Development of a modification kit for diesel engines suitable for PPO

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December 2008

For FACT Foundation

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0. Abstract

This report describes part of the activities executed by PPO Groeneveld of the "Development Traject for Modification Kit for Diesel Engines" of the FACT- Pilot Project Jatropha oil for local development Mozambique. See www.fact-fuels.org

The modification kits are necessary to modify existing diesel engines, mostly mechanically driving maize mills in Cabo Delgado, Mozambique, to run on PPO of Jatropha.

Requirement of the kits:

1. As simple as possible,
2. Lowest cost as possible
3. Materials should be locally available, as much as possible. Minimize importation of parts.
4. Parts like heat exchangers should be possible to make locally in workshops, etc with electricity available and normal equipment for steel work., such as welding equipment, drilling tools, grinders , etc.
5. should be possible to be mounted by medium skilled technicians in the field
6. using normal tools, like spanners (no torque wrenches), hack saws, etc.

1. Introduction

Illustration 1: Agriculture land not in use

The use of vegetable oil does have its disadvantages in modern engines: those are constructed for fuel properties like the modern type of diesel fuel in use. Some adaption is necessary to let the engine run well at its maximum capacity for its predicted life-time. Using vegetable oils also has advantages. Vegetable oil does not contain any sulfur, so no sulfuric acid (acid rain) will be produced. Fossil fuel is a combination of carbon structures ranging from C16 to C18 and nafta, phenol like structures. Vegetable oils are solely composed of chains of C16 and/or C18.

No dangerous goods like the nafta and such. Plant oil has better burning characteristics, giving out less soot.

The document will describe the necessary adaptations to stationary engines of the make of Lister and Feidong (a copy of the Lister/Petter engine from China)

2. Test site and facilities.

The first conversion of the Lister ST3 has taken place at PPO Groeneveld in The Netherlands.

The second conversion of the Feidong engine has taken place in Chimoio, Mozambique at the farm Evretz owned by Brendon Evans.

Brendon Evans is also a mechanic trained in the USA (Caterpillar) and has produced already bio-diesel from cotton seeds which he presses with Chinese presses on his farm.

This farm is chosen as a test location, instead of the project center in Cabo Delgado, because it has a well equipped workshop and trained personnel. An arc welder is available just like a TIG welding device. And Chimoio is a much more developed area than Bilibiza in CD.


Illustration 2: Feidong engine not adapted

Brendon Evans owns a dairy farm, producing cheese (Gouda Gold as trade mark) and other derivate products like yogurt. Most of the products are sold locally by salesman .

Producing the cheese in the factory requires an extensive amount of energy consuming equipment, like a steam boiler for pasteurizing milk, refrigeration engines for cooling and storing products, generator for providing electricity (used as emergency backup due to high fuel prices), water pumps for irrigation of land and a couple of tractor engines (counted 4)


Illustration 3: Freshly pressed cotton oil, red in color

3. Use of pure plant oil (PPO) as fuel

Plant oil that is going to be used as a fuel needs to be of a certain quality and has to fulfill certain criteria regarding contents of: water, particles, phosphor, Fatty Acids, etc.

Since there is no standard yet for PPO from Jatropha, the standard for PPO from rape seed named RK2000 will be used as a standard for maximum allowed values of Phosfor, FFA, particles etc.[1]

1 see also publication at FACT website and appendix 4

3.1 Cleaning of vegetable oil.

Oil noticeably waste cooking oil, contains a lot of dirt and maybe water. Before use the water has to be taken out down to a level of 3% or less. Most of the time this can be done by settling the oil for a long time. About 24 hours will do at a temperature of 30 degrees Celsius. Practical experience learned that a few weeks will be better but make sure that it happens in a container shaded from light and oxygen: oil will deteriorate into solid fats. The acidity level will raise as well.

Boiling of the oil will work but takes a lot of energy, raising the temperature of a batch of oil to 110 degrees Celsius. Using a vacuum pump to lower the boiling temperature of water will save a large amount of energy.

Another way of removing water and dirt would be by centrifugal force, decanting the clean oil. Installations do exist and are used often in the food processing industry. Using decanting devices has the disadvantage of the relative high costs: $25000 for a secondhand installation with a capacity of a 100 liters per hour.

Using simple gravity filtering with a belt filter will be the cheapest solution. Those type of bed filters are often in use for filtering hydraulic oil used with very large hydraulic presses (for example in the rubber industries pressing floor mats, Dunlop Drachten).

For cleaning vegetable oil the filter cloth used is from Kimberly & Clark named Workmans cloth X70. To produce a belt from it, it has to be sown together at the tear-off lines. For pictures of one implementation see pictures. For testing a simple cloth can be put over a jug or a barrel and the oil filtered. With simple method the dirt can be scraped off at regular intervals to clean the filter.

When not sure one can filter the oil multiple times. When only gravity is use as a driving force the mean size of particles going through the filter will be less than 5 mu. Re-filtering will decrease the size of the particles to:

$$\langle \text{mean size} \rangle / \sqrt{N}$$ with N being the number of filtering actions.

On engines the fuel filter normally has a means size of 10 mu so usually 1 time filtering will be enough. The oil should be filtered at temperatures preferably a few degrees below the mean environmental temperatures to make sure that the oil will not become solid after a while.

If the filtering is taken place as means preparing the oil and fats for conversion, it can be done at elevated temperatures: all fats are to be converted anyway. But keep the oil below the temperature grade of the filter cloth: elevated temperature will widen up the mazes, filtering the oil up to 20 mu instead of the intended 5 mu. Using even higher temperature will destroy the cloth. The X70 can stand temperatures up to 55 degrees Celsius.

If using the oil be sure to know the origin of the oil. If the oil has been treated with other type of chemicals, salt like materials might be still in the oil with sizes well below the 5 mu. Salt and other small metallic, hard particles are quite abrasive and will destroy injection pumps and injectors. Metal particles will sink during sedimentation due to the higher density. Salt like material will dissolve much better in water. Water washing of oil will help but, again, takes time and will result in a lot of dirty water which has to be cleaned. Suspicious batches of oil can be best converted to bio-diesel.

3.2 Minimal viscosity.

All current engines have been designed to be fed with fuel of a specified viscosity. For diesel fuel this is set at the range between 1.7 (winter diesel, to be used below 10 degrees Celsius) and 2.4

[centiStokes]. If an engine is running short on fuel it can damage the pressure pistons through lack of lubrication and the injector nozzles will not spray the fuel like a fine mist into the burning chamber. Most of the times the engine will begin producing a lot of smoke and soot (unburned fuel). In the previous shown table the viscosity of most vegetable oils is well above the specified range so engines can run short of fuel. To lower the viscosity one can heat up the oil. Heating it up will be limited by what the engine parts can cope with and the maximum temperature before the oil starts boiling.

If the viscosity will fall below the point of 5 [centiStokes] it will be fluid enough not to run into problems. Viscosity will drop in a hyperbolic way, a curve described by the VanderWaals forces which is depending on temperature like:

$$\text{viscosity} \propto 1 / T^3$$

One can not raise the temperature too much: the injection pump is adding heat to the fuel through the compression. The oil might rise an additional 50 to 70 degrees. Boiling point of most oils will be about 210 to 230 degrees Celsius. So maximum temperature of the oil fed into the pump must be well below 160 degrees. There are other limiting factors: the fuel lines. Although there are special fuel lines capable of handling up to 85 degrees Celsius, this will be the practical maximum temperature of the oil to flow through the flexible fuel lines. The table below shows the drop in viscosity for different type of oils. That the drop in viscosity will not be the same for all type of oils is due to the fact that chemical reactions will take place at elevated temperature.

4. Modification of the Diesel engines.

4.1 Specifications converted diesel engines[2]

Two engines have been converted to run on pure vegetable oil PPO. Specifications of both engines are in the next table.

