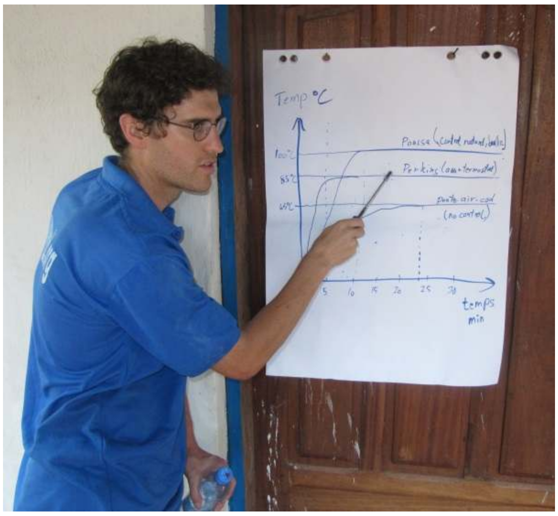
Mission report
for mission to DR Congo October 14th – 27th 2013
a Consultancy carried out
for

SNV, Democratic Republic of Congo

www.snvworld.org

SNV DRC project
"Gemena Palm Oil Produces Electricity"

Netherlands Development Organisation SNV Connecting People's Capacities







Author: Niels Ansø, DAJOLKA.dk

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1 Table of contents

2 Introduction

2.1 Project background

The project "Gemena Palm Oil Produces Electricity" is a joint project of SNV DRC and FACT Foundation. It is aiming to demonstrate of using palm oil as a fuel for energy production as an alternative to expensive diesel fuel. The activities includes improving the capacity of actors in the palm oil production chain, leading to the extraction of more oil of higher quality from the same amount of palm fruits; the upgrading of the (crude) palm oil to PPO; and the use of the PPO in modified gensets to produce electricity for a number of enterprises and of inhabitants in Gemena.

The first discussion about our possible involvement in project activities started back in march 2012.

2.2 DAJOLKA´s background

DAJOLKA is a Social Enterprise, established in Denmark in 1997, by Niels Ansø. (B.sc.Mec). Until 2005 DAJOLKA carried out non-profit activities parallel to Niels Ansø´s job as project engineer at the Danish NGO, Nordic Folkecenter for Renewable Energy, where he has worked with Pure Plant Oil (PPO) technology since January 1999. Since 2005 DAJOLKA has turned its activities to be profit oriented and Niels Ansø working full time within Renewable Energy Technologies.

2.3 Mission Terms Of References

The results of the consultancy are, as mentioned in the Terms Of References:

1. 5 to 10 people trained (both theory and hands on) on adaptation of generator sets. The trainees are able to adapt similar size generators and to train other technicians on the matter
2. Perkins 404-22G installed, adapted and initial test done and connected to the electricity grid.
3. 2 small diesel engines adapted and running with PPO.
4. Fuel quality control procedures and protocol elaborated and transmitted to the project. Local partners trained and able to implement these procedures.
5. Technical support in distance given to the Project. (after the mission)

The TOR´s in details are enclosed in the appendix 9.1

3 Engine conversion and use of PPO in an converted engine

3.1 Introduction

By nature, PPO has excellent properties as fuel in diesel engines, and generally any warm diesel engine will run on heated PPO. Nevertheless, for generations diesel engines have been designed and optimized for diesel fuel. Since some fuel properties of PPO differ from diesel fuel, different conditions must be followed, and modifications must be made to the engines in order to handle these different properties.

There are two equally important criteria's to follow in order to successfully use PPO as fuel in diesel engines:

- The PPO fuel quality should meet criteria's specified in PPO fuel quality standards.
- The diesel engine should be selected as suitable for PPO conversion, and it should be in a well maintained condition. In addition, when it's converted, care should be taken regarding the

special challenges for that exact type of engine. And the engine should be used in a suitable way (load pattern)

Both conditions are to secure efficient combustion of the PPO, minimizing the emissions and fuel consumption, and guarantee a normal, long lifetime of the engine. Under these conditions, the performance and fuel consumption when running on PPO will be comparable to that of diesel. On the other hand, if the PPO is combusted inefficiently, problems can be expected sooner or later. Typically, this is because of deposits or other ways of accumulating unburned fuel in the engine. Or the PPO could damage the injection system because of aggressive properties (high acid level).

