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USE OF WASTE VEGETABLE OIL AND COCONUT OIL AS SUBSTITUTES TO DIESEL OIL

Mauritius Research Council

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Acknowledgements

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The above persons do not bear any responsibility for the analysis and interpretation of data reported here.

EXECUTIVE SUMMARY

MRC has been conducting parallel projects to investigate the use of Waste Vegetable Oil (WVO) and Coconut Oil (CNO) as substitutes for diesel oil.

The usage and disposal of vegetable oil by large consumers, including hotels, fast food chains and hospitals have been investigated. Our study has shown that between 35-40% of oil is disposed of, and that the consumers of oil also have fleets of diesel vehicles. WVO can potentially be used as a substitute for diesel oil.

The CNO biofuel project forms part of a larger study that MRC has carried out with the collaboration of the Outer Island Development Corporation. The main objective of the study was to investigate the possibility of using CNO as a substitute to diesel in order to reduce the dependence of Agalega on Mauritius for its liquid fossil fuel requirements.

The engines of two 4 x 4 pick up trucks have been modified to run on WVO and CNO. The two vehicles have covered over 12,000 km and their engines have been scientifically monitored. In particular the engine performance, wear and tear and gas emissions have been assessed relative to that of conventional diesel. The results obtained are very promising

MRC has worked with Mr Michael Chan, owner of the vehicles, to realise this project. Hilton Resorts & Spa has already taken up the idea and it has two vehicles already running on WVO that it generates.

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1.0 INTRODUCTION

The main objective of this project has been to investigate the technical feasibility of using Waste Vegetable Oil (WVO) or Coconut Oil (CNO) as biofuels for the substitution of diesel oil in vehicles or electricity generation. Although all tests have been performed on the Island of Mauritius, through work commissioned by the Mauritius Research Council,[1] two distinct objectives can be found behind this project. For WVO, the principal driver has been to find an economic way to dispose of waste cooking oil on the Island of Mauritius (thereafter Mauritius), while the use of CNO as a biofuel is part of a larger project aimed at making the Islands of Agalega energy self-sufficient. The two parts of this project are discussed separately hereon. This study has, therefore, investigated the use of WVO and CNO as biofuels for the direct substitution of diesel oil in two pickup trucks.

The inception of this project was assisted by the fact that there was already one pick up truck that was running on WVO in early 2006, and that the owner (Mr Michael Chan) was prepared to work with MRC to conduct exhaust emissions and engine wear and tear tests described below.

1.1 Waste Vegetable Oil

The National Environment Action Plan (NEAP) II[2], seeks to address pressures on the environment due to economic growth, and changing production and consumption patterns for the period 1999 to 2009. Analysis of inadequacies in solid waste management revealed that used oil was a special waste that needed prompt attention. NEAP II pre-empted that improvement of this situation would require solution to strategic issues, including (1) inadequate institutional structure, capacity and capability; (2) deficient legal base, (3) lack of data, (4) unaware and uncommitted public, and (5) inadequate cost recovery and investment. Although, there is already commercial activity in Mauritius for treating and recycling mineral oil, used vegetable oil has received scant interest.3 This project seeks to address several of these issues, at least partly if not completely, through scientific analysis. A survey of major vegetable oil users was undertaken at the beginning of the project in order to estimate the volume of WVO that is generated in Mauritius.

1.2 A Energy Self-sufficient Agalega

The atoll of Agalega is situated at around 1000 km North of Mauritius and comprises two islands (North and South Islands) with a total of 2600 ha. Agalega has a population of 275 persons and is planted mainly with coconuts. The Outer Islands Development Corporation (OIDC) is responsible for the management and development of Agalega.

Despite attempts in the past to electrify Agalega using photovoltaics (PV), and in spite that it produces some 20,000 litres of CNO annually, Agalega is today completely dependent on fossil fuels (mostly diesel) imported from the Mauritius for its energy (electricity and transport) needs. OIDC's Action Plan 2005 — 2010 quotes: "Electricity is being provided to the three (3) villages by diesel-powered generator sets (pg.17)".[4] The complete dependence of Agalega on imported fuel and high price volatility may seriously impede its future development. Further, the heavily subsidised delivery of electricity and transport to the inhabitants of Agalega comes at a huge cost to OIDC as shown in Figure 1.[5] The volume of diesel shipped increased by ~4.2 times between 2000 and 2007 (reaching ~ 145,000 L in 2007), while the total cost of fuel soared by ~7.8 times to reach an expected Rs 5 million in 2007.