Engine specifications

	Lister ST3 Engine	Feidong 295 GJ
No cylinders	3	2
Displacement	1899 cc	1630 cc
Specified power	17 kW@1500rpm, 23kW@3000	18kW@2000rpm
Driving chain	Direct drive	V belt
Specific fuel consumption	0.800 kg/hr at 0 load, 1.00 kg/hr at 2kW load 2.00 kg/hr at 8 kW	0.258 kg/hr at 0 load 0.516 kg/hr at 2 kW 2.64 kg/hr at 8 kW (specified)
Exhaust gas temperature	190 C at 0kW (measured) 340 C at 8kW (measured)	170 C at 0kW (measured) 540 C at full load (specified)
Cooling method	Forced air	Water jacket cooled.

Modifications parts specifications

	Lister ST3 Engine	Feidong 295 GJ
2e fuel tank	Stainless steel 40 liters, available	Steel tank, available from Deutz engine.
2e filter with water bowl	Used for connecting three-way valve. Extra protection and visibility of oil. New. NoName make	Used for connecting three-way valve. Extra protection and visibility of oil. Glass was broken, removed. Re-used John Deere
Fuel hoses	Gates ecco fuel lines: max 85 size 10 mm (standard 8)	Standard transparent fuel lines, used for paraffin 10/12 mm (standard 8)
heat-exchanger	Stainless steel 304 1.0 meter	Stainless steel 304 1.0 meter.
ball-valves	Chromed-brass with steel ball	Chromed-brass with steel ball

2 The data for the Lister has been collected from internet sources. Feidong data from manuals supplied. Physical and chemical data used are listed in annex 4 and 6. Other physical properties, including of oil are from CRC 55th handbook of chemistry

4.2 Calculations for heat exchanger[3].

Heating up the fuel oil for lowering the viscosity can be done in different ways: By using the exhaust heat or -in case of a water cooled engine- the cooling water. In any country where temperature is above the cold plug point[4] of the used fuel -about 10 degrees Celsius- there is no need for tank heating. One can circumvent the use of tank heating by using larger fuel lines from the the tank to the heat-exchanger. But applying some heat to the tank will make the flow to the injection pump better.

Calculation beneath are initial made for a Lister ST3 air cooled engine. Added are calculations when using a water-cooled engine. The Lister is using a priming pump, whilst the Feidong does not.

The calculations are available in the form of a separate calculation sheet.

Length pipe	1.000000 m (meters)
Outer diameter pipe	0.015000 m (meters)
Wall thickness	0.002000 m (meters)
Temperature surrounding gas	527.355556 C(deg. Celsius)
Thermal transfer coefficient gas	0.190000 W/m2C (Watt/square meter.degree Celsius)
Heat conduction pipe	5.000000 W/mC (Watt/meter.degree Celsius)
Flow rate fuel	0.000001 m3/s (cubic m per second)
Heat capacity fuel	4200000.000000 J/m3.C(Joule / cubic meters degree Celsius)
Thermal conductivity fuel	W/m2C (Watt/square meter.degree Celsius)
Input heat available	
From gas:	
Rated maximum mechanical power:	15.000000 KW (1000 Watt)
Mechanical power taken:	10.000000 KW (1000 Watt)
Output power:	26.722222 KW (1000 Watt)
To cooling water :	5.016667 KW (1000 Watt)
To exhaust gas:	11.705556 KW (1000 Watt)
Fuel burning value	27.000000 MJ (Mega Joule)
Consumption related to power	0.989712 cm3/s
Fuel consumption/hr	3.562963 l/hr
Transportation speed fluid (m/s)	0.002605
Volume exposed to heat	0.000095
Mean duration of exposion	383.889480
Total amount power entered	5499.126104
Expected temperature raise at exit	13.820449 degrees Celcius

The yellow part is the data considering the heat exchanger: the length, wall thickness and width. The next colored block are heat transfer parameters for exhaust gas and stainless steel. The blue block is concerning the amount of fluid going through the heat exchanger. It is depending on the amount of power used by the engine and the caloric value of the fuel. The red block calculates how the heat power is being divided over the mechanical part, the cooling water and the exhaust fumes. Using power will raise the exhaust temperature allowing to transfer more power to the fuel. Using a

3 Theoretical argumentation for the calculations are in Annex 1.

4 The cold plug point is the point where the fuel filter of the engine would be blocked by solidifying fats from the oil. In appendix 4 most common features of SVO are mentioned.

water-cooled engine a large part of the extra heat will pass on to the cooling water, lowering the exit temperature of the fuel. But not low enough to cause trouble (yet). The cyan block is calculating the fuel consumption during power delivery. The last dark green block is calculating how much the fuel will be heated by the exhaust fumes.

The shown sheet above is an example which has to be calculated for different loads and different assumptions of engine efficiency. Current assumed parameters are:

engine efficiency : 45%

Cooling to water efficiency : 15%

Exhaust heat loss: 40%

In case of air cooled engines the heat loss to the air cooling will be about 2%, with exhaust temperatures well above 250 degrees Celsius (up to a 500). An efficiency of the engine of 45% is quite high. For the Feidong engine it will be about 33%. Efficiencies above 40% can be reached for four-stroke engines with a mechanical power outlet greater than 200 kW but is quite difficult for the smaller sized engines. For the best performance ratio a two-stroke blown diesel engine will be the best choice. A ratio of 52% (Wartisla) will be possible with a power outlet of 60 MW.

4.3 Endurance test performed with Lister ST3.

Using vegetable oil directly as a fuel is possible as has been shown with a 500 hour test with a Lister ST3 engine. The engine was converted to a dual tank system with a spiral wound heat-exchanger attached to the exhaust manifold. The engine does drive a generator of a maximum rated power of 12.5 kW. The age of the engine is about 30 years. The engine was run during day time with a constant load of about 2 kW for 10 hours and a load of 8 kW for 2 to 3 hours. Occasionally the load was a bit higher when using a welding machine (up to 10 kW).

This particular Lister has run for a 350 hours before the test on SVO already. Also other kinds of diesel like fuels had been fed to the engine: pyrolysis oil, gas oil and FAME. The kinds of vegetable oils used are palm oil, soybean oil, sunflower oil, rapeseed oil and mixes of the for mentioned types of oil.

For the test an amount of about 500 liters from a 1000 liters IBC container filled with used cooking oil, mainly sunflower oil, has been used. During the test the engine oil was replaced every 100 hours and checked for amounts of fuel. No fuel related problems did occur during the test. A couple of mechanical failures did occur, most of them related to the old age of the engine (metal fatigue) like a broken fuel-line and totally worn out injectors. Those failures did occur before the test started. Injectors parts (needle and nozzle part) were replaced by new ones, the pressure fuel line welded again and the priming pump metal lever repaired. Except that the priming pump was operating very badly, putting the tanks well above the injection pump level did make the use of a priming pump unnecessary. For a while an electric pump was used to prime the engine. Using an electrical priming pump comes in handy several times when both tanks ran empty: getting the air out of fuel lines is much more easier.

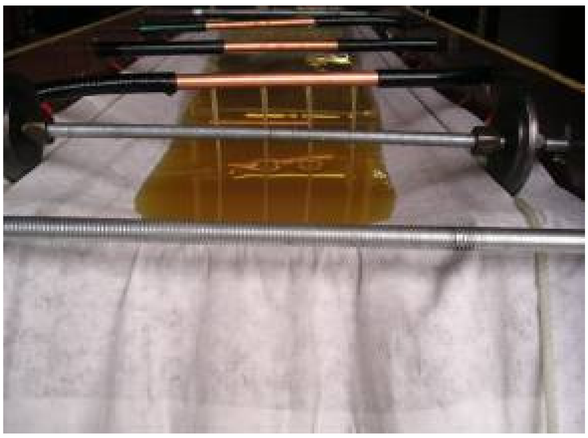

Illustration 4: View on filtering oil an band filter

4.4 Fuel preparation for Lister.

The received cooking oil, mainly sunflower oil, was being filtered with K&C work mans cloth X70. The oil was filtered at environmental temperatures, the same temperatures in the tank of the engine. Fats and food left overs where scraped off the filter cloth at regular times. For part of the filtering a special designed band-filter engine was used to produce the oil at a rate of 30 to 60 liters per hour. This engine is used when the oil used to be contaminated with a lot of hard fats and food material. The filtered oil was stored in a 1000 liter IBC container. The fuel was taken out of the bottom of the container tank.