3.2 Engine conversion

3.2.1 Usefull gloses

English	French
Heat exchanger	Echanger de chaleur
Glow plugs	Les Bougis de preschauffage
lift pump	pompe alimentation
diesel fuel	Gazoil

3.2.2 Engine temperature.

It is essential for efficient combustion of PPO that the engine reaches its designed operation temperature, which is typically 80-90°C. At this temperature most diesel engines can combust PPO as efficient at diesel fuel.

On water cooled engines, the temperature normally is controlled by a thermostat, which keeps all heat inside the engine until the temperature comes near to the operating temperature, an only at this moment it start to open and let the coolant pass the radiator. That means that the engine reaches operating temperature very fast, and keeps this temperature independent of the load.

With air cooled engines, the cooling is typically done by a fane rotating with speed depending on engine revolutions. But the air flow is typically not controlled, and therefor adjusted to full capacity(worst case), corresponding full load of the engine in a hot environment. That means that in all other situations at partial load and with colder ambient temperature, the engine is cooled more than necessary. The consequence is that the engine heats up very slowly, and that the temperature drops when idling, and increase when loaded.

3.2.3 Fuel heating

The PPO fuel should be heated for 2 reasons:

a) to reduce viscosity in order to pass the fuel filter with limited and acceptable pressure loss, and to melt eventual solid fats in the PPO, e.g. like Jatropha Oil which becomes solid or semi-solid from temperature below approximately 5-10 °C, or Palm oil which starts to solidify at higher temperature around 35-40°C.
b) To reduce viscosity before entering the injection pump.

the necessary temperature depends in the application, but typically PPO should be heated to 50-60°C to pass fuel filter, and 60-80°C to pass the injection pump.

Possible heat source are:

c) Coolant from water cooled engines, passing through en external fuel-coolant heat exchanger
d) Lube oil from air cooled engines, passing through en external fuel-lube oil heat exchanger
e) The injection pump, cylinder head or engine block itself, e.g. injection pumps and/or cylinder head on unit injections systems.
f) Electrical heating, but this demands permanent power from the battery/alternator
g) Exhaust gas, but only on special situations and solution, while exhaust gas temperature is very high with large fluctuations, e.g. exhaust gas temperature of 100°C when idling, at short time after 200°C when the engine is loaded. One way to control en exhaust temperature is to inject water in the exhaust gas, as done with small boat applications.

Other factors of the fuel system also influence on the choice of heating system. This includes the kind of lift pump if any, and the amount of return fuel from the fuel system to the fuel tank. E.g. if the injection pump is fed with fuel only by gravity, like on the Poussa engine and Jose Augusto´s Lister engine, the fuel flow is very slow, so the fuel can cool down on its way from the fuel filter to the injection pump. But on George Augusto´s engine the fuel return flow is large, which together with the loop system helps to an efficient heat transfer and heat distribution in the fuel system.

3.2.4 Fuel feeding

Most diesel engines has a lift pump, which should suck the fuel from the fuel tank, and either suck the fuel though the fuel filter, or push it through the fuel filter and deliver the fuel to the injections pump in a certain range of positive pressure.

3.2.4.1 Lift pump integrated in the injection pump

For distributer injection pumps like BOSCH, CAV, DENSO etc., the lift pump is integrated in the injection pump, and sucks the fuel from the fuel tank though the fuel filter and delivers it internal in the injection pump. Suction pressure before the lift pump is typically 0,3-0,5 bars. If the suction pressure is higher, the injection pumps might start starve from fuel, and the engine will lose power, but some integrated lift pumps can suck up to near vacuum (-1,0 bar), but it can be dangerous for the injection pump, and should be avoided. We have seen several injection pumps broken because of that (typical DENZO, which you find in many Toyota 2,4D engine). Surplus fuel is returned to the fuel tank.