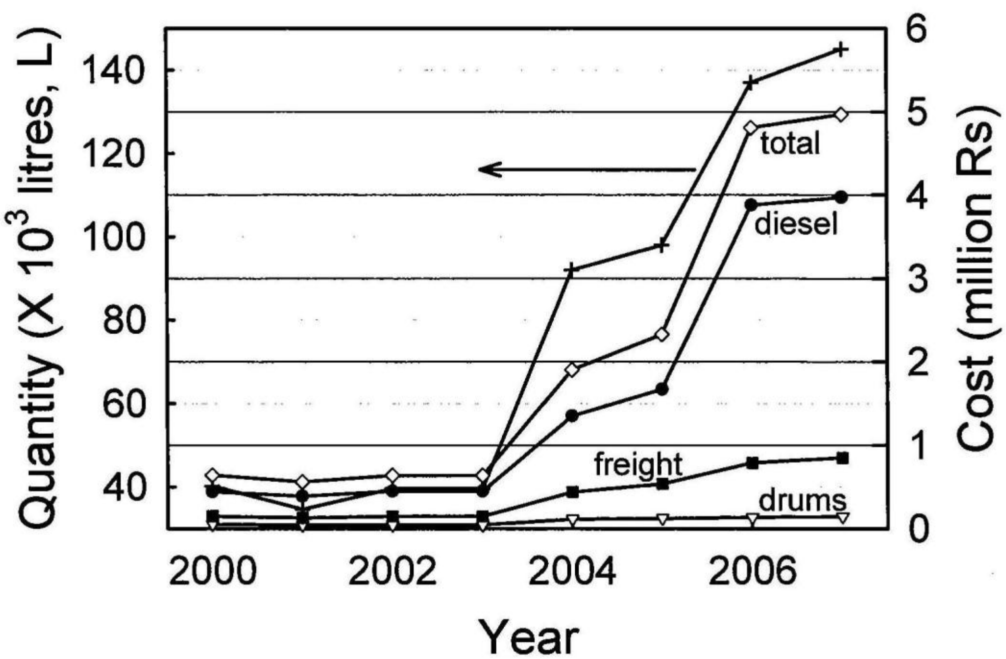

Figure 1. Quantity and cost of diesel shipped to Agalega, 2000 – 2007.

Further, Agalega has a frail ecosystem with shallow water tables. The disposal of diesel drums in the open is not only an eyesore but also a threat to the quality of underground water that is used by the inhabitants.[6]

1.3 Plant Oil as a Biofuel

A biofuel is defined as a renewable fuel that is derived from biological matter. Although the most often discussed biofuels are bioethanol, biodiesel and biogas, WVO and CNO would also categorize as biofuels. It is worth noting that the initial Diesel engine was designed in 1895 with the full intention of running it on a variety of fuels, including vegetable oil. Peanut oil was used during the demonstration of the Diesel engine at the World Exhibition in Paris in 1900. In 1912, Dr Rudolf Diesel stated, "the use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in the course of time as important as petroleum and the coal tar products of the present time.[7] However, as will be discussed later, these claims are not sufficient to use vegetable oil in just any diesel engine.

Despite the many claims and counterclaims concerning the use of vegetable oil (straight or waste/used) as a substitute for diesel in vehicles, the following guidelines usually apply:[8]

- Start engine on diesel (i.e. use a dual fuel system)
- Heat oil to decrease its viscosity (viscosity of CNO is "30 times higher than diesel at the same temperature)
- Remove water from oil
- Use in indirect injection engines
- Filtration of oil between 1-5 pm

For the generation of electricity, especially from coconut oil, is usually done using an admixture with either diesel or kerosene.9

An important point to note is that research has shown remote islands that are dependent on diesel oil for electricity production, and which have the option of using CNO as a biofuel can benefit tremendously from switching from diesel to CNO biofuel. In fact, 59-68% of the cost of the electricity produced with CNO is returned to the local economy, compared to only 5- 6% with imported diesel-generated electricity.'0 Hence, the use of locally produced coconut oil in electricity generation yields very high sustainable development dividends in remote island communities. The Pacific Islands are among those that have a strong experience in the use of CNO as a biofuel

2.0 METHODOLOGY

This section discusses the various methodologies used to achieve the objectives of this project.

2.1 Baseline Data

2.1.1 Generation of WVO

A survey of large users of vegetable oil (e.g. hotels and holiday resorts, fast food outlets, and hospitals) was carried out during the second half of 2006. The point of this exercise was to gauge the potential for the recovery of WVO for use as a biofuel. Half of all organisations responded to our request and they include, Naiade Resorts, Hilton Resorts & Spa, One & Only

Resorts, Tropical Paradise Co Ltd, Indigo Hotels & Resorts, KFC, Ministry of Health & Quality of Life (hospitals).