Free Fatty Acids

When the amount of free fatty acids in the oil is high, being above 3% of content, there is the risk of damaging the engine due to corrosion. Steel, copper, Aluminum (alloys) and such will corrode in due time, especially in high temperature environments. This is not of much concern for engines running full time: the amount of corrosion will be low due to the constant refreshment of burning fuel through all components, especially the nowadays aluminum alloy of the prime fuel pump. The corrosion will occur when the engine is stopped and paused for longer time so it cools down. For corrosion it needs oxygen not being burned away by the fuel. The acid in the fuel will etch off any protective layer of material CuO or Al2O3 exposing the bare metal to the oxygen again. Treating the oil alone with a caustic metal hydroxide compound will take away most of the free fatty acid, returning a soap. The soap can be washed out of the oil by water. The fuel used for the Lister test had a pH of 6.5. Rancy oil has also being used with a pH of 4. Most of it from a batch of not well converted oil

Phosphor contents

None. The waste cooking oil was sunflower oil as found in the Dutch shops. The label notes a phosphor content of zero.

Standard RK2000

Since there is no standard yet for PPO from Jatropha, the standard for PPO from rape seed named RK2000 will be used as a standard for maximum allowed values of Phosphor, FFA, particles etc. (see also publication at FACT website)

4.5 Test with Lister ST3 engine, air cooled.

Engine condition at start of test.

The Lister engine had already run on sunflower oil, fresh and used, with success. Starting the engine by hand at temperatures below 10 degrees was very difficult on sunflower. Due to use of pyrolysis oil of one of the tests all injectors where full of coke. As the injectors were never replaced during it's lifetime a new set of injectors was placed. No replacing of the injector pumps was done: the Bryne injectors did still look reasonable fine. All oil was replaced and the crankcase cleaned with petrol to remove about 30 years of neglecter of proper maintenance. The engine was refilled with 5 litres of SAE 30 engine oil. Fuel filters were replaced and special ecco-fuel lines (Gates ecco-fuel) put into place.

The test

The test was conducted in Kimswerd, Holland during the months December 2007, January, February, March and April in 2008. The test was prolonged for about another couple of months, just to make sure it did work.

Test period	Duration, load	Fuel used	Engine oil	Mean temperature
December	140 hrs, 2kW mean, 8 kW max	Used sunflower 80%, bio-diesel 20%	SAE-30. 40 cc more than added.	6 degrees Celsius
January	80 hrs, 2kW mean, 8 kW max.	Used sunflower 80%, bio-diesel 20%	SAE-30. 60 cc more than added	4 degrees Celsius
February	210 hrs, 2kW mean, 8-10 kW max (welding job)	Used sunflower 80%, bio-diesel 10%, used, filtered cooking oil (palm 30%, soja 20%, rapeseed 50%) 10%	SAE-30, unknown amount added due to leakage of fuel oil in engine oil.	7 degrees Celsius
March	110 hrs, 2kW mean, 8kW max	80% sunflower, 20% filtered waste cooking oil	SAE-30. 50 cc less.	8 degrees Celsius
April	80 hrs, 2kW mean, 8 kW max	70% sunflower, 30% filtered waste cooking oil	SAE-30. None missing.	9 degrees Celsius

Design by example.

The next series of pictures show the parts changed and added. Design of heat exchanger below.

Illustration 5: Overview Lister St3 engine

Illustration 6: Lister second fuel tank

Heat-exchanger performance.

The fuel heated by the heat-exchanger did reach a maximum temperature of 86 degrees at the outlet. Due to the use of non insulated fuel lines (Gates ecco-multi-fuel lines, stated usable to 85 degrees) the temperature dropped to 70 degrees at the first filter and to 65 degrees in the second filter. The second filter being attached close to the motor (original). Because of bad functioning of the prime fuel pump no return fuel was ever returned in the return-lines. The original fuel filter was adapted slightly (drilled a small hole in the connection of the return line) part of the fuel heated was returned to the tank. The amount returned could be regulated with the valves on top of the tanks.

Illustration 5: Heat exchanger and tank view.

During times of rainfall and wet snow the exit temperature of the oil could drop to 50 degrees due to the cooling effect of the water.

Exhaust soot.

Previous to the test, the engine had already run on PPO and the exhaust was redirected into a 1000 liter stainless steel water container. All soot and particles where captured by the water. When run on normal diesel fuel, noticeably a tiny film of unburnt fuel would form. When the water was heated up to 60 degrees this film would disappear. Running on PPO the film did not disappear: PPO has a much higher boiling point.

During all time the acidity of the water did not change, although the existence of NOx in the exhaust expected to give some lower pH value. For sure if any FFA was present in the fuel, it was completely burnt. In picture 10 the Lister was running with a one tank system without heat exchanger: the mean temperature in the greenhouse is well above 15 degrees Celsius.

Illustration 6: Lister soot and exhaust fume test on different kind of fuels

Motor oil condition.

Due to the air cooled engine, the motor oil does become quite hot. A maximum of 110 degrees Celsius was measured. A certain deficiency in the design of this forced air cooled engine: no oil cooler. Any non-English air cooled engine is using oil coolers (aka-heaters). All oil use was due to spillage of oil through leakage out of the engine. No oil was burnt. The oil spillage is also a design error of the Lister engine. During the test the oil level did not change (most of it was burnt out) but did get contaminated with unburnt fuel. PPO high boiling point prevented it to evaporate as normally happens with diesel No 2 fuel. The level of contamination was about 0.5% of the total volume. These are certainly not all blown by fuel: the complete injection system of the Lister is inside the engine. The fuel control handle did leak unburnt fuel before the injection pump pressed it to the injector.

5. Endurance test with a Feidong 295 GJ

5.1 Fuel preparation.

The simple way of filtering was used to collect about a 30 liters of stack burnt cotton seed oil. The oil was filtered by means of the K&C cloth also used for filtering the fuel oil for the Lister. The amount of garbage and solid fats in the oil was much less than the WVO used for the Lister. All oil was filtered with only two pieces of cloth.

FFA content.

All oil was treated with caustic soda on forehand to remove most of the color and removal of the FFA. For the stack burnt cotton oil used the color of the oil was still dark colored but transparent after filtering. The reason for the treatment is that the oil is also sold as cooking oil. The stack burnt oil is too much off color to be sold as such.

Illustration 7: Filtering oil with K&C Cloth in storage bottle, sack like construction

Phosphor content

All oil pressed at the Evertz farm is pressed cold. The phosphor contents is therefore not high. A sample is being asked for to investigate for content.

5.2 Test with Feidong 295 GJ, water cooled.

Condition of engine.

Brand new state, oil colorless. Excessive smoking from exhaust from start on any type of fuel. A noticeable remark on the general state of Chinese made machines: very badly constructed and tuned. Due to lack of better replacement parts no changes have been made.

First test.

After filtering the oil the engine was run for a couple of hours with unheated oil. The filter arrangement and fuel lines had been adapted already but fitting both lines to the engine was a bit cumbersome due to a lack of parts. A lot of parts have been scavenged from the private scrapyard, a few pieces have been bought in town.

The Feidong engine is not equipped with a prime pump, so bleeding the engine to get the air out was a bit cumbersome. Addition of a filter with a hand pump would help out, especially when the engine is not being used every day.

Also the Feidong is not equipped with an electrical starter, starting it to get the air out or starting directly on vegetable oil is a lot of labor. We took care to make the fuel lines as short as possible so before shutting down the engine it will be switched to fossil diesel again to clean all filters and fuel lines.

5.3 Modification kits as constructed.

Producing an exact copy of the Lister equipment is not very useful: the availability of parts locally will differ to much from the situation in Holland to the situation in Mozambique. Some parts have been taken from Holland, like the filter-cloth and heat exchanger materials because it is already known those materials have to ordered weeks in advance in countries like Mozambique.

