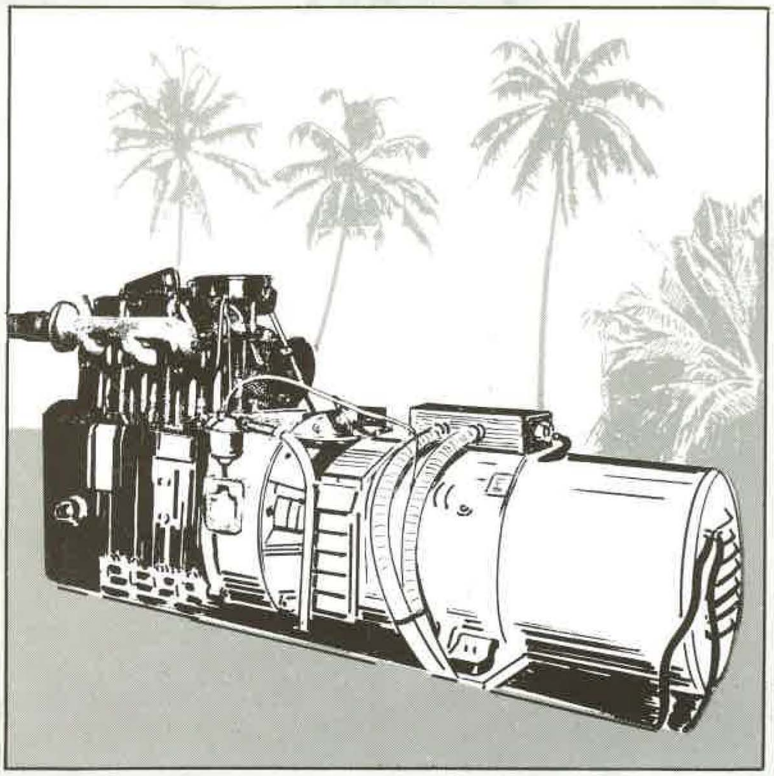
The use of coconut oil/diesel blends as a fuel for compression ignition engines (ODNRI Bulletin No. 31)

Bulletin No. 31

ODNRI

THE USE OF COCONUT OIL/DIESEL BLENDS AS A FUEL FOR COMPRESSION IGNITION ENGINES



OVERSEAS DEVELOPMENT
NATURAL RESOURCES INSTITUTE

BULLETIN

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THE USE OF COCONUT OIL/DIESEL BLENDS AS A FUEL FOR COMPRESSION IGNITION ENGINES

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Summaries

SUMMARY

This bulletin describes experimental and evaluative work carried out by the Overseas Development Natural Resources Institute (ODNRI) to investigate fuelling of a standard compression ignition engine with blends of coconut oil and diesel. Initial studies were made of fuel-related properties for pure coconut oil and for a full range of blends with diesel. A major upgrading of the standard engine's fuel filtration system was necessary but thereafter it was found that a blend of 80% coconut oil in diesel, when heated to 45°C, provided a technically feasible substitute fuel. A limited duration engine trial was completed with this alternative arrangement to assess maintenance and operational requirements. On the basis of these results a preliminary economic evaluation was made of the potential for wider adoption of this type of substitute fuelling. Whilst this indicated that at prevailing prices of coconut oil relative to diesel this was unattractive, circumstances were identified in which this technology could have potential application.

RESUME

Ce bulletin décrit des travaux expérimentaux et évaluatifs qui ont été entrepris par l'Institut pour le Development des Resources Naturelles des Pays d'Outre Mer (Overseas Development Natural Resources Institute (ODNRI)) sur la possibilité d'alimenter un moteur à ignition à compression standard au moyen de mélanges d'huile de noix de coco et de carburant diesel. Des études initiales ont été faites sur les propriétés en tant que carburant de l'huile de noix de coco pure et de toute une gamme de mélanges avec le diesel. Il a fallu améliorer sérieusement le système de filtrage standard du moteur, mais on a constaté ensuite que l'utilisation d'un mélange de 80% d'huile de noix de coco dans du diesel, chauffé à 45°C, fournissait un carburant de remplacement techniquement fiable. Un essai de moteur d'une durée limitée a été complété avec ce carburant, afin d'en vérifier les exigences d'entretien et opérationnelles. Sur la base des résultats une évaluation économique préliminaire a été faite du potentiel d'adoption plus générale de ce type de carburant. Bien que cela ait indiqué qu'au rapport actuel des prix entre l'huile de noix de coco et le diesel, le remplacement ne serait pas intéressant, on a pu définir des conditions dans lesquelles cette technologie pourrait avoir un potentiel d'utilisation.

RESUMEN

Este boletín describe los trabajos de carácter experimental y de evaluación realizados por el Instituto de Desarrollo de Recursos Naturales de Ultramar (Overseas Development Natural Resources Institute (ODNRI)) por cuanto al empleo de mezclas de diesel y aceite de coco como combustible para un motor normal de ignición por compresión. Si bien fue necesaria una importante mejora del sistema de filtrado de combustible del motor, pudo comprobarse que el empleo de una mezcla del 80% de aceite de coco en diesel, calentada a 45°C, constituía un combustible técnicamente viable. También se realizó una prueba de duración limitada del motor utilizando este combustible alternativo, a fin de evaluar los requisitos funcionales y de mantenimiento necesarios. Sobre la base de los resultados, se llevó a cabo una evaluación económica preliminar de su potencial, con vistas a una adopción más generalizada de este tipo de combustible. Y aunque dicha evaluación indicó que, a los precios prevalencientes para el aceite de coco y en relación con el diesel, carecía de atractivo, fue posible identificar circunstancias en las que esta tecnología podria tener aplicación.

The use of coconut oil/diesel blends as a fuel for compression ignition engines

INTRODUCTION

The supply of energy can be a major problem for less developed countries which are highly dependent upon imported petroleum products. Through its biomass energy programme the Overseas Development Natural Resources Institute (ODNRI) is assisting such countries to reduce this dependence by promoting greater use of fuels derived from their renewable plant resources. One such application, identified in the Pacific Islands, was for alternative fuelling of diesel engines used to power process machinery in the coconut industry. The supply of diesel fuel to remote island areas is both expensive and unreliable and so if it were possible to demonstrate that coconut oil could be used to supplement diesel fuel then the economic benefits to such areas could be considerable. The broad Project objectives were to:

power a compression ignition engine fuelled by coconut oil/diesel blend

and

assess the influence of coconut oil quality on engine performance.