3.2.4.2 Separate lift pump

Diesel engines with inline injection pumps, cassette type, and some unit injection systems, has a separate lift pump, typical membrane type, which sucks the fuel from the fuel tank, push it through the fuel filter, and deliver it to the injection pump at a pressure typically of 0,2-0,7 bars. The membrane type pump is typically "strong" for pushing, because its actuated mechanically by a cam, but its capacity for sucking is often depending on the strength of the spring which pushes it back. Therefor some membrane lift pumps have difficulties to suck cold PPO fuel from the fuel tank. Another issue for membrane type lift pumps is if the membrane material is resistant to PPO. If the membrane fails, there can be a risk that PPO enter the lubrication system and diluted the lube oil. Surplus fuel is returned to the fuel tank.

The Perkins 400D engine series are designed to operate also on Biodiesel (trans esterified vegetable oil), which is more aggressive to many rubber materials than Pure Plant Oil (PPO). Therefor we are not worried about the resistance of the membrane against vegetable oil.

The strength of the spring in the Perkins lift pump might be a challenge to suck semisolid Palm Oil from the fuel tank. If it is a problem, there are several solutions, e.g. install an electrical lift pump to replace or assist the original mechanical lift pump.

3.2.4.3 Gravity fuel feeding.

Some diesel engines have no lift pump, and are therefore fed by gravity. It means that the fuel tank is higher that the engine and the injection pump, the gravity will push the fuel though the fuel filter, and deliver it to the injection pump. Return fuel is not possible, except for the very small return flow from the fuel injectors. When an engine should operate on PPO with gravity feeding, it might be necessary to elevate the fuel tank to create higher feeding pressure, to overcome the higher pressure loss though the fuel filter.

3.2.4.4 Load

It is always best for an efficient combustion of PPO that the engine is loaded and not idling. Some engines are less sensitive to idling or low load, e.g. IDI engines, like the Perkins 400D, but many engines with direct inject are sensitive to low load, while the combustions becomes inefficient, leaving unburned fuel inside the engines as deposit on mechanical part, or unburned vegetable oil will dilute the lubrication oil.

3.2.4.5 Lube oil

Good quality lube oil can usually be used in PPO applications. IDI engines like the Perkins 400D are not that sensitive, because the tendency for unburned PPO to dilute the lube oil is small, and therefor mostly IDI engines can operate on PPO with standard oil change interval

DI engines has much higher risk of PPO dilution of the lube oil, so there for lube oil change interval is normally halved for DI engine compared to ordinary oil change interval in diesel application, to avoid problems from polymerization of lube oil, which are coursed by dramatically increase of the viscosity of the oil. Polymerization can easily lead to damage of the engine, and in worth case can cost life of the engine.

The photo shows polymerized lube oil with very high viscosity, taken out from an engine, which didn´t had the lube oil changed in time. To illustrate the high viscosity, the lube oil was purred out on a piece of A4 paper, which was then lifted to vertical position. The photo was taking 26 seconds after lifting the paper up, and the oil still didn´t start to drop from the paper.

It is an advantage to use special lube oil produced synthetics from vegetable oil as source of the raw material, e.g. like the product Fuchs Plantomot. That will not eliminate the problem, but postpone it. So if the lube oil is always changed in time, there will be no problems. It is advised to test the used lube oil for content of vegetable oil after the first couple of lube oil changes. If the content of vegetable oil is less than 10% it is usually not critically. If it is more that 10% there is an increased risk, and it is advised to reduce the oil change interval, as well as search for potential reasons why the content is too high.

When operating the engine is it very important frequently to check the lube oil level before cold start. If the level is increasing, it´s usually a sign off dilution of the lube oil with fuel. Also when checking the oil level with the oil level stick, it's possible to observe if the cold lube oil is getting a tendency of sticking to the level indicator, of if its drops normally from the indicator.

3.2.5 Engine conversion

The conversion should always be done by skilled technicians, and the result of the conversion should be evaluated by a person experienced in diesel engines running on PPO.

Generally any warm diesel engine will run fine on heated PPO. The main challenge is to get the engine started and run it with satisfactory clean combustion until it reaches normal operating temperature, typically about 80-90°C for a water cooled engine.