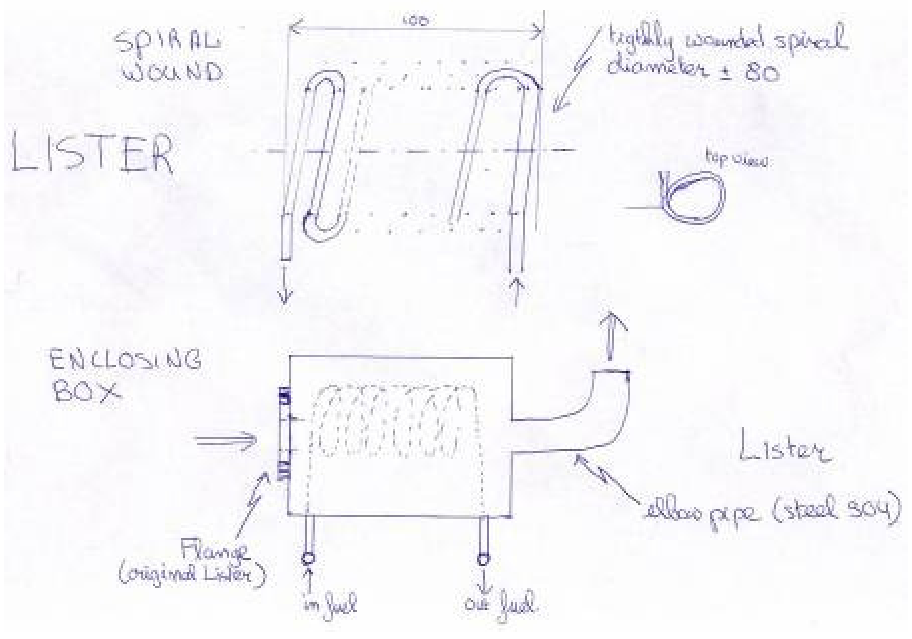

Illustration 8: Construction design Lister spiral wound heat exchanger

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Design considerations: For the Lister a spiral wound heat exchanger is used for multiple reasons:

1. The mixing of the fuel in the heat exchanger. With very low transport rate through the fluid the flow will be laminar in a straight pipe. Essentially the flow rate at the inner walls of the tube is than zero. By winding the pipe into a spiral a turbulent flow will be forces, mixing and heating all of the fuel evenly
2. Size. The 1 meter pipe used in the Lister is wounded into a just 10 cm long spiral with a diameter of 100 mm maximum. Having a short pipe like this guarantees that the temperature of the engulfing exhaust fumes will be the same everywhere.
3. The Lister has a prime fuel pump. The pump used (both the mechanical and the electrical) guarantee a flow of fuel to the injection pump. The increase of flow resistance of every bend is equivalent with about 1 meter of straight pip, thus giving an equivalence of about 8 meters of pipe. Not a problem for the fuel pumps.
4. Spiral in closed box. Originally the design did not include a box. By exposing the material to the outside, a better control of the fuel temperature could be arranged by isolating the spiral more or less. The box was added for convenience of installing the heat exchanger.

The basic engine is a Feidong 256 G, two cylinder indirect injected diesel without electric starter and without prime fuel pump. To start such engines by hand requires a start at the first try otherwise turning the machine will be to much of an effort. If a machine is to be run on SVO/WVO solely it should have an electrical start. This was the main reason to equip it with a dual fuel tank.

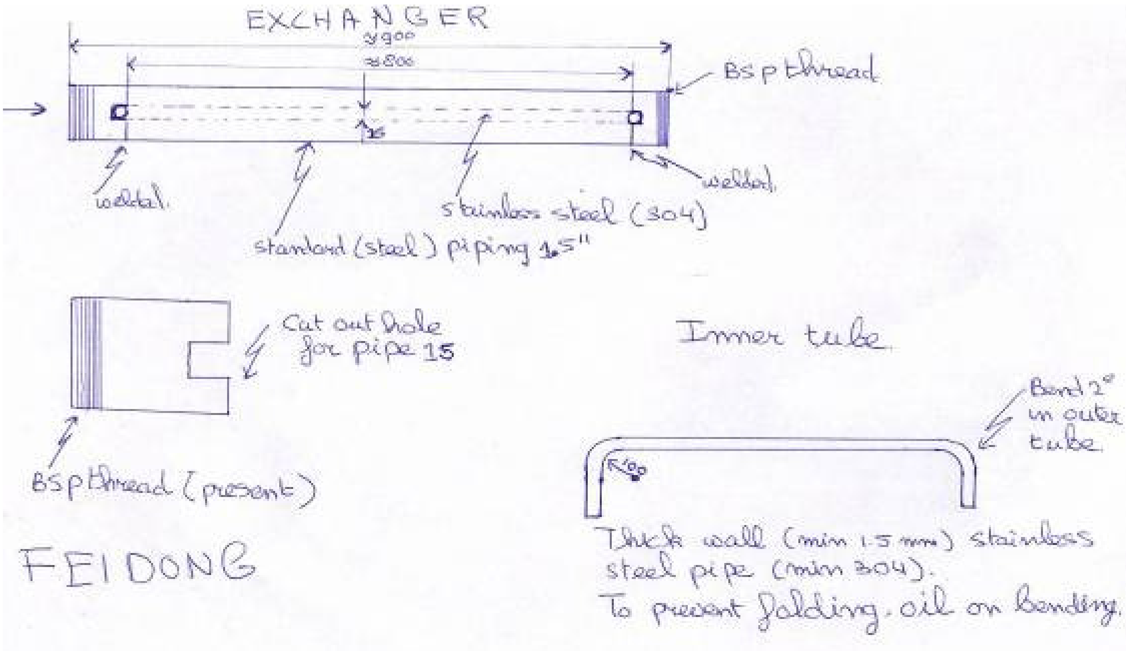


Illustration 9: Heat exchanger design applied to Feidong engine

Design adaptations:

1. Instead of a spiral wound heat-exchanger a straight line exchanger is used. The Feidong has a gravity fed fuel system and adding a resistance of an equivalence of 8 meters of pipe was considered too much.
2. The Feidong exhaust pipe was not fitted with flanges and the quality of the cast iron was not good. Welding stainless steel onto it would give problems.
3. There was no sheet metal available, nor could it be bought but some old metal water pipes were available. The pipe was shorted to the correct length of the (re-straighten) stainless steel pipe, inserted in the pipe and bended.
4. Calculations of heat loss due to long (uninsulated) exhaust pipe should be adapted but now allows for simple trial (isolating the exhaust) and measurement (of temperature on outlet) to reach the correct fuel temperature.

Illustration 10: Deutz engine stripped: fuel tank, oil cooler and mounting skid used

5.4 Materials used and located

Nr	Item	Dimensions	Number	Material	Cost US $
1	PPO fuel tank	40 liters	1	steel	15
2	Mounting plate for tank	re-used	1	steel	10
4	Exhaust extension pipe	1,50 m x 1 ½ ”	1	GI pipe	2
5	Sockets & elbows	1 ½””	2	GI pipe	5
7	Fuel pipe for heatexchange	1 m x 12 mm inner, 15 mm outer diameter	1	Stainless Steel 304	13
8	Fuel filter from John Deer tractor	Standard size	1	Al 2 inlets and 2 outlets	30
9	Fuel filter FRAM 19xx	Standard size	1	Paper	6
10	Fuel hose of 10 mm inside	4 m	1	Transparant re-inforced PE	8
11	Fuel hose of 12 mm	1 m	1	“”	2
12	Adapter parts to adapt 12 mm/15 mm steel pipes to 8/10 mm hoses	100 mm x 12 mm OD	2	steel	0.50
13	Ball valve tap for PPO tank	½ “”	1	Chrome brass, steel ball	12
14	Washers, 8,10, 12, 15 mm	Seal washers	2	brass	1
15	Tool:Pipe bender	For 15 mm pipe	1	Steel	65
16	Tool:Grinding disk for flex cutter	140 mm	10	sio2	15
17	Tool:filter cloth	300x300 mm	40	X70	8

Used were a number of items taken from an old, rusted engine, standing for about 5 years on the farm.