2.1.2 Potential to increase the yield of CNO on Agalega

The production of CNO on Agalega currently stands at 20,000 litres per annum. Around 20,000 coconut trees are cultivated on 500 ha of land. It is estimated that 25 nuts / tree are produced annually. A yield of CNO of 40 L/ha is very low compared to world average yields ranging from 648 to 1458 L/ha — i.e. factors 16.2 to 36.45 lower.[12]

This study has also estimated the potential to increase the yield of CNO on Agalega by considering 5 factors of production:

1. Land productivity (density of palms & use of fertilizers)

2. Coconut palm productivity (palm species & biotechnology)

3. Oil extraction efficiency

4. Plantation management

5. Land area cultivated

Exhaustive literature search was conducted to investigate best practice in coconut palm plantation. Further, a field trip of three days was undertaken on both islands of Agalega in April 2007 to assess the general practices on Agalega.

2.2 Emissions Tests and Engine Wear & Tear

The main aim of the study was to investigate the use of WVO and CNO as biofuels in two pickup trucks. The study comprised testing of (1) exhaust emissions, and (2) analysis of lube oil as an indication of engine wear and tear for biofuels compared with diesel oil.

2.2.1 Biofuel properties

WVO oil used in this study was collected mainly from the public hospital in Flacq. Moisture was removed from the WVO through heating until the turbidity in the oil was removed, and it was then filtered progressively from 50 pm to 5 pm. These steps were carried out prior to loading the fuel into the tank.

The CNO used here was produced in Agalega and provided by OIDC at cost price. The CNO was not of “energy” grade biofuel since it contained some solid matter, contained moisture and still retained its free fatty acid (FFA) contents. Before using the CNO as a biofuel, its moisture was removed and it was filtered as above. The biofuel still retained its FFA contents. No experiments were carried out to measure the FFA content of CNO.

2.2.2 Vehicle modifications

Two Nissan IDI diesel engine D22 pickup trucks had dual fuel systems fitted to them, as well as heat exchangers to preheat the biofuels before injection. The duel fuel system allowed engine start/stop on diesel. Although engine start/stop on diesel was adhered to for CNO because of solidification in fuel tank and lines, one pickup truck was run exclusively on WVO (following a trial period wherein the truck was run on a dual fuel system). No modifications were made to engines or their settings (e.g. air-fuel ratio).

2.2.3 Vehicle mileage

Each vehicle was driven for approximately 12,000 km with lube oil servicing carried out at 5,000 km interval. A sample of lube oil after vehicles were run on diesel oil for 5,000 km was also recovered for comparative analysis.

2.2.4 Exhaust emissions

Tests were carried out at the National Transport Authority (NTA) motor vehicle testing ground at Les Cassis using an Autologic Analyser. Exhaust emissions, including carbon monoxide (CO), carbon dioxide ($C0_2$), hydrocarbon (HC), and oxygen (0_2) were monitored. Emissions were measured at idling (~740 rpm), 2500 rpm and 3500 rpm. Data correspond to measurements averaged over a 1-minute period at each engine revolution.

Since the equipment housed at NTA does not carry a gas analyser for sulphur dioxide, such measurements were not performed. This is well an area where future research could be undertaken, and which could potentially highlight yet another benefit of biofuels relative to high-sulphur content diesel oil used in Mauritius.

The opacity of exhaust emissions, which is a standard test carried out in Mauritius on vehicles to secure roadworthiness, was also measured. This test was carried out using two different equipments; the Autologic Analyser and a Red Mountain meter.
In order to make comparative studies between biofuels and diesel, the vehicles were run over a distance of at least 15 km between fuel switchovers. This procedure ensured that the first fuel had been displaced by the second in cylinders and fuel lines. Memory or residual effects on emissions upon fuel switchover were not accounted for in this study.

Experiments were carried out at two different times in order to establish reproducibility of results, if not in absolute then in relative terms.

2.2.5 Engine wear & tear

This was investigated at 5000 km interval through analysis of lube oil for wear metal residues (Fe, Cu, Pb, Cr, Al, Sn, Mo and Ni), contaminants (Si, Na, Li), additives (Ca, Ba, Mg, Zn, P, B and K), oil viscosity, fuel dilution, dispersancy, insolubles contents, flash point, moisture content and Total Base Number (TBN)'3. Lube oil used was Caltex Gold Delo, and a sample of virgin lube oil was analysed for reference purposes.

Lube oil analysis was performed by SpectraCare (Pty) Ltd, South Africa, through Chevron (Mauritius) Ltd.

2.2.6 Engine test bed & Dynamometer

The scope of experiments also included laboratory tests on a 1.9 L Ford IDI diesel engine mounted on a test bed and coupled to a dynamometer. Planned tests were: (1) specific fuel consumption, (2) brake horsepower, (3) thermal & mechanical efficiency, and (4) effects of fuel-to-air ratio. We had anticipated to also carry out exhaust emissions tests on the test bed engine to augment the scope of this study.

