

THERMAL EFFICIENCY OF COCONUT OIL AS A COMPRESSION IGNITION FUEL.

Primary investigation unit

Document number 9,

Research Report No 76

Physics Dept

James Cook university of North Queensland

Townsville Australia

July 1983

COCONUT OIL AS A DIESEL FUEL

Philippines

The longest-term vehicle running trials with coconut oil fuel have been conducted by Professor Ibarra Cruz, previously of the University of the Philippines and more recently the manager of Energy Research and Development Center, Philippine National Oil Company. Initial trials were done with a ASTM-CFR stationary diesel engine. In seventy five experimental runs, the thermal efficiency with crude coconut oil was 3.33% with an average indicated horse power of 6.83Hp, compared to a thermal efficiency of 32.4% and indicated horse power of 6.84Hp with petroleum diesel fuel. Similar results were obtained with a DUCATI IS-11 single cylinder diesel engine, commonly used in the Philippines for motorboats. Crude coconut oil was used to fuel an "ISUZU" diesel engine of a passenger Jeep. 64 trips were made with crude coconut oil over a distance of 7742 kilometers. The thermal efficiency was 11.3 and 12.1 kilometers per kilocalorie for coconut oil and petroleum diesel fuel respectively. The only problems reported were that the coconut oil solidified overnight during the cooler weather.

A limited fleet test was carried out with seven buses equipped with M.A.N. diesel engines and five buses with either Hina or Fiat engines. A mixture of 30% coconut oil with 70% petroleum fuel was compared with buses operating on 100% petroleum fuel. The sum of the distance traveled during the trials was 40,000 kilometers. Buses operating on the coconut oil diesel fuel obtained efficiencies the same as when operating on 100% petroleum fuel within the experimental variation. The only problem reported was clogged fuel filters due to the formation of slimes in the fuel from the presence of water.

PNG

The Department of Works and Supply in Papua New Guinea have carried out extensive tests with coconut oil in a 13Hp indirect injection Yanmar diesel engine. This engine was run on coconut oil fuel under controlled conditions in excess of 200 hours under the direction of Mr. Laurie King. Fuel injection is by means of a single hole injector closed by a pintle pin (normal injector). The major problem encountered during the trials was the formation of extensive deposits around the injector hole. This led to poor atomization and a decrease in the efficiency of combustion as shown by increase in the fuel consumption. Poor combustion of the fuel resulted in hard deposits being formed within the cylinder and sticking piston rings. The deposits on the piston rings led to one of the rings breaking causing extensive scoring the cylinder wall.

A number of variations were investigated in order to minimize the formation of deposits on the injector. A proprietary fuel detergent was mixed with 50% coconut oil and diesel fuel. Injector deposits were reduced, but not below the level at which inefficient combustion occurred. The pintle pin was shaved to increase fuel bypass. By this means the temperature of the injector orifice might be expected to be decreased and the rate of shut off of the fuel after injection should also be increased. Although this measure did reduce the rate of injector deposits, again these were of sufficient levels to cause inefficient combustion. The injection pressure was increased from 140 atmospheres to 170 atmospheres in order to increase the efficiency of fuel atomization and also increase fuel bypass with subsequent injector cooling. No reduction in injector deposits was observed, as the relative increase was considered too small.

The engine cooling in the vicinity of the injector nozzle was increased by the use of a second water-cooling system this modification was

also found to decrease the injector deposits, although not to a level that they would not cause reduced combustion efficiency. Tests were carried with 10% Ethanol coconut oil mixture. Reduction in injector deposits was observed, although carbon deposits in the cylinder increased. Problems were also encountered with vapor locks in the fuel line. A fuel of 20% kerosene and 80% coconut oil fuel gave similar results to coconut oil-petroleum fuel mixtures.