Illustration 11: Deutz tank used from scrapyard as SVO tank

Illustration 12: Mounting for fuel tank attached to Feidong

The total cost of locally bought items for the conversion did not exceed the 900 Mt (about 30 Euro). Items were salvaged from the local scrapyard and a reasonable price tag to it was assigned based on prices paid on scrapyards for such items. For the fuel system a pipe-bender was

Illustration 14: Exhaust from used steel water pipe+ view on heat-exchanger outlet

bought , a piece of stainless steel pipe (10 Euro) , some 40 cloths X70 (8 Euro) two cotton filters 5mu (4 Euro) and some bio-diesel adsorption (1.80 Euro)

Illustration 13: Fuel tank+ ball valve

5.5 Basic working of fuel system.[5]

The fuel system is designed to heat up the SVO or WVO before entering the injection pump. The suction of the fuel is solely done by the distribution pump and will not be that powerful. It is designed to start on diesel, being a hand started engine and than switch over to SVO/WVO. A two inlet fuel filter is being used to connect both tanks to the single inlet fuel lines. Fuel will be filtered twice but that will not hurt anything. Before starting the diesel fuel valve on the tank is opened and the engine is started. Immediately after starting the SVO fuel valve can be opened and afterwards the valve on the diesel fuel closed. The engine does not need more than 30 seconds to heat up the SVO to run well. The SVO is led through a heat exchanger entering the filter hot. After 5 to 10 minutes the SVO will reach a temperature of 50 to 60 degrees Celsius, enough to assure a large enough flow of fuel to the engine. The engine can now be loaded for maximum horsepower (-5% due to lower caloric value of cotton oil fuel). When shutting down the engine the diesel fuel valve is opened again and the SVO valve closed. Due to the double filtering the engine will take at least 5 (loaded) to 10 minutes (idle mode) to remove the SVO from the filters and fuel lines. Visual inspection of the transparent lines will show the progress as diesel fuel will be white transparent and the SVO (at least) yellow or black. There is no need to clean the lines complete as just a little bit of diesel will be enough to start the (cold) engine again. Precaution must be taken not to load the engine too fast after start: due to the left SVO the fuel will have a high viscosity.

Illustration 15: Workplace cleaning, Bench and some bending tools

5 A simplified drawing of the complete fuel line is being shown in appendix 3

If the engine at cold start does have troubles when loaded, leave the diesel valve open for a while and slowly reduce the diesel valve opening with the SVO valve opened completely.

5.6 Testing of usability

Before proceeding with the conversion of the engine , a first test was conducted to determine the actual usability of the vegetable oil available. These steps took place during conversion of the engine. The 'usual' produced cooking cotton oil and the stack-burnt oil were examined. On visual check, the quality seemed to be acceptable.

5.7 Experiences during actual conversion.

The first start was the mounting of plate to rest the second fuel tank. A tank of an old Deutz engine was available. The engine was solid rusted together and could only be made runnable against (too) high costs. The fuel tank, with mounting and some more bolts and nuts of this engine were reused.

After mounting the skid plate on the Feidong, first thing done was checking if the engine would run at all on SVO. Therefore a 20 liters of stack burn cotton oil was filtered into a barrel. The Feidong was started and run for a while (30 minutes) on SVO. The original fuel line was way too short to go into the barrel of oil and was replaced with 4 meters of fuel hose. Because the Feidong has neither a prime pump nor a filter hand pump, bleeding the air out of the engine is cumbersome. By shortening the fuel lines down to 2 meter and pressurizing the tank we were able to fill up the fuel hoses almost airless.

After this initial test with an unloaded engine and cold SVO, the old tank was cleaned with a flexcutter copper brush (metal wire brush for flex cutter could not be found) and mounted onto the skid. In the mean time the exhaust heat exchanger was constructed from the 15mm/12mm stainless steel pipe and 1.5 inch steel pipe. Fixing the heat exchanger permanently on the engine in the form of a spiral wound stainless steel pipe is not a good idea: The Feidong exhaust manifold is made out of bad quality cast iron and without flanges to fit a decent piping to it. With a stationary engine, space is not so much of a problem: instead of using a spiral wound, compact heat exchanger, we constructed a straight line heat exchanger of about 80 cm and bending the stainless steel pipe with a 90 degrees at both ends out of the pipe. On both ends with a 10 cm length pipe containing already cut thread. Important was the use of the already available thread because the cutting plate for 1.5 inch pipe was gone missing and in Chimoio the local machine shop was not able to cut on new thread.

With some standard piping elbows and knees, bits and pieces of pipe the exhaust was constructed. In first instance the exhaust manifold was put on the original way (outlet pointing upward) but then the heat exchanger would be above tank level. Having an engine with little suction on the fuel input, it would probably not be able to have a sufficient flow. As the exhaust manifold was perfectly symmetric turning it around (outlet facing down) would give just enough clearance. The heat exchanger now is just below the bottom of the tank.

The stainless steel pipe inside the exhaust is 15 mm from the outside size and 12 mm inside. The thick walled steel has been chosen because it does not fold easily when bended in sharp angles.

Due to the high(er) viscosity of the vegetable oils even when heated, it was intended to use 12 mm fuel hose as well. But this diameter was not available (at the moment) in Chimoio. So 8 mm fuel hose was used instead. When the engine is to be loaded to the maximum power usage this might give a problem: the fuel pump can not take in enough fuel through the long fuel hoses. The inlet from the tank to the heat exchanger is made out of old fuel hose of a slightly larger diameter (12 mm). (it is the fuel hose from the boiler, can withstand paraffin for about 2 years).

5.8 First Testing of the modified engine

After construction took place, the engine was put to work for about 2 hours to run on PPO. Right after the start some of the welding had to be redone due to leakage. In about 3 minutes the oil was hot enough to start leaking from several (heated) joints. A small leak in the PPO tank did also appear. A number of measurements were made to check on the performance of the heat-exchanger. Measurement was done with a Voltcraft infrared thermometer IR 364 and K type sensor (not used).

Measurement point	**Value after running 2 minutes (degrees Celsius)**	**Value after running 90 minutes (degrees Celsius)**
From Tank to heat exchanger	30	31
Outlet heat exchanger fuel	42	63
Inlet 1e fuel filter	34	48
Inlet 2e fuel filter	32	36
Injection pump		38

Measurement devices and method used. The readings have not been corrected for measuring through plastic (insulating) fuel lines

Illustration 16: Measuring the heated fuel

6. Conclusions

The endurance test of the Lister ST3 of over 500 hrs in the Netherlands under variable load and rather cold ambient temperatures, showed that it is running well on PPO, without problems.

The Feidong diesel engine (Chinese copy of a Lister Petter) has been converted in Mozambique and ready to start with an endurance test of 500 hours on PPO of cotton oil.

Although the second modification kit was of similar design as the first one, the target of developing kits as universal as possible fitting to the many engine types as operating in Cabo Delgado Mozambique proved not to be possible for the two Lister type engines. The design of the engines did not allow it.

The general requirements for the modification kits as mentioned in chapter1: Introduction, are in general quite well complied with.

7. Recommendations.

The testing has just started. To optimize the performance it is advised to insulate the exhaust pipe with the heat exchanger to have a outlet temperature of 85 degrees. Also insulate the fuel line to the 1e filter, possible the fuel lines from and to 2e filter as well so the temperature of the oil will reach the engine at the intended 55 to 75 degrees. Shortening the hot oil carrying fuel lines to a minimum size will help losses.

Check oil regular and change if level arises above maximum: the fuel spillage of the Feidong is considerable, contaminating the oil at a rapid rate. PPO is a good lubricant but only for a short period of time but 500 hrs is too much.

As the engine is to be applied in the field, one may consider fitting a generator, start motor engine and a battery to the set. Starting the engine by hand is by no means an easy task. Having a battery would also allow the use of an electrical fuel pump. In case of running out of fuel, bleeding the air out of the system will be a hell of a job. An electrical pump will also make the engine indifferent to the placement of the fuel tank. Then the fuel tank may be placed lower than the heat exchanger. Having an fuel pump will make the pressure drop due to the longer fuel lines.

8. References

1 Jatropha oil quality related to use in diesel engines and refining methods, Technical Note, Jan de Jongh, Ger Groeneveld, et al. Sept 2007 FACT.