The investigation included a comprehensive literature survey to assess the nature and impact of work already undertaken in this area, filtration tests to determine filter life, laboratory work to compare the physical characteristics of the blends with those exhibited by commercial diesel fuel, a pre-trial engine assessment of coconut oil/diesel blend suitability, a 500-h duration engine trial and a preliminary assessment of the economics of the system.

REVIEW OF LITERATURE

The interest in vegetable oil fuelled diesel engines has a long history. As early as 1900, Rudolf Diesel operated engines on such oils but their use for powering engines was never fully exploited because of the abundance of petroleum and coal-tar products. Conventional diesel fuel oil is derived from the distillation of crude mineral oil. Specifications for diesel fuel include the parameters pour point (its lowest flow temperature) and viscosity. These are particularly important since the fuel must flow at ambient temperature and be atomized on injection to ensure a controlled and constant burning rate in the combustion chamber.

Coconut oil is liquid at temperatures above 26 °C, becomes cloudy and forms solid particles in the temperature range 20–26 °C, and solidifies at temperatures below 20 °C (Solly, 1980). This is in contrast to diesel which solidifies in the temperature range −20 to −10 °C (Solly, 1980). The chemical properties of vegetable oils are different from those of diesel oil. Vegetable oils consist predominantly of glycerol esters of fatty acids (triglycerides) with typically 57 carbon atoms per molecule, e.g. sunflower oil (Child, 1941). Diesel oil generally has 16 carbon atoms per molecule. This difference in chemical structure between diesel oil and vegetable oils results in variation of fuel properties, particularly the increased viscosities of vegetable oils (Harrington, 1982). Transesterification of vegetable oil with a suitable alcohol reduces the number of carbon atoms to a maximum of 18 per ester molecule (Banjon, 1981). Through transesterification, fuel-related qualities of vegetable oils, particularly viscosity, are significantly improved compared to the untreated vegetable crudes, but the cost of producing the esters is prohibitive compared to diesel fuels (Cross, 1985). Incomplete combustion of coconut oil is reported to produce a toxic chemical, acrolein, and other polynuclear aromatic hydrocarbons; these emissions are much reduced if esterified coconut oil is used (Banjon, 1981; Mills and Howard, 1980). Notwithstanding the theoretical advantage of using transesterified coconut oil there have been various reports on the successful use of untreated coconut oil as a diesel fuel substitute.

Coconut oil as a substitute fuel

The use of coconut oil to fuel diesel engines dates back to 1933 (Child, 1941). Early experiments suggested that coconut oil fuelling of engines caused injector problems and frequent decarbonization was required. In more recent trials on engines fuelled with 50% blend of coconut oil in diesel, Solly (1982) reported a successful operation over an 18-month period. A 10-HP engine was also reported to have been operated successfully over a 2-year period fuelled by 100% coconut oil in Vanuatu (Solly, 1982). In another trial, Dela Paz (1983) successfully carried out a 115 km road test using a diesel engined pick-up vehicle fuelled by a 25% blend of coconut oil in diesel. In addition, studies have been carried out with blends of coconut oil in kerosene. Mongkoltanatas and Amnauypongsa (1984) found that the performance of an internal combustion engine was comparable when fuelled with diesel or a 20:1 mixture of coconut and kerosene. They reported that some aspects of the process needed further investigation, particularly the long-run effects on engine components and the economic feasibility.

Vegetable oil as a substitute fuel

The use of other vegetable oils such as palm oil, soyabean oil, cottonseed oil, sunflower seed oil and groundnut oil as diesel fuel substitute has been studied extensively. Whilst it has been established that a compression ignition engine will operate on a mixture of diesel fuel and vegetable oil, there are numerous engine-related problems that make the fuel a less practical substitute for diesel. The increased viscosity of the vegetable oils leads to poor atomization and incomplete combustion (Geyer *et al.*, 1984). Other problems include coking of injector nozzles, sticking piston rings, fuel system clogging and polymerization during storage (Solly, 1982; Geyer *et al.*, 1984).

EXPERIMENTAL TRIALS ON FUEL CHARACTERISTICS

Preliminary testing of the fuel filter and fuel supply system

To assess the performance of the fuel filter and fuel supply system, trials were carried out at high coconut oil concentrations using a standard filter with a standard gravity fuel feed or a fuel feed using a lift pump. The life of the filter using diesel was quoted as 1000 h. The results of the trials with coconut oil were:

under standard gravity feed conditions, using 100% coconut oil, the filter blocked after 10 h;

with a simulated lift pump feed, although an improvement in the total volumetric flow rate was obtained, the filter again blocked after 10 h;

with a 90% (by volume) blend of coconut oil in diesel and a simulated lift pump feed, filter operation was extended to 20 h;

running two standard filters in parallel made no significant difference.

The trials showed that coconut oil severely reduced the filter life and that the standard filter with a gravity feed would not be practical under these conditions. For this reason a substantially larger filter, in conjunction with a fuel lift pump, was used for the 500-h duration engine trials. For the preliminary assessment of the engine performance the manufacturer's supplied fuel filter and gravity feed system were used.

Determination of the physical properties of coconut oil, blended fuel and diesel

To understand the nature of the fuel blends and to select an appropriate level of blend, investigations of certain physical properties, which are related to performance, were carried out. The properties studied were viscosity, calorific value, moisture content, free fatty acid content, pour point, saponification value, iodine value and lubricity. Descriptions of the test methods used are given below.

Viscosity. The viscosity has a direct effect on the performance of an engine because of its influence on the flow characteristics of fuel. The fuel supply system becomes inefficient if a continuous flow of fuel cannot be maintained. Testing was carried out in accordance with British Standard BS2000: Part 71 (1982), *The determination of kinematic viscosity of transparent and opaque liquids and calculation of dynamic viscosity.*

Calorific Value. The calorific value of fuel mixtures is required for the calculation of energy balances for the engine system and for the comparison of energy values between fuels. It was determined with a bomb calorimeter following the method used in British Standard BS4379 (1968).

Moisture Content. The moisture content of the oil mixture has a significant effect on the amount of energy available from combustion. Any water present will need to be converted into gas, which will require energy released during combustion. Moisture content was determined by freezing a sample of approximately 40 g of oil at a temperature of −30 °C, and then freeze-drying it for approximately 36 h.