Since the trials in Papua New Guinea, reports have been published for the effect of injector cooling with sunflower oil fuel. The results are similar to that with coconut oil fuel. Although injector deposits may be reduced in some cases, this reduction is not sufficient to eliminate the problem of decreasing efficiency of fuel combustion as injector deposits increase. None of the many modifications to the fuel or the engine investigated with coconut oil as a fuel in Papua New Guinea were sufficient to prevent the build up of injector deposits. The subsequent poor combustion due to the decreasing fuel atomization will lead to permanent engine damage if steps are not taken periodically to physically remove the deposits from injector openings. (This is required periodic maintenance when running on petroleum diesel anyway).

Samoa

The Electric Power Corporation of Western Samoa has carried out trials with coconut oil fuel over a number of years under the direction of Mr. John Worrall. The results are of much interest as coconut oil was used to fuel a 420 BHP Mirless type J6 stationary diesel engine driving an electric generator. This is probably the largest engine fuelled by coconut oil. It was found that over an eight-hour period that the engine gave the same thermal efficiency as diesel fuel at standard load conditions for the engine and was slightly less efficient (5%) when operating with coconut oil at light loads. Subjective comparison with this engine indicate that it produced less smoke and less noise with coconut oil, had similar exhaust and cooling water temperatures, but was slightly more difficult to start as compared to diesel. The major problem has been frequent blockage of the engine fuel filter when operating on coconut oil diesel fuel mixtures. A number of tests have been carried out with coconut oil fuel in 3 liter and truck Land Cruiser engines for the vehicles in normal use. The major problem during these trials was the formation of solid particles in the fuel as the temperature approaches the solidification point, blockage of fuel filters and difficult starting after overnight cooling. The thermal efficiency of coconut oil was approximately 20% less than that of diesel fuel. The trials were not conducted for a sufficient period for the non-combusted coconut oil to cause any serious deterioration of engine lubrication. Operators of the vehicles reported that the engine running was smoother with coconut oil than diesel fuel once the engine is operating at normal temperatures.

Vanuatu

The longest term for which an engine has been run regularly on coconut oil would appear to be 18 months. This is the period that Mr. Keith Barlow of Vanuatu has been operating a Ford 60Hp Stationary diesel engine on a mixture of 50% coconut oil and diesel fuel. The engine continued to operate satisfactorily after this period. A smaller 10Hp Southern Cross engine has been operating satisfactorily over a two-year period on **100% coconut oil** although this engine has only been operating intermittently over the last 6 months. The coconut oil, which was used as a fuel for these two engines, is oil produced in Vanuatu and being rejected as oil below export grade food quality unrefined coconut oil. The only modification to these engines is to **preheat the fuel with exhaust gases and careful filtration prior to the engine filter.**

Perkins Engines Ltd in the United Kingdom.

Further evidence for the better fuel qualities of coconut oil compared to other vegetable oils has been reported by Perkins Engines Ltd in the United Kingdom. In a series of short term tests they investigated fuel injector nozzle coking, fuel system deposits and lubricating oil gelation of a number of vegetable oils including coconut oil. Using engine noise as a criteria for cetane numbers, they obtained values 40 per cent greater than normally obtained from ignition delay methods. From ignition noise measurements, cetane value of 60 for rapeseed. oil was obtained compared to usual range of 50-60 quoted for diesel fuel. Many operators who have trailed Coconut oil as a fuel quote it is "quieter" than diesel fuel. On this basis, the cetane number for coconut oil may be greater than 60. The engine trials by the Perkins Engine Company were run, at the "worst" conditions for engine coking. This was continuous running under part load. Within a 10 hour period extensive nozzle deposits, cylinder gums and varnishes were formed with sunflower oil, slight deposit with very little cylinder deposits with coconut oil and virtually no deposits from heated animal tallow from which the slight amount of unsaturated fats had been removed.