The only such laboratory set up in Mauritius, housed at the Department of Mechanical Engineering, University of Mauritius, has been out of service for a protracted period of time. Hence, the above tests could not be performed. Nevertheless, the ensuing discussions make reference to results published in the literature.

3.0 RESULTS & DISCUSSIONS

3.1 Generation of WVO (Island of Mauritius)

The volume of WVO generated by hotels & holiday resorts has been kept confidential. WVO in this sector varies between 9% and 8O% of oil used. However, a figure in the range 28 — 38% is applicable to the majority of hotels. The quantity of WVO generated by public hospitals is listed in Table 1 by region. The 384 kg of WVO generated by all hospitals each week corresponds to approximately 417 L, [14] or around 36°h of oil used — i.e. similar to hotels and holiday resorts.

Table 1. Quantity of WVO generated by hospitals.

Region	Oil (kg Used /week)	WVO (kg/week)	WVO **(%)**
1	307	99	32.2
2	501	147	29.3
3	64	22	34.4
4	127.5	53.5	42.0
5	68	62.5	92.0
Total	1067.5	384	36.0

The above figures should be treated with caution since it is difficult to gauge the exact volume of WVO that can be recovered around Mauritius.[15] We suspect that the use of WVO as a replacement for diesel oil will be applicable to operators who have access to WVO. For instance, we are aware that the Mauritius Glass Gallery collects WVO to be used as a fuel in its furnaces used to melt glass.[16]

3.2 Potential to increase the yield of CNO on Agalega

A desk study was performed to investigate the potential to increase the relatively low yield of CNO on Agalega. Through the practices outlined below, it is expected that CNO production can be ramped up in five years to volume equivalent to 7.2 times the volume of diesel consumed in 2007 (i.e. 145,000 L).[17]

1. Land productivity — This can be increased by a factor of 2 within 5 years by adopting the optimum density of palms planted on Agalega. Current practice is sub-optimal because of lack of best management practices of the plantations. For instance, uncollected nuts germinate and grow into mature trees in clusters, or palms destroyed by cyclones are not replanted. Land productivity can also be increased through the use of fertilizers. However, this cannot be practiced on Agalega to avoid pollution of shallow water tables. Composting of green waste is being implemented on Agalega,[18] and experiments will have to be carried out to investigate the impact of compost on the yield of nuts.

2. Palm productivity — The yield of palm nuts can be increased through the use of hybrid palm varieties. OIDC does not intend to start a hybridisation technology programme on Agalega since

existing local tall palm varieties are resistant to cyclones. Hence, no gains have been assumed for palm productivity.

3. Oil extraction efficiency — The outdated expeller used has a efficiency between 25% and 50%. Hence, up to 50% of oil remains in the copra meal, which is used as feedstock for chicken and cattle. It is, therefore, expected that the yield of CNO during extraction can be increased to close to 100% using modern technology. Hence, a yield gain of 2-4 times can be obtained through the adoption of state-of- the-art technology that is currently being investigated by OIDC.

4. Management of plantation — The management of palm plantation is done in a ad hoc way. For instance, palms are not trimmed or nuts are not collected at the right time, and renewal of unproductive trees is not carried out systematically. Best palm plantation practices can easily be adapted to increased yield of nuts by another factor of 2. Work is already being carried out to clear plantations of weeds to make space for: (1) accessing existing palms to collect nuts, and (2) renewal of old palms.

5. Cultivated land — Land area under palm cultivation is planned for increase from 500 ha to 1500 ha, implying a three-times increase in yield.

3.3 Emissions Tests and Engine Wear & Tear

Before considering emissions and engine wear & tear results, the modifications made to vehicle are discussed.

3.3.1 Vehicle modifications

As mentioned above, the vehicles were fitted with a dual-tank system. The designs for the two vehicles were different because of different characteristics of WVO and CNO. A heat exchanger was fitted in each vehicle to pre-heat the biofuel (to reduce viscosity and combustibility) before injection in cylinders. The design of the heat exchanger is proprietory to Mr Michael Chan, but it effectively transfers the heat from water that cools the engine to the biofuel. For the vehicle running on CNO, the tank and fuel lines were also fitted with heat exchangers so that the CNO can be liquefied before combustion. As noted earlier, the vehicle running on CNO had start/stop on diesel, whereas the one running on WVO was run exclusively on WVO after a trial period on diesel start/stop.

Two-tank WVO systems

A fuel diagram is shown in Figure 2 (source: internet). With two-tank SVO kits one tank holds the vegetable oil and the other petro-diesel (or biodiesel). The engine is started on the petro-diesel tank and runs on petro-diesel for the first few minutes while the vegetable oil is heated to lower the viscosity. Fuel heaters are electrical or use the engine coolant as a heat source. When the fuel reaches the required temperature, usually 70-80 deg C (160-180 deg F), the engine is switched over to the second tank and runs on SVO. Before the engine is shut down, it must be switched back to petro-diesel and the fuel system "purged" of vegetable oil before switching off, so that there's no cold veg-oil left to coke up the injectors next time you start the engine. Some systems have manual fuel switches, some do it automatically.