Free Fatty Acid Content. A higher value of fatty acid content indicates a greater viscosity. Free fatty acid content was expressed as a percentage of lauric acid using, as a guide, British Standard BS684: Section 2.10 (1976/1983), *Determination of acidity, acid value and mineral acidity.*

Pour Point. This property is useful in specifying the range of operating conditions because if the pour point is higher than the maximum operating temperature then problems will be encountered with the solidifying of the fuel mixure. Pour point is the lowest temperature, expressed as intervals of 3 °C, at which the oil is observed to flow under prescribed conditions. Determinations were carried out using British Standard BS2000: Part 15 (1982), *Pour point of petroleum oils.*

Saponification Value. This is an indication of the chain length and hence the viscosity of the oil. Saponification value was expressed as the number of milligrams of potassium hydroxide required to saponify one gram of the fat. Tests were conducted in accordance with British Standard BS684: Section 2.6 (1977/1983), *Determination of unsaponifiable matter.*

Iodine Value. This is a measure of the unsaturation of the fat. The higher the iodine value the more unsaturated and hence the more liquid the fuel will be at a given temperature. Iodine value was expessed as the number of grams of iodine absorbed by 100 g of the fat, in accordance with British Standard BS684: Section 2.13 (1976), *Determination of iodine value.*

Lubricity. In these tests comparison is made of the ability of the fuel to form an adhesive film of molecular dimensions necessary to prevent wear and minimize friction when the fluid film created by the fuel has broken down. The tests were carried out by the Industrial Unit of Tribology, Leeds, United Kingdom and full details are given in Appendix 1.

The coconut oil used throughout the trials was processed by the Oilseeds and Edible Nuts Section of ODNRI from copra, originating from Solomon Islands. The quality of the oil was comparable to that found in an island processing situation. The physical properties of the coconut oil, a blend of 80% (by volume) coconut in diesel, and diesel are given in Table 1.

Table 1

Physical properties of coconut oil, a blend of 80% coconut oil in diesel and diesel

Sample	Kinematic viscosity ($m^3/s \times 10^{-6}$)		Calorific value (MJ/kg)	Moisture content (%)	Free fatty acid (%)	Pour point (°C)	Saponification value	Iodine value
	25 °C	37.8 °C						
Coconut oil	49.35	29.56	37.12	0.1–0.5	5.3	19	265.4	9.9
Blend of 80% coconut oil in diesel	32.53	19.69	38.52	—	4.4	14	219.8	9.9
Diesel	5.41	3.37	44.69	—	—	−10	—	—

The relationship of temperature with viscosity and density

A series of experiments was carried out to determine the effect of temperature on the viscosity and density of diesel and a blend of 80% coconut oil in diesel.

The kinematic viscosity of diesel and a blend of 80% coconut oil in diesel was determined at various temperatures in the range, 20–90 °C. The density of each fluid was also determined so that the dynamic viscosity could be calculated.

$$\text{kinematic viscosity} = \frac{\text{dynamic viscosity}}{\text{density}}$$

The results for diesel and a blend of 80% coconut oil in diesel are shown in Tables 2 and 3 respectively.

Table 2

Viscosity and density measurements for diesel

Temperature (°C)	Kinematic viscosity ($m^2/s \times 10^{-6}$)	Density ($kg/m^3 \times 10^3$)	Dynamic viscosity ($kg/ms \times 10^{-3}$)
26.1	5.08	0.8406	4.27
34.4	4.08	0.8350	3.41
44.8	3.25	0.8277	2.69
54.7	2.62	0.8209	2.15
66.2	2.21	0.8096	1.79
74.5	1.89	0.8070	1.53
85.4	1.70	0.7990	1.36

Table 3

Viscosity and density measurements for a blend of 80% coconut oil in diesel

Temperature (°C)	Kinematic viscosity ($m^2/s \times 10^{-6}$)	Density ($kg/m^3 \times 10^3$)	Dynamic viscosity ($kg/ms \times 10^{-3}$)
26.2	29.75	0.9025	26.85
36.1	20.91	0.8970	18.76
45.4	15.35	0.8896	13.66
56.2	11.01	0.8816	9.71
65.4	8.70	0.8773	7.63
75.2	7.00	0.8697	6.08
85.3	5.67	0.8654	4.91

Diesel and the blended fuel show a similar reduction in density with increased temperature, although the absolute figure is always lower for diesel. The viscosity of the blend at 86 °C is similar to that of diesel at 26 °C.

Change in calorific value of fuel with temperature

Increasing the inlet temperature of the blended fuel would cause some reduction in engine performance because the fuel injection system works on volumetric basis. Using the formula,

$$CV_{vol} = D_t \times CV_{mass}$$

where,
CV_{vol} = volumetric calorific value (MJ/m^3)
D_t = density of fuel (kg/m^3) at temperature, t (°C)
CV_{mass} = mass calorific value = 38.67 MJ/kg for a blend of 80% coconut oil in diesel,

a decrease in density as the temperature rises results in a lowering of the volumetric calorific value. The effect of temperature on the volumetric calorific value for a blend of 80% coconut oil in diesel is shown in Table 4.

Table 4

Volumetric calorific value for a blend of 80% coconut oil in diesel with respect to temperature and density

Temperature (°C)	Density ($kg/m^3 \times 10^3$)	Calorific value ($MJ/m^3 \times 10^3$)
20	0.9121	35.27
30	0.9016	34.86
40	0.8930	34.53
50	0.8854	34.24
60	0.8786	33.98
70	0.8728	33.75
80	0.8670	33.53
90	0.8619	33.33

Outcome of experimental trials

The experimental trials on fuel characteristics established that:

the lubricating properties of the coconut oil/diesel blend are not inferior to those of diesel;

the viscosity of the coconut oil/diesel blend undergoes a six-fold change within the temperature range 20–90 °C, whereas diesel has a three-fold change; this can be explained by the fact that, at these temperatures, the blend is closer to its pour point of 14 °C, in contrast to diesel whose pour point is −10 °C;

the flow properties of the blended fuel can be manipulated through temperature adjustment and the viscosity of the blend at 85 °C approaches that of diesel at 26 °C;

a blend of 80% coconut oil in diesel at 85 °C would have a volumetric calorific value of 33.45×10^3 MJ/m^3 which is approximately 5% less than the volumetric calorific value at 26 °C;

a compromise temperature of about 45 °C was selected for fuel injection which was sufficient to minimize filtering and atomization problems whilst not resulting in a large reduction in the fuel volumetric calorific value.