From these results it was concluded that the problems in the use of vegetable oils as diesel fuel were largely due to the unsaturated bonds (as measured by the iodine number). The use of ethyl esters of saturated and unsaturated vegetable oils was also briefly investigated. Compared to the unchanged tri-glyceride oils, all injector deposits were greatly reduced. However with a highly unsaturated ester, injector deposits were formed. **With relatively saturated esters from coconut oil and animal fats, virtually no injector deposits were observed. The conclusion of the Perkins engine company is that the ester has physical characteristics very closely resembling conventional petroleum diesel fuels, but with better combustion characteristics due to the absence of the non-carbon chain aromatic compounds present in petroleum fuel.**

James Cook University of North Queensland

Trials with various vegetable oils in a 6Hp power. **Indirect injection Yanmar** diesel engine have been carried out at the University of the South Pacific over a number of years. These trials were initiated by Professor James Ward of the James Cook University of North Queensland and more recently have been directed by myself. During this period, most helpful correspondence has been maintained with most of the investigators whose results are outlined above. Vegetable oils, which have successfully fueled the stationary engine for short periods, include coconut, sunflower and soybean oil. These fuels have been used as **100% oil** and in admixture with various ratios of petroleum diesel fuel and also to a lesser extent with kerosene.

In one of these trials the engine was operated continuously under partial load with a 50% mixture of crude coconut oil and diesel fuel. At the start of the trial, the thermal efficiency of the coconut oil was the same as that of 100% diesel fuel. After 130 hours of continuous operation, the efficiency Of the coconut oil had decreased by 11%. Immediately following this period, the specific fuel Consumption of diesel fuel was measured in the Engine. It was found that this had decreased by 16% compared to the start of the trial. The injector was removed from the engine and found to have extensive "trumpets" around the nozzle. These were removed and the injector Surface polished. The injector was replaced in the engine and the specific fuel consumption for coconut oil and diesel fuel determined. Compared to the coked injector, the fuel efficiency had increases 5% per and 8% respectively for coconut oil and diesel fuel.

The fuel efficiency remained less than that at the start of the trial, so the engine was partially dismantled. It was found that the holes connecting the injector pre-chamber with the combustion chamber were partly blocked with solid particles. These particles were removed and the engine reassembled. When the fuel efficiency of the coconut oil and petroleum fuel was again determined, these had returned to the values prior to the trial. It may be concluded that the engine had been returned to its original condition. Of interest is the fact that with a coked injector, the decrease in fuel efficiency with coconut oil fuel was less than that with diesel fuel, although neither is satisfactory.

When the engine was partly dismantled, the upper cylinder walls and piston surface were also inspected. No heavy deposits or scoring was seen on these surfaces. Similarly, there were no heavy deposits on the valve surfaces or the exhaust manifold. Small samples of the lubricating oil were withdrawn from the sump while the oil was still hot after each 20 hours of operation during the trials. The used oil samples were analyzed by atomic absorption spectroscopy for the major wear metals of iron, chromium, lead and copper. A regular increase was found during the period of the trial, but no greater than would be expected for an engine operating on petroleum fuel. The dispersive properties of the oil were then qualitatively examined. These remained within specification for used oil under diesel fuel operation. As discussed previous the specific fuel consumption for coconut oil fuel had increased by 11% at the completion of the trial.

It would appear that non-combusted fuel was not causing serious degrading of the lubricating oil after the 130-hour trial. The oil was then changed.