2 Feidong Operation and Maintenance manual, Shandong Tractor Works Engine Branch

3 Transport Phenomena, A unified approach, Robert Brodkey,Harry Hersey, ISBN 0-07-100152-2.

4 CRC Handbook of Chemistry and Physics, 55th edition, ISBN 087819-454-1

5 http://www.realdiesels.co.uk/listerdata.htm.

6 http://www.journeytoforever.org/biofuel_library.html.

7 Putting a 12 HDVT120 Kromhout generator set to work on biofuels. (not published yet)

8 wikepedia and derivate of wiki specialized in bio fuels.

Annex 1. Formula's used in calculation of heat exchangers.

To lower viscosity of the PPO fuel heat is being applied. The temperature raise of the fuel needed is depending on the type of PPO. The maximum allowed raise of the fuel is depending on the type of injection system, which will add an extra amount of heat to the fluid.

Some numbers used:

Thermal transfer coefficient N2 0.18 W/m2/K

Heat capacity of PPO (mean value) 114.1 [Cal/g mol/K] = 4.7 kJ/kg/K.

Heat capacity of N2 0.229 [cal/g/K] = 1.0 kJ/kg/K

In case of a submerged, spiral wound exchanger, all exhaust gas around the exchanger will be of the same temperature. The amount of heat power Wh will depend on the area of the heat exchanger.

The maximum power transferred from the (hot) air to the metal will be:

$$A*k*(Tg-Tf)$$

with A being the outer area of the heat exchanger

k the thermal transfer coefficient of N2,

Tg the temperature of the surrounding gas

Tf the temperature of the fluid.

Of course when energy is transferred the temperature of the gas will lower and the temperature of the fluid will rise. Important is that the heat should be conducted from the gas to the fluid. Most metals, including stainless steel, will conduct far much better than a gas or fluid so transferring power from the gas to the steel will not be blocked by the thermal conductivity of the steel, except for very high temperatures. Temperatures should be than well above a 1200 K.

Assumed is that the gas temperature is nearly constant and the fluid temperature will be at 85 degrees Celsius. All of the power received is to be transferred to the fluid, giving a temperature raise of the fuel of:

$$Wh/Cpf \ [K/kg/s]$$

With Wh being the amount of heat available

Cpf the heat capacity of the fuel.

The amount of fuel used is depending on the power output of the engine. The length and the diameter of the tube determine the volume of fuel being heated. The speed of flow of the fuel set the time which is applied for heating the fuel.

Assumed is that all fuel is being burned releasing Wm+Ww+Wf+We of energy. Wm is the mechanical energy (useful energy) Ww is the amount of heat to the water cooling system, Wf is the frictional forces and We is the energy released through the exhaust.

The efficiency of an engine is set at 45% for the mechanical labor Wf. This is rather high for engines of small size but not impossible for well adjusted stationary engines. About 15% is transferred to the water cooling, including the heat from the frictional forces internally and 40% is emitted through the exhaust in the form of hot gases. The frictional forces are depending on the delivered mechanical power, lowering the actual maximum mechanical output

Given a certain load, one can backwards calculate how much fuel has to be burned to deliver the horse power requested. Burning more fuel in the same amount of space and time will give rise to an higher outlet temperature, which does give a rise in the available heating power for the fuel.

Given the displacement of an engine, the engine speed/2 (for four-stroke) one can calculate the amount of burned gases. With above efficiency figures the amount of fuel to be burned is calculated. The amount of gas will stay the same (with constant speed) so the extra amount of heat will give a rise in exhaust temperature. The exhaust temperature will rise to:

$$Te = L / (Cg * (K*\omega*Ve/2) / Mf*H)$$

With Te the temperature of the gas

L = 0.4 being the proportion of heat in the exhaust stream

Cg the heat capacity of the exhaust gas.

K a constant converting the volume of the displacement to a mass

ω Rotational speed per second.

Ve volume engine.

Mf mass of extra burned fuel

H energy released J/kg.

Annex 2. Terms of References completion.

The report is written to fulfill the assignment: Part of Contract Ref letter: JJ05008_PPO-Groeneveld which states:

Requirement of the kits:

1. As simple as possible,
   The heat exchanger is a 2mm thick 12 mm inner diameter piece of 1 meter stainless steel 304. Initially the design was a spiral wound pipe. Two bends where produced locally.

2. Lowest cost as possible.
   By reusing materials available, about 350 Mt were spent on parts (10 Euro). The stainless steel pipe was bought in Holland at 8.70 Euro. A number of grinding disks, elbows, knees and other fitting material were bought total amounting of 20 Euro. Complete set build for just over 30 Euro.
3. Materials should be locally available, as much as possible. Minimize importation of parts.
   Except for the pipe-bender and the stainless steel pipe all materials were bought locally or recycled materials.
4. Parts like heat exchangers should be possible to make locally in workshops, etc with electricity available and normal equipment for steel work., such as with welding equipment, drill equipment, grinders , etc.
   Complete system was build locally by local people.
5. should be possible to be mounted by medium skilled technicians in the field
   The complete kit has been installed by medium and low skilled technicians. Only instructions have been given. Most solutions have been suggested by me but executed by the local technicians.
6. using normal tools, like spanners (no torque wrenches), hack saws, etc.
   No extra tools have been used except the ones present. Due to some broken pieces of tools (die and thread-cutter) bits and pieces have been welded together.

Specifications of development traject:

1. Design the kit, based on the data from the engines and specify the components of the kit with price indication.
   Using a spreadsheet program a set of calculations have been made for every type of operation and type of machine. The data of this engine has been entered based on experience with the Lister engine. Calculations have been checked on both machines and have been found correct within 10%. No attempt has been done to calculate the non-steady state transitions which occur under heavy change loads (for example when a generator is used for welding tasks)

2. The design will be send to a number of experts who will give their comments. They will be asked to come over for a one **Mini-Workshop** day meeting in Holland. The following people will be asked: Niels Anso, Sander de Waal of BRODTECH, and maybe some more experts or students from Tue, Prof Naveen Kumar of Delhi College of Engineering or represented by Christian Fenger.
   Design has been made and incorporated in this report including the local changes. An overview of the test method was given in Utrecht.

3. Built the kit.
   The kit has been build as described above.

4. Take the kit along to Mozambique, and modify an existing diesel engine there with the kit; either in Chimoio with Brendon Evans, or in Bilibiza (near Pemba) with the engine used at the EPF school for the maize mill. One of these options will be chosen; possibly earliest to do this is June 2008.
   The heat-exchanger pipe was taken from Holland. All other materials were locally collected and bought. The engine was modified at the ranch of Brendon Evans near Chimoio. The adaption took place during 20 till 26 November 2008.

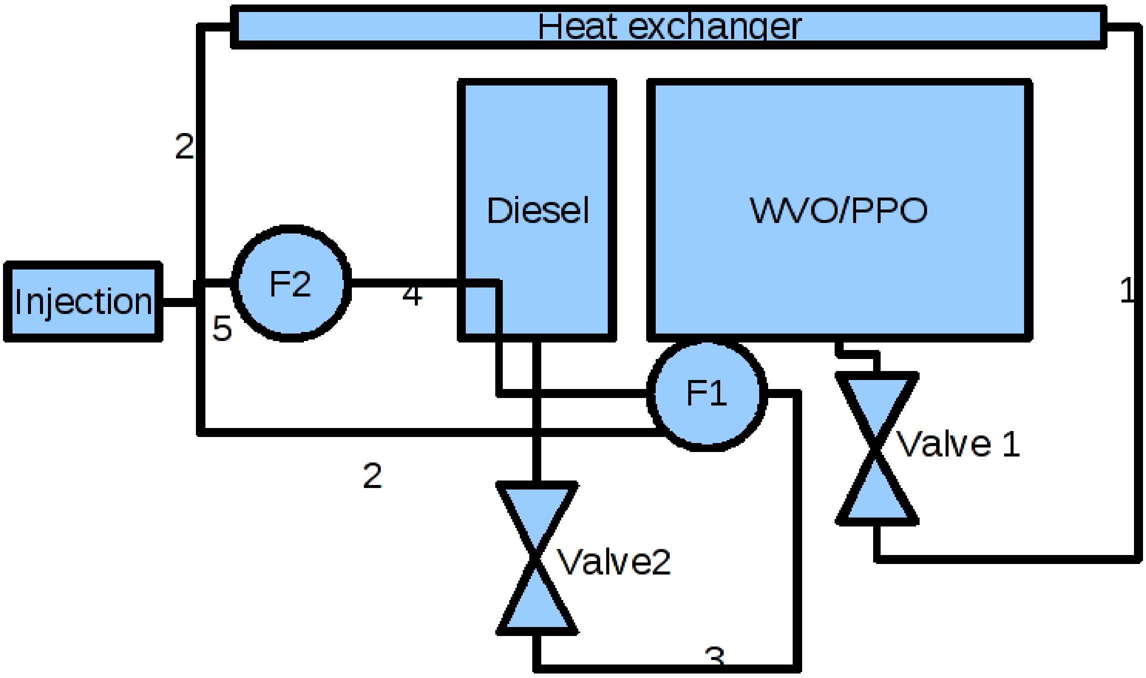
5. Define the load during the test and run the engine with the kit for at least 500 hrs on PPO of known quality.
   The load on the test Lister was defined at 2kW constant and 8 kW peak. The test has run for 650 hours in total. The load for the Feidong is a water pump. The water pump could not be installed yet due to a missing part.