PRELIMINARY ASSESSMENT OF THE ENGINE PERFORMANCE AT VARIOUS BLENDED FUEL CONCENTRATIONS

Before undertaking a 500-h duration trial operating on a blended fuel, an assessment was made of the engine's power output and fuel consumption with diesel, coconut oil and blends of 10%, 20%, 30%, 70% and 90% (by volume) of coconut oil in diesel.

Equipment

The equipment consisted of a Petter compression ignition engine (Type P600/3) coupled to an alternating current generator rated 400/230 V, 24.6 amp. The engine was designed to run at an operating speed of 1500 rev/min, and performance and technical data are given in the Petter Diesel Engine Handbook, No. 360648. The generator was manufactured by Newman Generators Ltd, of the type BKB, self-exciting and self-regulating. The engine and generator were housed in an acoustic chamber fitted with a fan to cool the unit.

Fuel was delivered through a twin burette, designed to allow switching of the engine's operation from diesel to a blended fuel. Surplus fuel from the injectors was routed back to the burettes. The fuel system was fitted with an 'Isopad' trace heating method to keep the temperature of the blend above its pour point, and thus prevent solidification. The fuel filtration system was supplied by the manufacturer and the fuel was gravity fed to the fuel-metering pumps.

Generator power, voltage, current and frequency readings were displayed during each run on an electronic digital wattmeter linked to a line printer. The electrical load was of the resistive type and was infinitely variable between zero and full load using a rheostat. Temperatures were measured using a digital indicator linked to chromel-alumel thermocouples.

Experimental design

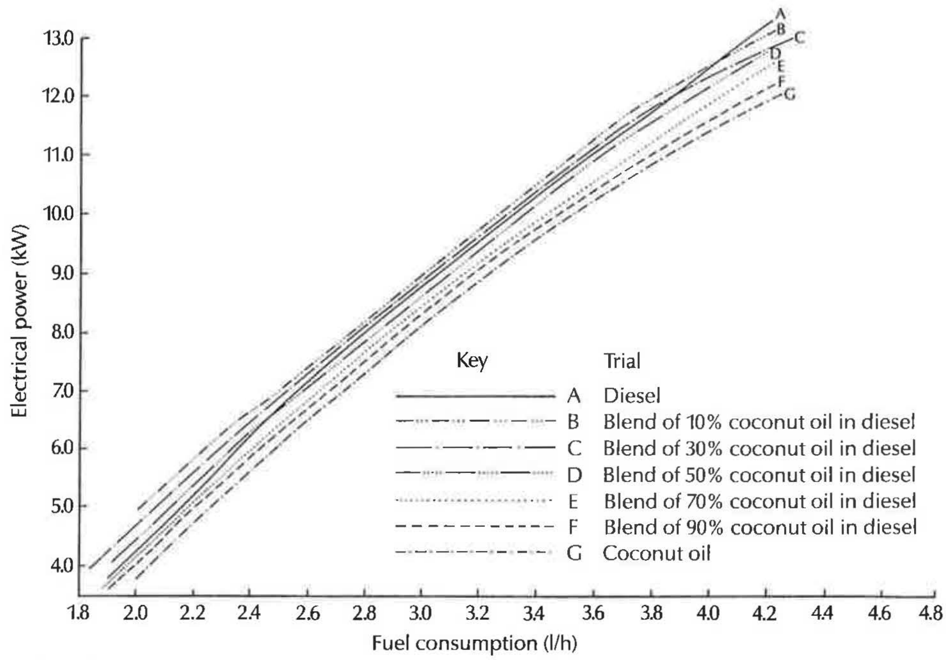
Before each run, the engine was started on diesel and left to equilibrate for 30 min at the desired load and then switched to the blended fuel and left to equilibrate for a further 30 min. After each load setting a further 30-min equilibration period was carried out before taking a set of readings. Fuel consumption was recorded for each blend at various load settings and the system's reaction to overload conditions was recorded during each test.

Results

The results of the trials with coconut oil, diesel and the blended fuels are graphically shown in Figure 1. It can be seen that at higher coconut oil concentrations there is a slight reduction in power output, which is directly proportional to the difference in the fuel's calorific value. It was noted however,

Figure 1

Fuel consumption versus engine power output



that during operation at a blend of 90% coconut oil in diesel, the ability of the engine to accept maximum and overload conditions was slightly reduced. A blend at 80% coconut oil in diesel provided reasonable governing and better load holding.

ENGINE TRIAL OF 500-H DURATION

Test procedure

Following the preliminary assessment of the engine performance, a 500-h engine trial, fuelled with a blend of 80% coconut oil in diesel, was carried out. The blend was chosen on the analysis of performance data obtained during the preliminary trials.

Based on the results of the filter trials, the engine's fuel supply was modified to incorporate a lift pump and a twin cartridge filter system. Compared to the standard filter, the cartridge provided an eight-fold increase in filter surface area. The blended fuel was heated to prevent solidification and improve atomization. Under field conditions this could be carried out using waste engine heat, or by electrical power from the engine's own generator.

The engine was operated for periods of 8 h a day: 7 h at a normal running load of 10.4 kW, followed by 1 h at overload conditions of 11.4 kW. The engine was started up on diesel and after 10 min switched to the blended fuel. On completion of each day's run the engine was switched to diesel operation and purged for about 10 min to ensure that coconut oil would not solidify in the system overnight.

During the trial, data was collected for an assessment of injector and fuel filter performance, and engine wear. Maintenance inputs, fuel and oil consumption, and exhaust, engine oil and fuel temperatures were recorded. Samples of lubrication oil were taken from the sump for analysis and an assessment of the wear was made on the basis of metals in the oil. Inspection of the engine before and after 500 h of running was carried out in conjunction with Lister Petter Ltd.

Results

Fuel supply

The fuel lines containing the blended fuel were heated to prevent solidification and to reduce viscosity. Reduction in the viscosity improved flow and atomization properties of the fuel. The average temperature of the fuel at the filtration stage was 45 °C.