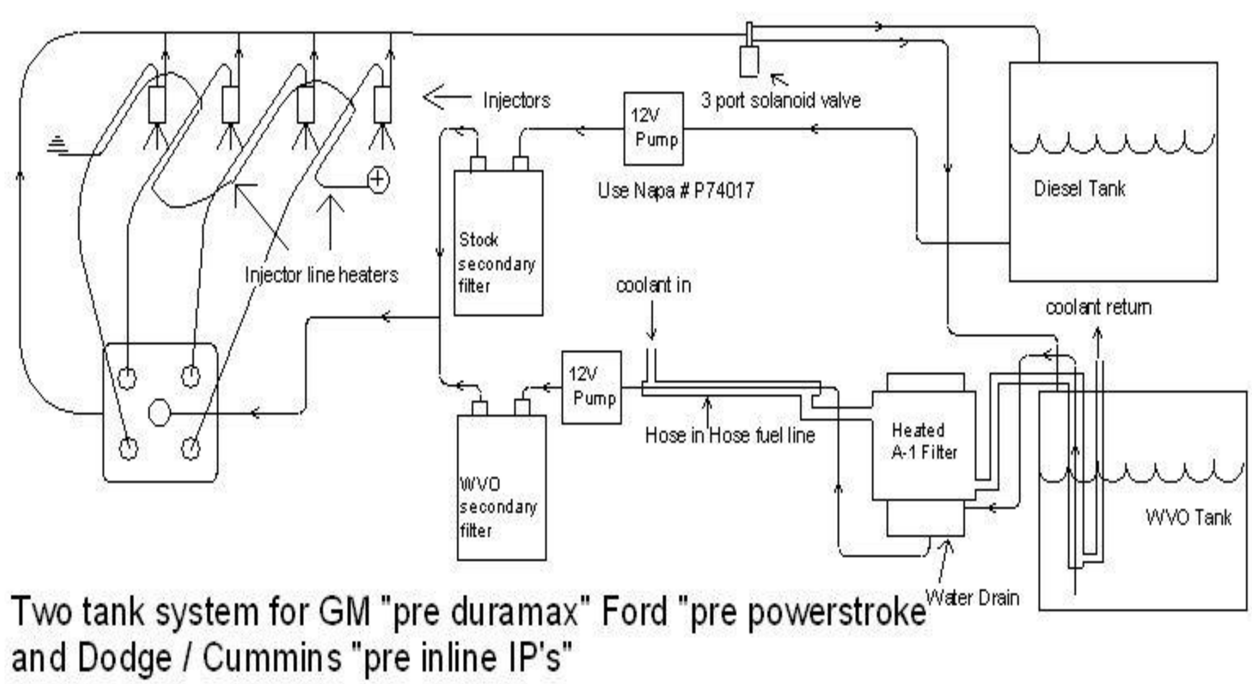

Figure 2. Schematic of Vehicle Modifications

3.3.2 Payback period for vehicle modifications

The costs associated with the above modifications are Rs24,905 and Rs39,125 for WVO and CNO dual-tank systems, respectively. The breakdown of costs are summarised in Table 2, and do not consider scale of economies.

Table 2. Breakdown of costs associated with vehicle modifications.

Items	WVO (Rs)	CNO (Rs)
Heat exchanger	9800	9800
Heater hose	1500	3000
Tank (+ heater for CNO)	80	800
LPG valves	800	800
Oil hose, pumps, filter, fittings, filler	*7725*	10325
Labour	5000	7500
Total Costs	**24905**	**39125**
Payback period (km)	7116	N/A

For ease of use, the payback period has been calculated in terms of kilometres. The effective payback time will then depend on vehicle use.

The payback period (in km) has been computed using:

$$TC \text{ X } FE / \{Pdiesel — [Pwvo \text{ X } WF]\} \quad (1)$$

Where, TC = Total Cost of modification, Rs

FE = Fuel Economy, Km/L

P_{diesel} = Price of diesel, Rs/L

Pwv0 = Price of WVO, Rs/L

WF = Weighting Factor = 1.2 (see endnote 17)

Although no experiments have been performed to measure FE in the laboratory, observations during use have revealed FE 9 km/L. Further, with Pdiesel = 31.50 Rs/L and assuming WVO is obtained free of charge, the equivalent payback period is ‘‘7116 km. This would correspond to a payback period between 3-7 months.[19]

Some operators are selling WVO at Pwvo = 5 Rs/L. In this case, the equivalent payback period is 8790 km — i.e. less than 9 months.