The deposits in the pre-combustion chamber were not black and shiny as would be expected from polymerized carbon deposits. They were predominantly a red brown colour, characteristic of metallic silica deposits, particularly of iron. The deposits were similar in appearance to those obtained when a sample of vegetable oil was combusted in air in a static system to a temperature of 775°C. The amount of non-combustible ash deposits was determined in crude coconut oil and a number of other oil samples. The results are shown in table three. The highest value was that for the crude coconut oil taken from near the bottom of the 200-liter drum. This contained 0.121% non-combustible ash. Samples from the top of the drum were 0.047% ash. Specification for petroleum fuel is less than 0.01% ash. The results are similar to the ash contents of crude rapeseed and peanut oil obtained from Dunedin and Townsville. Standard commercial alkali refining of these crude oils reduced the ash contents to 0.008% and 0.02% for refined coconut oil and rapeseed oil respectively. These values may be compared with a ash content of 0.001 and 0.004 per cent for two samples of partly esterfied coconut oil which has been previously called "COCOHOL". The impurities forming the major constituents of the ash in crude coconut oil are removed as part of the bottom glycerol layer **by a simple decantation** (settling) in the preparation "COCOHOL". It would appear that the ash impurities in coconut oil are selectively absorbed in the more glycerol bottom layer. A similar effect is found in reverse when diesel fuel is added to crude coconut oil. Impurities in the coconut oil tend to separate as a slimy solid. This material is particularly effective in blocking fuel filters.

Pre Refining coconut oil

In the trials above it was necessary to pre-filter the mixture of crude coconut oil and petroleum diesel fuel to minimize blockage of the engine fuel filter. For then pre-engine filtration, frequent changes of the

filtering element were required. The process for the preparation of "COCOHOH" requires less sophisticated industrial plant than that for the standard alkali refining process. The loss of coconut oil is also less than that of the standard alkali refining process. No coconut oil is lost in fact, but part is converted to glycerol, which may form a valuable byproduct. Industrial glycerol currently has a value five times that of coconut oil, compared to a relatively low value soap stock as the byproduct from the alkali refining process.

"COCOHOH" is the product formed by partial esterification of coconut oil after separation of the glycerol fraction by decantation. The major constituent is the ester, although depending on the conditions, although depending on the condition under which it is prepared; it also contains unchanged coconut oil, alcohol and some glycerol. The solidification point is generally less than 15°C compared to greater than 20°C for coconut oil itself. The ester and coconut oil making up the major constituents of the mixture are not soluble in water. Addition of water to the mixture results in the formation of a separate layer, containing largely the added water with small amounts of ethanol and glycerol from the mixture. The effect of water on the mixture is not unlike the effect of added water to petroleum diesel fuel itself. The viscosity of "COCOHOH" depends on the conditions of preparation, but it is generally similar to petroleum diesel fuel itself. The flash point is largely dependent upon the amount of unreacted alcohol, as the ester itself has a flash point higher than that of petroleum diesel fuel.

Limited trials have been conducted with "COCOHOH" in the indirect combustion Yanmar diesel. Within the experimental error, the thermal efficiency is the same or slightly greater than that with petroleum diesel fuel. After 20 hours continuous operation on partial load, there was no decrease in the thermal efficiency. Only a light coating of a uniform carbon coating was formed on the injector similar in appearance to those with petroleum diesel fuel. A problem, which occurred during these trials, was the removal of the glue attaching the paper fuel element of the engine fuel filter to a metal holder. This process occurred within one or two hours of passing the "COCOHOH" fuel through the filters. A similar process was found with two other standard Yanmar filters. Discussions with Mr Ron McLeod in New Zealand, following the use of partially esterified rapeseed oil as a fuel for a short period in a Datsun sedan, indicate a similar problem with removal of the adhesive from the fuel filter. With the Datsun vehicle, the adhesive subsequently caused gumming in the injectors. Esters in general are much more effective solvents than hydrocarbons and more extensive materials testing trials are required before esters can be used with confidence as a fuel.

Conclusions And Recommendations

There is no doubt that vegetable oils will successfully fuel diesel engines. Coconut oil has the best characteristics as a fuel of all the common vegetable oils. The engine trials, which have been carried out with coconut oil, are limited. Conclusions from these trials would suggest that the only short term, problem with coconut oil is the possible clogging of the engine fuel filter. This problem is easily remedied by changing the filter element; the rate at which the engine filter clogs may be minimized by efficient **pre-filtration (or settling)** of the coconut oil fuel. A standard portable filter as used by electricity authorities in the region for the filtration of transformer oil is well suited for this purpose.