Fuel filter performance

The filter, type 'CAV' manufactured by Lucas, has a quoted life of 1000 h or 3.6×10^3 l when operated on diesel. When operated on the blend of 80% coconut oil in diesel, the filter required changing after 188 and 331 h.

Fuel consumption

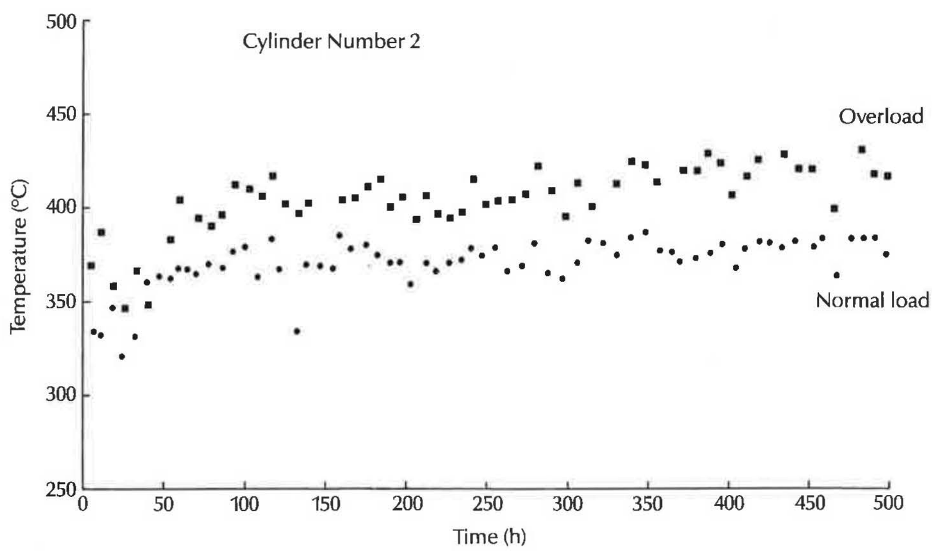
Fuel consumption was recorded during normal load conditions of 10.4 kW engine output and overload conditions of 11.44 kW. Consumption averaged 3.6 l/h and 3.9 l/h respectively. The average specific consumption was approximately 0.345 l/kWh.

Exhaust gas temperatures

The exhaust gas temperature for the three cylinders was monitored at each exhaust manifold branch. A typical temperature plot of one of the cylinders is shown in Figure 2. The temperature probes were located at a specific distance from the machined face of the cylinder head blocks so that results can be compared between cylinders and with the standard Petter methods.

Figure 2

Exhaust gas temperatures



Injectors

The performance of the injectors was monitored by observation of the exhaust manifold gas temperatures. As the trial progressed a conical-shaped build-up of carbon formed around each nozzle. This, however, did not show any marked interference with spray formation and it was evident from looking at the exhaust gas temperature traces that this carbon build-up would continue to a critical point and then break off within the combustion chamber. This is characteristic of diesel-fuelled engines.

Bench testing of the injectors revealed occasional sticking of the injector spindle through what appeared to be a build-up of lacquer over the spindle's surface. This was remedied by cleaning, lapping and re-shimming the injectors.

Engine oil consumption

The engine oil used was Shell Rotella X and the frequency of oil and filter change complied with the engine manufacturer's recommendations. Oil consumption was checked daily and the results are summarized in Table 5. The oil consumption is well within the engine manufacturer's acceptable level of 1% of the value of the fuel consumption.

Table 5

Oil consumption

	Oil consumption rate		
	l/hour	Percentage of the fuel consumption (%)	
		normal load	overload
Excluding oil changes	0.0179	0.50	0.46
Including oil changes	0.0312	0.89	0.82

Engine oil temperature

The temperature of the engine oil was monitored and found to average approximately 110 °C at 10.4 kW engine output and 115 °C at 11.4 kW. These temperatures were slightly above normal United Kingdom operating temperatures because of the insulation effect of running the engine in an acoustic enclosure but low compared to Lister Petter extreme tropical test temperature of 150 °C (see Appendix 2).

Engine oil analysis

Samples of engine oil were taken every 50 h after the initial 250-h oil change. The samples were analysed for wear metal concentrations and additive metal concentrations, see Tables 6 and 7.

Table 6

Analysis of wear metal concentration in lubricating oil samples over a period between oil changes (ppm)

Hours since oil change (h)	Al	Cr	Cu	Fe	Pb	Sn	Mo
Reference	1	1	1	1	1	1	1
50	3	1	5	17	5	1	4
100	5	1	7	30	5	3	4
150	5	3	9	43	6	1	4
200	6	2	6	42	7	2	8
250	6	2	9	60	8	3	8

The wear metal concentration gives an indication of the wearing of engine components over time.

Table 7

Analysis of additive metal concentrations in lubrication oil samples over a period between oil changes (ppm)

Hours since oil change (h)	Ba	Ca	Mg	P	B	Zn
Reference	1	1100	300	1000	6	1500
50	1	1700	440	1300	2	1500
100	1	1300	520	1200	3	1800
150	1	2000	550	1400	4	2200
200	1	2100	520	1300	2	1800
250	1	2000	570	1400	5	2100

The additive metal concentration gives an indication of evaporative losses of the engine oil over time.

The results were examined by Lister Petter Ltd who concluded that the elemental wear debris was normal for the construction of this particular type of engine and evaporative loss of oil was acceptable. An extract of their report is contained in Appendix 2.

In addition, tests were carried out for viscosity, oil condition index (a measure of soot content), triglyceride (coconut oil) contamination and silicon contamination (a measure of dirt in the system). The results are summarized in Table 8.

Table 8

Analysis of lubrication oil samples over a period between oil changes

Hours since oil change	Viscosity at 40 °C ($m^2/s \times 10^{-6}$)	Oil condition index	Triglyceride contamination (%)	Silicon (ppm)
Reference(1)	66	11	0	3
50	47	12	3	5
100	49	14	4.4	9
150	50	15	6.5	10
200	82	22	14	10
250(2)	64	18	7.5	17

Notes: (1) Sample of unused Rotella X oil
(2) An oil leak occurred between 200 and 250 h, approximately 700 cm^3 was lost and replaced with fresh oil

Engine maintenance

During the engine test period the manufacturer's recommended schedule was followed, as detailed in Table 9.