The payback period for CNO has not been computed since its use on Agalega is not entirely motivated by financial aspects of the fuel switch. There are other sustainable development dividends that will accrue from the fuel switch on Agalega. This fuel switch will require the valuation of social and environmental benefits, and also the economic benefits of generating and retaining more wealth within the community, and which are beyond the scope of this study.

3.3.3 Exhaust emissions

Opacity

Opacity data obtained using both analysers are averages of three measurements. Tables 3 and 4 summarize the opacity results for 2829 JU 98 (WVO vs diesel) and 5448 DC 97 (CNO vs diesel), respectively.

Table 3. Summary of opacity data for 2829 JU98 (WVO vs diesel).

Autologic Analyser		**Red Mountain Analyser**	
Diesel (%)	WVO (%)	Diesel (%)	WVO (%)
7.52	**8.28**	**1.56**	**3.2 (4.54)**

Table 4. Summary of opacity data for 5448 DC 97 (CNO vs diesel).

Autologic Analyser		**Red Mountain Analyser**	
Diesel (%)	CNO (%)	Diesel (%)	CNO (%)
6.49	**2.45**	**7.77**	**1.76**

The opacity of exhaust from engine running on WVO is slightly higher than when engine is run on diesel. The difference of 0.76-1.64% between WVO and diesel is well within the estimated experimental error.[21] The situation is reversed for CNO that yields lower exhaust opacity than diesel. The difference between exhaust opacity of the two fuels is also more significant -i.e. 4-6 %. This suggests that CNO is a cleaner fuel than diesel, while WVO is not necessarily the case. The results from other emissions tests support this observation.

Organic-based oils are known to have higher oxygen content than diesel, which results in cleaner burning. However, this is not necessarily true for WVO that has been subjected to high temperature treatments, leading to lower combustibility (due to changes in chemical composition).

The engine temperature (via a probe / temperature sensor immersed in engine oil) is also measured during opacity tests performed using the Autologic Analyser. For both WVO and CNO, the engine temperature was 183.2 F (84°C). Engine temperatures were slightly lower when diesel was used -170.6 F (77°C) for 2829 JU 98 and 161.6 F (72°C) for 5448 DC 97.

The temperature of engines run on either WVO or CNO is higher compared to diesel. This is probably due to the fact that vegetable oils have a significantly higher viscosity (27 — 54 mm2/s) compared to diesel fuel (2.6 mm2/s).[23]

Other Emissions

In this section, the C02, CO and HC emissions are reported. The content of 0_2 in exhaust gases is also discussed. The comparative results for 2829 JU 98 and 4458 DC 97 are summarised in Tables 5 and 6.

Table 5. Summary of emission gases for gases for 2829 JU 98 (WVO vs diesel)

Engine Speed (rpm)		740	2500	3500
CO2 (%)	**diesel**	2.10	2.47	3.25
	wvo	2.14	2.43	3.37
CO (%)	**diesel**	0.015	0.017	0.020
	wvo	0.056	0.020	0.026
HC (ppm)	**diesel**	1	4	6
	wvo	19	13	19
O2 (%)	**diesel**	17.99	17.35	16.24
	wvo	17.72	17.16	15.90

Table 5. Summary of emission gases for gases for 5448 DC 97 (CNO vs diesel)

Engine Speed (rpm)		740	2500	3500
CO2 (%)	**diesel**	2.07	2.39	3.24
	CNO	2.13	2.54	3.48
CO (%)	**diesel**	0.013	0.015	0.020
	CNO	0.036	0.017	0.018
HC (ppm)	**diesel**	8	9	11
	CNO	10	7	7
O2 (%)	**diesel**	17.81	17.19	15.98
	CNO	17.97	17.25	15.98

WVO vs diesel - The most significant difference between WVO and diesel fuel is the much higher emissions of HC from the latter. This is despite the fact that emission of HC from WVO decreased by ~32% from idling speed to 2500 rpm. At 3500 rpm, WVO produced ~3.2 times the concentration of HC than diesel. This marked difference is also most probably due to the degraded chemical composition of WVO (see footnote 22).

The C02 emissions were similar for both WVO and diesel for all engine speeds. Although the concentration of CO was also similar for both fuels at the higher engine speeds, the emission of CO was ~3.7 times higher for WVO than diesel during idling. One possible reason for the slight decrease in HC and CO emissions at higher engine speeds observed for WVO (and CNO) could be the increase in volumetric efficiency of the engine at higher revolutions. However, more experiments will be required to verify this assumption.