6. Explain your method of checking the state of the engine during the test and at the end of the test to the people who are going to test it in Mozambique and supply a report format.
   Three parameters are of utmost importance: quality of fuel, cleanness of fuel and viscosity of fuel. Explained and demonstrated method of filtering as described in report. Materials used for filtering are on the farm Everetz, extra materials for filtering a 1000 liter of oil left behind. The fuel used is cold pressed, stack burnt, cottonseed, treated with caustic soda. A sample of the oil is requested for further investigations. After the rebuild and during the 2 hour test the temperature of the oil was sufficient to lower its viscosity to a required level.

7. Check the availability of needed materials to make these kits in Mozambique.
   All materials can be found on scrapyards or bought, be it often not of the right size and the quality of newly bought items is low. Improvising is necessary.

8. Report halfway the test and at the end.
   End test Lister reported in this document. Test Feidong just started.

Annex 3. Simplified drawing fuel line system on Feidong engine.



Line 1: cold PPO to heat exchanger,
Line 2: hot PPO to filter F1 in
Line 3: cold diesel to FilterF1
Line4: hot or cold fuel to filter F2
Line5: hot or cold fuel to injection pump
Valve1: ball valve closing PPO tank
Valve2: original valve on original tank
F1: Fuel filter John Deere
F2: Fuel filter Feidong
Injection: Injection pump

Procedure starting and stopping of engine with above fuel-line system.

1. Starting up with opening valve2 of diesel fuel.

2. Start engine.
3. Close valve2 and open valve1 for PPO

Shutting down engine running on PPO

1. Open up valve2 and close valve1
2. Run engine until transparent fuel line from F1 to F2 shows diesel fuel color
3. Shutdown engine and close both valves, valve1 and valve2

Annex 4: Overview of important physical and chemical characteristics of vegetable oils.

http://journeytoforever.org/biofuel_library/fatsoils/fatsoils2.html)

Acid	Elementary Formula	Constitutional Formula
Lauric	$C_{12}H_{24}O_2$	$CH_3(CH_2)_{10}COOH$
Myristic	$C_{14}H_{28}O_2$	$CH_3(CH_2)_{12}COOH$
Palmitic	$C_{16}H_{32}O_2$	$CH_3(CH_2)_{14}COOH$
Stearic	$C_{18}H_{36}O_2$	$CH_3(CH_2)_{16}COOH$
Oleic	$C_{18}H_{34}O_2$	$CH_3(CH_2)_{14}(CH)_2COOH$
Linolic	$C_{18}H_{32}O_2$	$CH_3(CH_2)_{12}(CH)_4COOH$
Linolenic	$C_{18}H_{30}O_2$	$CH_3(CH_2)_{10}(CH)_6COOH$

E. T. Webb, *Oils and Fats in Soap Manufacture*, Soap Gazette and Perfumer, October 1, 1926, xxviii, 302, gives the following percentages of the more important fatty acids in commonly used fats and oils. Other investigators may find somewhat different proportions, but in general these are representative:

Fat or oil	Lauric	Myristic	Palmitic	Stearic	Oleic	Linolic	Linolenic
Coconut	45	20	5	3	6	-	-
Palm kernel	55	12	6	4	10	-	-
Tallow (beef)	-	2	29.0	24.5	44.5	-	-
Tallow (mutton)	-	2	27.2	25.0	43.1	2.7	-
Lard	-	-	24.6	15.0	50.4	10.0	-
Olive	-	-	14.6	-	75.4	10.0	-
Arachis (peanut)	-	-	8.5	6.00	51.6	26.0	-
Cottonseed	-	-	23.4	-	31.6	45.0	-
Maize	-	-	6.0	2.0	44.0	48.0	-
Linseed	-	3	6.0	-	-	74.0	17.0
Soy bean	-	-	11.0	2.0	20.0	64.0	3.0

It is obvious, then, that it is important for industrial users of fats to know the degree of unsaturation of a given parcel of fat. This might be ascertained by determining the amount of hydrogen required to convert it into a saturated fat. In practice this is a complicated procedure and so simpler methods are resorted to. The simplest of these is the determination of the amount of iodin that can be made to combine with the fat. The percentage by weight of iodin absorbed by the fat in the natural state is known as the *iodin number.* It is an index to the degree of unsaturation of the fat. The iodin number of the commoner fats are given in Table 1. (For details concerning this and other methods of testing fats, see *Standard Methods for the Sampling and Analysis of Commercial Fats and Oils,* Industrial and Engineering Chemistry, December 1926, xviii, 1346.) Examination of the table shows that the fats with the highest iodin numbers are the drying oils par excellence, linseed and tung oil, with which must also be classified menhaden fish oil.

Table 1. Iodin Numbers of Common Fats6

Fat or Oil	Iodin number
Linseed oil	173 - 201
Tung Oil	170.6
Menhaden oil	139 - 173
Whale oil	121 - 146.6
Soy bean oil	137 - 143
Sunflower oil	119 - 135
Corn oil	111 - 130
Cottonseed oil	108 - 110
Sesame oil	103 - 108
Rapeseed oil	94 - 102
Peanut oil (arachis)	83 - 100
Olive oil	79 - 88
Horse oil	71 - 86
Lard	46 - 70
Palm oil	51.5 - 57
Milk fat	26 - 50
Beef tallow	38 - 46
Mutton tallow	35 - 46
Cacao butter	32 - 41
Palm kernel oil	13 - 17
Coconut oil	8 - 10

6 Data from J. Lewkowitsch, *Chemical Technology and Analysis of Oils, Fats, and Waxes*, pp. 419-24.

Annex 5: Other Useful Tests

There are, of course, many other tests besides iodine absorption that are used in commercial practice. This is not the place to discuss them in detail. A few of them, however, deserve mention in passing.

The iodine number of a fat tells us the degree of unsaturation of a fat. It does not tell us whether the unsaturation is the result of the presence of triolein only, of trilinolin only, of trilinolenin only, or of a mixture of the three. As the drying qualities depend mainly upon trilinolin and trilinolenin, paint manufacturers are not always satisfied with the determination of the iodine number. In such cases they determine the amount of oxygen the oil tested will absorb under standard conditions. As the absorption of oxygen is mainly by the trilinolin and trilinolenin, this test is used to supplement the iodine number.

In the preceding section it was stated that fats often become decomposed and rancid and that they then contain free fatty acids -- i.e., acid uncombined with glycerin. It was also pointed out that it is important to the industrial user to know the amount of free fatty acid present, since this determines in large measure the refining loss. The amount of free fatty acid is estimated by determining the quantity of alkali that must be added to the fat to render it quite neutral. Sometimes, in addition to estimating the free fatty acid in this way, the actual loss in refining is also determined. This is done by warming a known amount of the fat with strong aqueous caustic soda solution, which converts the free fatty acid into soap. Caustic soda is a compound of one atom each of sodium, oxygen, and hydrogen; its formula is therefore NaOH. Its proper scientific name is sodium hydroxide. It is also known as soda lye or simply as lye. It is very alkaline and corrosive. This soap is then removed and the amount of fat remaining is then determined. The loss is estimated by subtracting this amount from the amount of fat originally taken for the test. The amount and strength of caustic soda solution, the temperature, and the length of treatment are so chosen that only the free fatty acid and other impurities present in the oil are removed and but little, if any, saponification of neutral fat takes place[7].