Table 9

Engine maintenance

Interval (h)	Maintenance
50	Clean the oil bath air cleaner and refill.
250	Drain and flush the sump, change the oil filter. Clean any carbon deposits from the exhaust system. Bleed the fuel system, clean the fuel filter bowl and vent holes in the fuel tank cap. Clean and test the injectors. Check valve and decompressor settings. Check the tightness of all the nuts and bolts. Check the fan belt tension.
500	Change the fuel filter element.
In addition to the recommended maintenance, the following was also carried out:	
6.10	Valve and decompressor clearances reset. Fuel line tightened.
34.75	Injectors 2 and 3 replaced.
72.33	Fuel filter bracket tightened.
118.67	New filters fitted.
153.33	Battery replaced.
192.00	Injector fuel return line replaced.
331.83	Fuel filters replaced.

AN ECONOMIC ASSESSMENT OF THE ENGINE PERFORMANCE

This brief assessment is based on operational data obtained from Lister Petter Ltd for the engine on which the ODNRI trials were conducted. The evaluation is based solely on the differences between the capital and running costs for diesel and coconut oil/diesel blends. The comparisons are based on factors and costs prevailing in Sri Lanka but the results for other regions, for example the Pacific Islands, are unlikely to differ appreciably.

The conversion cost and year-to-year maintenance costs are shown in Table 10. It should be noted that a zero entry is given for diesel operation in Year 0 since there are no conversion costs; the basic capital cost of the unit is identical for all options. The maintenance costs are estimated in the knowledge that the blends containing a greater percentage of coconut oil require a higher input of parts and labour each year.

Table 10

Conversion and maintenance cost (US dollars)

		Blended fuel (percentage of coconut oil in diesel)		
Year	Diesel	25%	50%	75%
0	–	450	450	450
1	272	372	502	645
2	272	372	1190	1363
3	991	1091	546	1363
4	272	372	1190	645
5	272	1091	502	1363
6	991	372	1264	1363
7	272	372	502	645
8	272	1091	1190	1363
9	991	372	546	1363
10	272	1091	1090	645

The annual increases in costs for the unit compared with the unconverted unit are given in Table 11. These figures include conversion and maintenance costs at 1987 Sri Lankan rates converted in to US dollars.

Table 11

Increased costs using blended fuel (US dollars)

Year	Blended fuel (percentage coconut oil in diesel) 25%	50%	75%
0	450	450	450
1	100	230	373
2	100	918	1091
3	100	−445	372
4	100	918	373
5	819	230	1091
6	−619	273	372
7	100	230	373
8	819	918	1091
9	−619	−445	372
10	819	918	373

The next stage in the evaluation is the calculation of combinations of the price of diesel and coconut oil such that the difference between the cost of diesel usage and that of diesel/coconut oil blend usage exactly offsets the increase in maintenance cost schedules given above, at a 10% discount rate. The respective fuel consumptions for three engine-loading levels for the models being compared are shown in Table 12. It should be noted that it is technically inadvisable to run a diesel engine on a blend at loading levels below 50%.

Table 12

Fuel consumption at selected blends and engine loading (l/year)

Engine loading	Diesel	Blended fuel (percentage coconut oil in diesel) 25%	50%	75%
50%	3916.8	4032.0	4128.0	4300.8
75%	5856.0	6048.0	6163.2	6528.0
100%	7872.0	8242.0	8580.5	9021.3

On the basis of these fuel consumption figures, the price of coconut oil can be calculated which conforms with the exact difference between the costs of using blended and non-blended fuels. For each blend, at the three levels of engine loading, the value of diesel saved minus the additional costs are used to calculate the net present value (NPV) of total costs using a discount rate of 10% and a 10-year project life (see Appendix 3, Table 1). The annual cost (annuity) is found by dividing the NPV by the appropriate annuity factor (see Appendix 3, Table 2). Dividing the annuity by the annual quantity of coconut oil used gives the maximum price per litre at which using a coconut oil blend would be financially viable at a given price of diesel. The calculated coconut prices are given in Table 13 for three diesel oil price levels.

From the above calculated data and given the recent world price levels and trends for diesel and coconut oil, it will be apparent that the use of diesel/coconut oil blends is consistently uneconomic in comparison with the use of diesel. At current diesel prices in Sri Lanka and the Pacific Region (about 40 US cents/l), any coconut oil price much in excess of 25 cents/l would

Table 13

Coconut oil price necessary to cover cost of blended fuels for different blends, diesel fuel prices and engine loading (US cents/l)

Diesel fuel price (cents/l)	Engine loading (%)	Blended fuel (percentage of coconut oil in diesel) 25%	50%	75%
30	50	3.8	5.5	5.7
	75	11.0	12.6	12.2
	100	13.4	14.7	15.0
45	50	17.0	19.0	18.9
	75	24.1	26.2	25.2
	100	25.8	27.2	27.5
60	50	30.3	32.4	32.1
	75	37.2	39.7	38.1
	100	38.1	39.8	39.9

favour diesel operation; the current world price of coconut oil is around 40-45 cents/l. Even at a diesel price of 60 cents/l, the use of blends remains uneconomic.

CONCLUSION

The 500-h engine operation trial provided the necessary technical information to modify a standard Lister Petter diesel engine (Type P600/3) and define a maintenance schedule for extended operation when fuelled with a blend of 80% coconut oil and 20% diesel oil.

Additional heavy-duty fuel-filtering components were tested and these required more frequent replacement compared to operation with diesel. In the standard routine maintenance schedule with diesel, fuel filters required changing at 1000-h intervals but with an 80% coconut oil blend the schedule time for changing the heavy duty filters was between 100 and 200 h.

Injector performance with this modified fuel-filtering system was not reduced compared to diesel and the prescribed cleaning and testing of injectors at 250-h intervals as in the standard maintenance schedule was adequate.

Lubricating oil quality was monitored and although there was appreciable contamination by the coconut oil it was apparent that wear rates were acceptable. Lubricity testing of the 80% coconut oil blend in diesel indicated that extra engine component wear with coconut oil blends was not a constraint, so it would not be necessary to alter the lubricating oil change interval of 250 h recommended in the manufacturer's maintenance schedule for United Kingdom operation.