CNO vs diesel — Emissions of C02 and CO are similar for both CNO and diesel. An exception is the ‘2.8 times higher CO emission of CNO over diesel during idling (qualitatively similar as WVO). Similar to opacity results, emission of HC is more favourable for CNO than diesel. In this case, the emission from CNO is 25% during idling but it decreased by 22% and 36% at 2500 rpm and 3500 rpm, respectively, compared to diesel fuel.

3.3.4 Engine Wear & Tear[24]

Table 7 summarises the data from analysis of lube oil for vehicles run of WVO and CNO. Data for control sample and vehicle run on diesel oil are also given.

Table 7. Lube oil analysis.

Fuel	**Viscosity**	**Water**	**Flash**	**Diln**	**Insols**	**Disp**	**TBN**
Control	**118.6**	**0.00**	-	-	-	-	11.22
Diesel	**105.4**	**0.02**	**>180**	Negl	0.5	good	10.19
WVO (5000km)	110.9	0.70	>180	Negl	0.3	good	10.40
(10000km)	106.6	0.40	>180	Negl	0.2	good	11.14
(15000km)	101.4	0.00	>180	Negl	0.2	good	10.81
CNO (5000km)	105.5	0.70	>180	Negl	0.3	good	11.22
(10000km)	95.6	0.00	>180	Negl	0.4	good	9.64

The data for metal wear which is a proxy for long-term engine performance, as obtained from lube oil analysis are summarised in Table 8.

Table 8. Metal wear in lube oil.

Fuel	**Fe**	**Cu**	**Pb**	**Cr**	**Al**	**Mo**	**Sn**	**Ni**
Control	**1**	**0**	**0**	**0.0**	0	129.0	0	0.0
Diesel	**34**	**9**	**30**	**4.3**	**3**	**139.4**	**2**	**1.6**
WVO (5000km)	38	26	51	8.2	**2**	**134.0**	**4**	**0.3**
(10000km)	23	19	28	2.2	4	129.6	2	0.2
(15000km)	18	13	24	1.9	4	122.3	1	0.3
CNO (5000km)	30	17	28	3.0	3	129.0	2	0.3
(10000km)	36	21	22	4.8	2	120.9	2	0.2

4.0 CONCLUSIONS

The following can be concluded from the results obtained:

1. Wear and Tear results of WVO & CNO relative to that of the diesel sample were found to be normal.
2. WVO & CNO do produce CO2 but the quantity is no more than that when the engines were run on diesel.
3. The opacity from the exhausts when the engine was run on CNO yielded lower values than that of diesel.
4. WVO & CNO overall tests results indicate they are good substitutes to diesel oil.

5.0 RECOMMENDATIONS

WVO

The use of WVO as a biofuel in diesel vehicles is already being practiced in Mauritius. There are currently six (6) vehicles that are run on 100% WVO in Mauritius. The results reported here should be disseminated to engage more persons or organisations having access to a supply of WVO to make the fuel switch. In particular, the following groups of stakeholders can be targeted immediately:

1. Hotels that are currently paying for the collection and disposal of their WVO. It would be productive to reach hotels through AHRIM. The Beachcomber Group of Hotels should be reached independently since it is not a member of AHRIM;

2. Hospitals through the Ministry of Health & Quality of Life; and

3. SMEs that generate WVO through their business operations (e.g. SMEs involved in the production of deep fried food products such as potato chips, babana chips, and peanuts).

CNO

There are several aspects to the work that will have to be carried out in Agalega.

1. The use of CNO as a biofuel in transportation should be implemented through OIDC. The success of this project will reply on adequate training of personnel to (1) treat CNO — i.e. filtering particulate matter and removal of moisture — before use as a biofuel, and (2) perform regular maintenance on vehicles as carried out in this study. It is pointed out here that the compatibility of engines (i.e. injection mode) with the biofuel should first be investigated. Experiments could also be done in parallel to remove FFAs from CNO; and

2. As mentioned earlier in the introduction, the long-term objective is to make Agalega self-sufficient in its energy needs. In this context, it would be good to experiment on the generation of electricity in Agalega using a mixture of diesel oil and coconut oil produced locally. The technical assistance from the Pacific Islands that are already using CNO biofuel for the generation of electricity could be contemplated to achieve this objective.

Summary

These preliminary results suggest that CNO performs somewhat better than diesel from an exhaust emissions perspective, whereas it is the opposite for WVO. It is proposed that the experiments should be repeated in the near future to investigate reproducibility of results. Further, it may well be that engines could be optimised for leaner burning of WVO and CNO biofuels, which would result in lower exhaust emissions.

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[1] MRC is a statutory body whose role is to advise government on all matters pertaining to Science & Technology, and to influence the direction of technical innovation by funding projects in areas of national priority and encouraging strategic partnerships. The current project covers two of these research priority areas, namely (1) To develop a road map aiming for zero dependency on fossil fuel, and (2) To reduce, Reuse and Recycle for a zero waste Mauritius. MRC's Strategic Plan 2007-2011 can be found at www.mrc.org.mu.