As also pointed out in the first section, many crude fats as they come upon the market are either naturally deeply colored or have become so through decomposition. Since for many uses such fats must be decolorized, the ease with which this may be done is an important factor in determining their commercial value. Hence one of the commonest tests applied to fats is the test of bleachability. This is done by mixing a given weight of alkali-refined fat with a given weight of fuller's earth and then estimating the amount of color remaining in the fat or oil after this treatment. (Fuller's earth is a special kind of clay that has the property of absorbing coloring matters. It derives its name from the fact that it has been used in the fulling of cloth to remove grease.)

Many fats and oils contain substances that are not tri-glycerids. These may be natural constituents or they may be adulterants or contaminants. The presence of a considerable proportion of them of course reduces the commercial value of the fat. The commonest of these is moisture. It is estimated very simply by placing a weighed portion of the fat in an oven heated to a temperature slightly higher than that of boiling water. The moisture is thereby driven off. The fat is then again weighed; the loss is regarded as moisture.

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7 (Cf. *Rules Governing Transactions between Members of the Texas Cottonseed Crushers' Association* (Dallas. Texas, 1927), pp. 71-76.)

The determination of non-fat materials other than water is done by saponifying the fat by heating with strong caustic soda or potash solution until all the tri-glycerids have been decomposed into glycerin and soap. (Caustic potash is the compound of potassium analogous to caustic soda.) These are soluble in water and may be washed away. What remains behind is the non-triglycerid part of the fat and may be weighed. It is known as the unsaponifiable matter. In practice the procedure is not as simple as this, but the basic principle is correctly stated above.

The determination of unsaponifiable matter must not be confused with the saponification number of a fat. The saponification number is the number of milligrams of potassium hydroxid required to convert one gram of the fat completely into glycerin and potassium soap. It gives information concerning the character of the fatty acids of the fat and in particular concerning the solubility of their soaps in water. The higher the saponification number of a fat free from moisture and unsaponifiable matter, the more soluble the soap that can be made from it. The information is of especial importance to soap makers. Table 2 gives the saponification numbers of the commoner commercial fats and oils.

Table 2. Saponification Numbers of Common Fats8	
Fat or Oil	**Saponification number**
Rapeseed oil	170 - 179
Menhaden oil	190.6
Corn oil	188 - 193
Olive oil	185 - 196
Soy bean oil	193
Cacao butter	193.55
Linseed oil	192 - 195
Cottonseed oil	193 - 195
Lard	195.4
Mutton tallow	192 - 195.5
Peanut oil (arachis)	190 - 196
Horse oil	195 - 197
Beef tallow	193.2 - 200
Palm oil	196 - 205
Butter	220 - 233
Palm kernel oil	242 - 250
Coconut oil	246 - 260

Examination of this table shows that butter ranks with palm kernel oil and coconut oil as having a very high saponification number. This is due to the fact that its triglycerids contain appreciable

8 Data from J. Lewkowitsch, *Chemical Technology and Analysis of Oils, Fats, and Waxes*, pp. 395-400.

quantities of myristic acid and small quantities of lauric acid, both of which when they form soap combine with relatively more sodium than the more common acids of fats. These acids occur in undecomposed butter in chemical combination as triglycerids. Their sodium soaps are quite soluble in water. The high saponification number of coconut oil and palm kernel oil is due to the large proportion of lauric acid and myristic acid that they contain. These oils therefore yield quite soluble soaps.

Before leaving the subject of the commercial chemical testing of fats, the *titre test* deserves mention because it is of much importance in certain branches of industry. The *titre* of a fat or oil is the temperature at which the mixture of fatty acids derived from it solidifies after it has been melted. The test is performed in several steps. First, the fat is completely saponified, usually by heating with a solution of caustic soda. Then the mixture of soaps thus obtained is treated with a strong acid, usually sulfuric, which takes the sodium away from the soaps, thereby converting them into free fatty acids. After these have been washed and dried they are melted and the temperature at which the melted mass solidifies when cooled is noted. This temperature gives an index to the consistency of the original fat, a matter of great importance to manufacturers of candles and of products like margarin, in which consistency and texture are of the utmost importance.

Finally, the viscosity of a fat is a property of commercial significance, especially to manufacturers of lubricants. It is usually estimated by comparing the length of time it takes a given volume of oil (or melted fat) to flow through a tube of small bore, or through a small orifice, with the time it takes an identical volume of water. Castor oil has the highest viscosity of any fat that is fluid at ordinary temperatures. Olive oil has the highest viscosity of any of the common vegetable oils. The viscosities vary greatly with the temperature. When fats are cooled to the solidifying point they can no longer be said to be viscous.

Annex 6:Fuel properties of fats and oils

Because the main purpose here is using the oil as a fuel, the most important fuel properties:

Fuel-related properties and iodine values of various fats and oils							
Oil or Fat	**Iodine Value**	**CN**	**HG** (kJ/kg)	**Viscosity** (mm 2/s)	**CP** (deg C)	**PP** (deg C)	**FP** (deg C)
Babassu	10-18	38	-	-	-	-	-
Castor	82-88	?	39500	297 (38 C)	-	-31.7	260
Coconut	6-12	-	-	-	-	-	-
Corn	103-140	37.6	39500	34.9 (38 C)	-1.1	-40.0	277
Cottonseed	90-119	41.8	39468	33.5 (38 C)	1.7	-15.0	234
Crambe	93	44.6	40482	53.6 (38 C)	10.0	-12.2	274
Linseed	168-204	34.6	39307	27.2 (38 C)	1.7	-15.0	241
Olive	75-94	-	-	-	-	-	-
Palm	35-61	42	-	-	-	-	-
Peanut	80-106	41.8	39782	39.6 (38 C)	12.8	-6.7	271
Rapeseed	94-120	37.6	39709	37.0 (38 C)	-3.9	-31.7	246
Safflower	126-152	41.3	39519	31.3 (38 C)	18.3	-6.7	260
High-oleic safflower	90-100	49.1	39516	41.2 (38 C)	-12.2	-20.6	293
Sesame	104-120	40.2	39349	35.5 (38 C)	-3.9	-9.4	260
Soybean	117-143	37.9	39623	32.6 (38 C)	-3.9	-12.2	254
Sunflower	110-143	37.1	39575	37.1 (38 C)	7.2	-15.0	274
Tallow	35-48	-	40054	51.15 (40 C)	-	-	201
No. 2 DF	-	47	45343	2.7 (38 C)	-15.0	-33.0	52

CN = cetane number; CP = cloud point, PP = pour point, FP = flash point[9].

9 Iodine values combined from Applewhite, T.H., in Kirk-Othmer, *Encyclopedia of Chemical Technology*; Third Ed.; John-Wiley & Sons: New York, NY, 1980, Vol. 9; pp. 795-811; and Gunstone, F.D.; Harwood, J.L.; Padley, F.B. *Lipid Handbook*; Second Ed.; Chapman & Hall: London, 1994.
Fuel properties from Goering, C.E.; Schwab, A.W.; Daugherty, M.J.; Pryde, E.H.; Heakin, A.J. *Trans. ASAE* 1982, 25, 1472-1477 & 1483.
All tallow values from Ali, Y.; Hanna, M.A.; Cuppett, S.L. *J. Am. Oil Chem. Soc*. 1995, 72, 1557-1564 (no CN given, calcd. cetane index 40.15).

(*From*: **Biodiesel: The Use of Vegetable Oils and Their Derivatives as Alternative Diesel Fuels**, G. Knothe, R.O. Dunn, and M.O. Bagby, in *Fuels and Chemicals from Biomass*, Washington, D.C.: American Chemical Society.