A preliminary economic assessment found that while coconut prices are subject to large cyclical fluctuations, a large drop in the price of coconut oil relative to diesel would be necessary before the alternative fuelling option would be attractive financially. However, the Project defined the necessary alterations for engine installation and the associated operational procedures so that fuelling by coconut oil blends could be adopted as a viable technical alternative in areas where local costs were favourable, such as the coconut oil-producing Pacific Islands.

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Appendices

APPENDIX 1: RESULTS OF THE LUBRICITY TESTS

Pin-on-disc testing of diesel fuel and coconut oil

Samples of coconut oil, a coconut oil/diesel mixture and a diesel fuel were submitted to the Industrial Unit of Tribology, Leeds, United Kingdom for an assessment of their boundary lubricating characteristics, as diesel engine fuel pumps are thought to rely on the lubricity of the fuel for adequate operation. Tests were intended to rank fuels in order of lubricity.

The test procedure adopted was based on the one evolved by the Industrial Unit and other laboratories for investigating the boundary lubricating characteristics of aviation fuel, particularly the hydro-fined type. In these tests comparison is made of the ability of lubricants to form the adhesive films of molecular dimensions necessary to prevent wear and minimize friction when the fluid film created by the lubricant has broken down. These adhering films of polar or chemically bonded material separate the metal surfaces of a mechanism and permit satisfactory operating even in unfavourable lubricating situations.

Test details

A 1-mm diameter high-carbon steel pin was loaded against a hardened medium-carbon disc ground to a 0.17 mm surface finish. Disc speed was around 100 rev/min and the track radius was 40 mm. Before each test the flat end of the pin was polished with 600 grade corosil paper and both pin and disc degreased. The three oils were tested under the same conditions using identical procedures and up to 600 g (equivalent to 6 N) on the pin. Tests were repeated to establish a consistent friction pattern for each lubricant.

Friction was measured by mounting the arm carrying the loaded pin on a pivot and restraining the horizontal movement of the arm by a sensitive load cell. The signal from the load cell was fed into a chart recorder.

Between the tests, both disc face and pin were abraded using 600 grade corosil paper and degreased in acetone.

Radiant electrical heating was used to maintain a disc temperature of approximately 70 °C to reproduce conditions similar to those found in an engine-mounted fuel pump.

The test disc was flooded with fuel and centrifuged off at 600 rev/min so as to leave only the immobilized molecules at the surface. The disc was heated at 70 °C before the test.

A continuous friction trace, taken by means of a chart recorder, was taken for 4 min at each 50 g load stage until failure of the surface film was recorded. A comparison of failure loads thus obtained enabled ranking of the specimen fuels in order of lubricity.

Results

Identification

The samples to be tested are identified as follows:

coconut oil 100%
coconut 80%, diesel 20%
diesel 100%

Colour

The coconut oil was a beige solid at room temperature. The 80% coconut oil/diesel mixture was a pink semi-solid at room temperature. The 100% diesel fuel was a reddish clear liquid at room temperature.

Lubricity

The failure load of the lubricant was the load under which the straight steady friction trace became erratic, indicative of the breakdown of the boundary lubricating film.

	Failure load (N)
Coconut oil 100%	2.0
Coconut 80%, diesel 20%	2.0
Diesel 100%	2.0

Comments

All three samples gave a similar performance in this test with the surface film breaking down at 2 N in each case. The level of friction force at the lower load increments was also comparable in each test run.

It appears that under these test conditions the lubricity of coconut oil and the coconut oil/diesel mixture was not inferior to the performance of 100% diesel fuel.

The results suggest that lack of lubricity should not be a constraint on the development of coconut oil based products as engine fuels. However, laboratory bench tests of this type can only be indicative of service performance and fuel pump wear should be monitored in any subsequent engine test programme to confirm these results.

APPENDIX 2: ANALYSIS OF WEAR METAL CONCENTRATION IN THE LUBRICATION OIL

The results of the analysis shown in Table 6 were examined by Lister Petter Ltd, and an extract of their report is given below.

"These results have been compared with similar analyses carried out during our development testing, albeit only running on 100% diesel fuel, on a number of different engines.

With the bulk oil temperature being lower than our extreme tropical test temperature of 150 °C the resultant lower increase in viscosity indicates lower evaporative loss of the lighter fractions of the base stock of the oil. Hence, the level of depletion suffered by the oil would be expected to be acceptable. This is confirmed by the levels of elemental wear debris which are some three times lower than those which occur during our tropical test. All elemental wear debris is normal for the construction of the P600 engine. From these results the oil can be considered satisfactory for an oil change period of 250 h at these conditions."

APPENDIX 3: TABLES OF DISCOUNT FACTORS

Table 1

Discount factors for irregular flows

Rate year	0	2	4	5	6	7	8	9	10	11	12	13	14	15	18	20	25
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	1.000	.980	.962	.952	.943	.935	.926	.917	.909	.901	.893	.885	.877	.870	.847	.833	.800
2	1.000	.961	.925	.907	.890	.873	.857	.842	.826	.812	.797	.783	.769	.758	.718	.694	.640
3	1.000	.942	.889	.864	.840	.816	.794	.772	.751	.731	.712	.693	.675	.658	.609	.579	.512
4	1.000	.924	.855	.823	.792	.763	.735	.708	.683	.659	.636	.613	.592	.572	.516	.482	.410
5	1.000	.906	.822	.784	.747	.713	.681	.650	.621	.593	.567	.543	.519	.497	.437	.402	.328
6	1.000	.888	.790	.746	.705	.666	.630	.596	.564	.535	.507	.480	.456	.432	.370	.335	.262
7	1.000	.871	.760	.711	.665	.623	.583	.547	.513	.482	.452	.425	.400	.376	.314	.279	.210
8	1.000	.853	.731	.677	.627	.582	.540	.502	.467	.434	.404	.376	.351	.327	.266	.233	.168
9	1.000	.837	.703	.645	.592	.544	.500	.460	.424	.391	.361	.333	.308	.284	.225	.194	.134
10	1.000	.820	.676	.614	.558	.508	.463	.422	.386	.352	.322	.295	.270	.247	.191	.162	.107
11	1.000	.804	.650	.585	.527	.475	.429	.388	.350	.317	.287	.261	.237	.215	.162	.135	.086
12	1.000	.788	.625	.557	.497	.444	.397	.356	.319	.286	.257	.231	.208	.187	.137	.112	.069
13	1.000	.773	.601	.530	.469	.415	.368	.326	.290	.258	.229	.204	.182	.163	.116	.093	.055
14	1.000	.758	.577	.505	.442	.388	.340	.299	.263	.232	.205	.181	.160	.141	.100	.078	.044
15	1.000	.743	.555	.481	.417	.362	.315	.275	.239	.209	.183	.160	.140	.123	.084	.065	.035
16	1.000	.728	.534	.458	.394	.339	.292	.252	.218	.188	.163	.141	.123	.107	.071	.054	.028
17	1.000	.714	.513	.436	.371	.317	.270	.231	.198	.170	.146	.125	.108	.093	.060	.045	.023
18	1.000	.700	.494	.416	.350	.296	.250	.212	.180	.153	.130	.111	.095	.081	.051	.038	.018
19	1.000	.686	.475	.396	.331	.277	.232	.194	.164	.138	.116	.098	.083	.070	.043	.031	.014
20	1.000	.673	.456	.377	.312	.258	.215	.178	.149	.124	.104	.087	.073	.061	.037	.026	.012
25	1.000	.610	.375	.295	.233	.184	.146	.116	.092	.074	.059	.047	.038	.030	.016	.010	.004
30	1.000	.552	.308	.231	.174	.131	.099	.075	.057	.044	.033	.026	.020	.015	.007	.004	.001
40	1.000	.453	.208	.142	.097	.067	.046	.032	.022	.015	.011	.008	.005	.004	.001	.001	.000
50	1.000	.372	.141	.087	.054	.036	.021	.013	.009	.005	.003	.002	.001	.001	.000	.000	.000