Partial solidification when the coconut oil is occurs when the coconut oil is cooled to temperatures below 25°C for an extended period. A

mixture of the coconut oil with diesel fuel reduces the temperatures at which solids forms. A 50% mixture with petroleum diesel fuel has a solidification point below 15°C, The effect of water on the mixtures is not fully understood. Small amounts of water will dissolve in the mixture. Larger amounts of water form a separate layer with the separation of solid particles in some instances.

Longer term running of the engine with coconut oil fuel may produce deposits on the injector(s) of the engine. These deposits may lead to poor fuel combustion and contamination of the lubricating oil with un-burnt fuel. Chemical reaction between the vegetable oil and antioxidants in the engine may lead to loss of lubricating properties and subsequent permanent damage to the engine. **No damage is done to the engine if the injectors are cleaned on a regular basis with regular changes of the engine oil** (as required with normal diesel fuels).

Engines for which injector coating has been significant have been small single cylinder indirect injection engines. Although not as closely monitored as the large engines, there has been no evidence for injector deposits leading to poor combustion with larger direct injection engines in stationary engines, light commercial vehicles or in buses.

Careful monitoring of a number of larger diesel engines operating on coconut oil is required so that factors controlling the formation of injector deposits are better understood. Should international prices for coconut oil remain at present levels or decrease, these trials can be done with an **economic saving** compared to the utilization of petroleum diesel fuel at many centers in the Pacific Islands. It is not recommended that crude coconut oil be used directly as a fuel, just as the use of crude petroleum oil is not recommended. However, **the use of filtered coconut oil under technical supervision is economically and technically feasible at the present time.**

At a small price premium, less than that for alkali refining of vegetable oils, the coconut oil may be chemically reacted with alcohol to form a fuel mixture containing largely the ester. **The ester of coconut oil is a better fuel for diesel engines than petroleum diesel fuel itself.** The esters of coconut oil may also be used as a kerosene substitute in domestic appliances such as in pressure lamps and stoves and in wick stoves. In these applications, the esters are a much safer fuel than kerosene due to a higher flash point and lower volatility. The esters cannot be used in wick (Hurricane) lamps, as the combustion is too efficient leading to a non-incandescent flame (the capillary action cannot keep up with the wick due to higher viscosity of the fuel). These esters may be transported and stored in the region as with diesel fuel or kerosene with a much greater fire safety factor.

Table 1

VEGETABLE OIL CHARACTERISTICS

Oil	Solidification Point C	Iodine Value	Saponification Value
Coconut	20-25	10	268
Palm	30-35	54	199
Rapeseed	-10	98	175
Sunflower	-17	125	189
Peanut	3	93	192
Soybean	-16	130	191
Linseed	-14	179	190

Table 2

DIESEL OIL CHARACTERISTICS

Characteristic	Diesel fuel	Sunflower Oil	Coconut Oil	Cocohol
K Viscosity 40C mm ² s ⁻¹	2-Apr	30-34	24-28	3-Jun
Cetance No	40-60	30-40	>60	>60
Cloud Point C°	-9	-6	25	2-Jun
Calories Mj	38	36	35	33
Flash Point C°	60-70	320		
Ash%	0.02%	0.05-.4%	0.05-0.15%	0.001%

Table 3

VEGETABLE OIL MEASURED ASH LEVELS

Oil	Origin	Ash%
Crude Coconut	Fiji	0.05%-0.12
Alkali Refined Coconut	Fiji	.008-0.071
Crude Peanut	Queensland Aust	0.08
Crude rapeseed	New Zealand	0.1
Alkali refined Rapeseed	New Zealand	0.02
Processed Palm	Solomon Islands	0.006
Cocohol	Fiji	0.0008-0.002