[2] National Environment Strategies for the Republic of Mauritius: National Environmental Action Plan for the Next Decade (Government of Mauritius, July 1999).

[3] Ecofuel Ltd is recycling mineral oil, while the Mauritius Glass Gallery is recovering WVO from some hotels & holiday resorts and large fast food outlets for use as a fuel in its furnaces for melting glass.

[4] Outer Islands Development Corporation Action Plan 2005-2010 (Port Louis, August 2005).

[5] Inhabitants rent houses owned by OIDC at Rs150 per month, which also includes the cost of using electricity. Further, OIDC runs a free transport system for the islanders.

[6] In the past, empty diesel drums were shipped back to Island of Mauritius. However, this practice was recently abandoned due to its high costs. Now empty drums are stacked in the open and no special precaution is taken to prevent residual diesel oil from leaking into the ground. Other sources of pollution to underground water are waste water and solid waste disposal.

[7] Quoted in Joshua Tickell, From the Fryer to the Fuel Tank — The Complete Guide to Using Vegetable Oil as an Alternative Fuel (Environmental Publications International, Covington, 2000), pg. 23.

[8] Jan Cloin, Coconut Oil as a Biofuel in Pacific Islands-Challenges and Opportunities; TW Ryan III, LG Dodge and TJ Callahan, The Effects of Vegetable Oil Properties on Injection and Combustion in Two Different Diesel Engines, J. Am. Oil Chem. Soc. 61(10), 1610 (1984); J Tickell, From the Fryer to the Fuel Tank — The Complete Guide to Using Vegetable Oil as an Alternative Fuel (Environmental Publications International, Covington, USA); P Calais and AR Clark, Waste Vegetable Oil As A Diesel Replacement Fuel -www.shortcircuit.com.aulwarfalpaper/paper.htm (accessed 12 April 2008); J Cloin, Coconut oil as a fuel in the Pacific Islands, Natural Resources Forum 31(2), 119 (2007).

[9] Thermal Efficiency of Coconut Oil as a Compression Fuel, Research Report No 76 (James Cook University, Townsville, 1983); Jan Cloin, Coconut Oil as a Biofuel in Pacific Islands -Challenges and Opportunities.

[10] A Leplus, Biofuel Energy from Coconut in Pacific Islands — The Lory cooperative pilot project, MSc Thesis (University of Wageningen, 2003); P Courty, G. Valtilingom and A Liennard, Copra Bio-Fuel for a Sustainable Decentralised Rural Electrification, 2000.

[11] J Cloin, Coconut oil as a fuel in the Pacific Islands, Natural Resources Forum 31(2), 119 (2007).

[12] The average yield of CNO can vary between 600 and 1350 kg/ha [James A Duke, Handbook of Nuts (CRC Press, Boca Raton, 2001, pg. 105]. Converting using ρ_{cno} = 924.27 kg/m^3 (at 15°C) gives CNO yields in the range 648-1458 L/ha.

[13] Total Base Number is reported in mg HC1/gm sample, and measures the basic (alkaline) constituents in the oil due to corrosion inhibitor additives or contaminants.

[14] Corresponds to 0.417 m3/week (or 417 L/week) if a density of 920 kg/m3 is assumed. Generally, the density of vegetable oils vary by only 10%.

[15] It can be assumed that the generation of WVO by households is virtually zero in Mauritius. The general practice is for oil to be recycled during cooking.

[16] Private communication with Mr Rose, General Manager of the Mauritius Glass Gallery.

[17] Based on calorific values, it has been assumed that 1.2L of CNO is equivalent to I L of diesel oil. Same applies for most other plant oil biofuels.

[18] Private communication with Mr Davay, General Manager of OIDC [Monday 9 June 2008].

[19] The upper bound is obtained assuming a cumulative mileage of around 12,000 km per year. Commercial users are assumed to accumulate at least twice this distance per annum.

[20] Two sets of measurements were performed. The difference between the two values could be due to the combination of (i) experimental (systematic and random) errors and (ii) non-homogenous quality of WVO.

[21] The technical experts at NTA have mentioned that a 5% absolute point can be taken as the maximum error for opacity measurements.

[22] Waste Vegetable Oil As A Diesel Replacement Fuel, Phillip Calais and AR (Tony) Clark, Environmental Science, Murdoch University, Perth, Australia, pcalais@ieee.org, Western Australian Renewable Fuels Association Inc, tony.clark_NO-SPAM@arach.net.au

[23] Engine Manufacturers Association, Use of Raw Vegetable Oil or Animal Fats in Diesel Engines, March 2006; (www.enginemanufacturers.org, accessed on 24 January 2007).

[24] www.usoilcheck.comloilcheck/services