Source: Reprinted from *Appraisal for projects in developing countries – a guide for economists.* London: Overseas Development Administration, 1988.

Table 2

Discount factors for regular flows

Rate year	0	2	4	5	6	7	8	9	10	11	12	13	14	15	18	20	25
1	1.000	0.980	0.962	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893	0.885	0.877	0.870	0.847	0.833	0.800
2	2.000	1.942	1.886	1.859	1.833	1.808	1.783	1.759	1.736	1.713	1.690	1.668	1.647	1.626	1.566	1.528	1.440
3	3.000	2.884	2.775	2.723	2.673	2.624	2.577	2.531	2.487	2.444	2.402	2.361	2.322	2.283	2.174	2.106	1.952
4	4.000	3.808	3.630	3.546	3.465	3.387	3.312	3.240	3.170	3.102	3.037	2.974	2.914	2.855	2.690	2.589	2.362
5	5.000	4.713	4.452	4.329	4.212	4.100	3.993	3.890	3.791	3.696	3.605	3.517	3.433	3.352	3.127	2.991	2.689
6	6.000	5.601	5.242	5.076	4.917	4.767	4.623	4.486	4.355	4.231	4.111	3.998	3.889	3.784	3.498	3.326	2.951
7	7.000	6.472	6.002	5.786	5.582	5.389	5.206	5.033	4.868	4.712	4.564	4.423	4.288	4.160	3.812	3.605	3.161
8	8.000	7.325	6.733	6.463	6.210	5.971	5.747	5.535	5.335	5.146	4.968	4.799	6.639	4.487	4.078	3.837	3.329
9	9.000	8.162	7.435	7.108	6.802	6.515	6.247	5.995	5.759	5.537	5.328	5.132	4.946	4.772	4.303	4.031	3.463
10	10.000	8.983	8.111	7.722	7.360	7.024	6.710	6.418	6.145	5.889	5.650	5.426	5.216	5.019	4.494	4.192	3.571
11	11.000	9.787	8.760	8.306	7.887	7.499	7.139	6.805	6.495	6.207	5.938	5.687	5.453	5.234	4.656	4.327	3.656
12	12.000	10.575	9.385	8.863	8.384	7.943	7.536	7.161	6.814	6.492	6.194	5.918	5.660	5.421	4.793	4.439	3.725
13	13.000	11.348	9.986	9.394	8.853	8.358	7.904	7.487	7.103	6.750	6.424	6.122	5.842	5.583	4.910	4.533	3.780
14	14.000	12.106	10.563	9.899	9.295	8.745	8.244	7.786	7.367	6.982	6.628	6.302	6.002	5.724	5.008	4.611	3.824
15	15.000	12.849	11.118	10.380	9.712	9.108	8.559	8.061	7.606	7.191	6.811	6.462	6.142	5.847	5.092	4.675	3.859
16	16.000	13.578	11.652	10.838	10.106	9.447	8.851	8.313	7.824	7.379	6.974	6.604	6.265	5.954	5.162	4.730	3.887
17	17.000	14.292	12.166	11.274	10.477	9.763	9.122	8.544	8.022	7.549	7.120	6.729	6.373	6.047	5.222	4.775	3.910
18	18.000	14.992	12.659	11.690	10.828	10.059	9.372	8.756	8.201	7.702	7.250	6.840	6.467	6.128	5.273	4.812	3.928
19	19.000	15.678	13.134	12.085	11.158	10.356	9.604	8.950	8.365	7.839	7.366	6.938	6.550	6.198	5.316	4.843	3.942
20	20.000	16.351	13.590	12.462	11.470	10.594	9.818	9.129	8.154	7.963	7.469	7.025	6.623	6.259	5.353	4.870	3.954
25	25.000	19.523	15.622	14.094	12.783	11.654	10.675	9.823	9.077	8.422	7.843	7.330	6.873	6.464	5.467	4.948	3.985
30	30.000	22.396	17.292	15.372	13.765	12.409	11.258	10.274	9.427	8.694	8.055	7.496	7.003	6.566	5.517	4.979	3.995
40	40.000	27.355	19.793	17.159	15.046	13.332	11.925	10.757	9.779	8.951	8.244	7.634	7.105	6.642	5.548	4.997	3.999
50	50.000	31.424	21.482	18.256	15.762	13.801	12.233	10.962	9.915	9.042	8.304	7.675	7.133	6.661	5.554	4.999	4.000

Source: Reprinted from *Appraisal for projects in developing countries – a guide for economists.* London: Overseas Development Administration, 1988.

Notes: This table shows the discount factors to be used to derive the present value of a stream of uniform values over a number of years. For example a uniform annual flow of £y from years 1 to 10 will have a cumulative PV at a discount rate of 8% of £y multiplied by 6.710. The discount factors in this table are the factors in Table 1 cumulated over the years from Year 1.