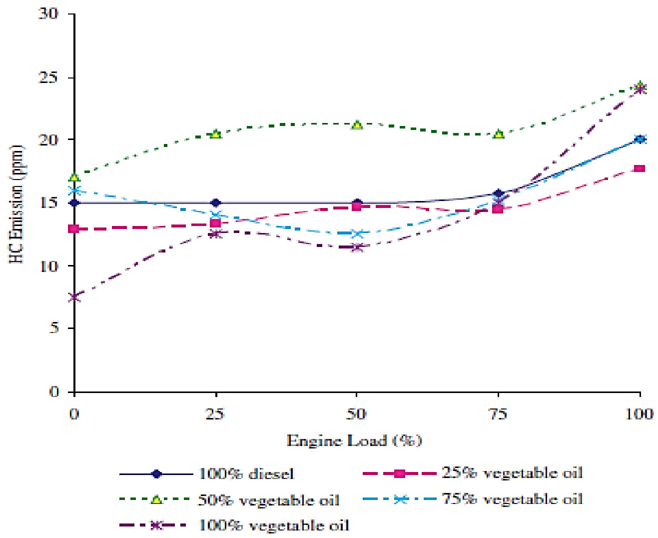

Fig. 8 *Comparison of HC emission versus engine power output for different fuels/oil blends [4].*

Cottonseed and sunflower oils need to be at least degummed for fuel use, as shown in short-term performance tests with an engine having a pre combustion chamber, but even at the state of refinement, they are unsuitable for runs of more than 40 hours when used as the straight, unblended fuel. Although vegetable oils apparently can be tolerated in direct-injection engines only as dilute blends in diesel oil, there is accumulating evidence worldwide that the simple esters can function as a diesel fuel by themselves because of improved viscosity and volatility properties compared to triglyceride [37].

The results from the experiments prove that vegetable oil and its blends are potentially good substitute fuels for diesel engine in the near future when petroleum deposits become scarcer [4].

4. Conclusion

First generation biofuels for diesel engines are produced from vegetable oils. After more or less deep purification, they can be used directly as fuel in diesel engine and are still currently used in some limited applications.

A number of investigations have been made, and the test results have proved that vegetable oils are feasible substitutes for diesel fuel.

The usage of vegetable oils as diesel fuel depends on world market prices for mineral products and is therefore of special interest at present only for countries with a large excess of vegetable oil production

Vegetable oils are available everywhere in the world and are renewable as the vegetables which produce oil seeds can be planted year after year. Also, they are “greener” to the environment, as they seldom contain sulphur element in them.

The main problem of using vegetable oils in diesel engines is the high viscosities of such fuels.

Due to the need to adapt the combustion time, use of vegetable oils in diesel engines generally leads to higher CO, HC and PM. In contrast, due to their slower combustion and lower temperatures in the combustion chamber, vegetable oils reduce NO_x emissions.

While vegetable oils represent an alternative fuel, they will continue to present risks related to their intrinsic characteristics, which neither car nor agricultural tractor and machinery manufactures are willing to assume.

The results from some experiments prove that vegetable oil and its blends are potentially good substitute fuels for diesel engines in the near future when petroleum deposits become scarcer.

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