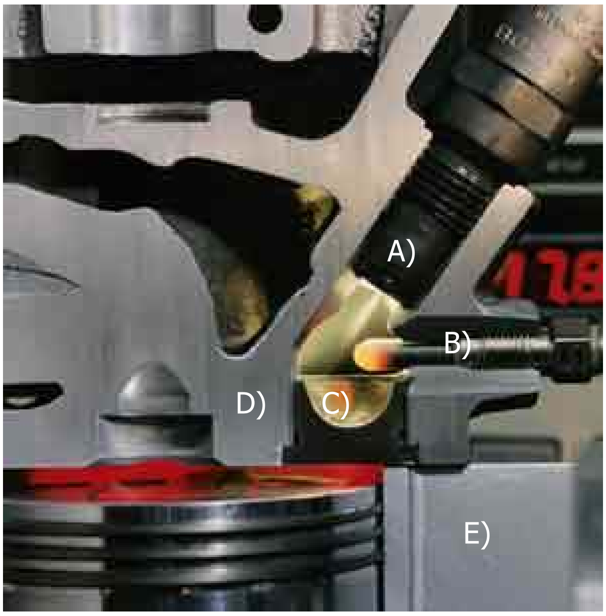
There are two ways to overcome this challenging part:

- With a 1-tank system, the engine starts directly on PPO. The original fuel tank can be filled with PPO, diesel or any mixture of PPO and diesel.
- With a 2-tank system, the engine starts on diesel supplied from a separate fuel tank, and operates on diesel until the engine reaches normal operating temperature. Then it is switched to heated PPO supplied from the other fuel tank. Before stopping the engine for cooling down, it should be switched again to diesel in order to purge the injection system. The diesel tank should always be filled with diesel, but the PPO tank can be filled with PPO, diesel and any mixture between PPO and diesel.

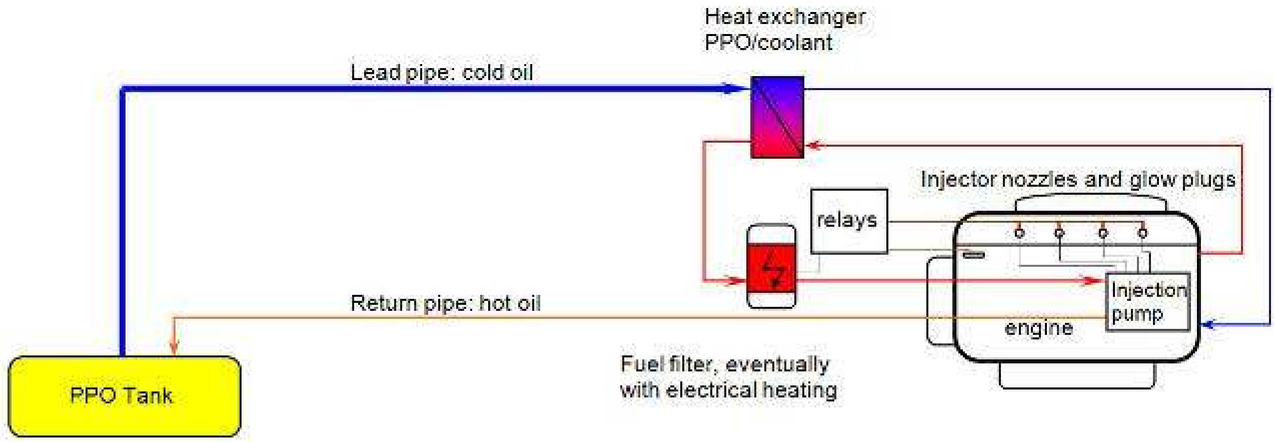
3.2.6 1-tank system

Most engines with Indirect Injection(IDI) can be converted with a 1-tank system, enabling them to start directly on PPO. The first condition for realizing a 1-tank system is that a glow plug must be present in the combustion chamber, and it is necessary to install special glow plugs and injectors, and to adjust the injection timing and injection pressure, to ensure prompt starting and efficient combustion.

The photo to the right shows a cross section of an IDI combustion chamber:
A) single-hole Injector, B) glow plug, C) pre chamber, D) cylinder head, E) piston, F) cylinder wall
(photo: Robert Bosch GmbH)



Operating an engine converted with a 1-tank system is very similar as to operate the original engine on diesel. The only difference is the cold start, where the operator must learn to start the engine on PPO – usually it just requires letting the pre-heating work 5-10 seconds longer than when starting on diesel, eventually combined with adjusting the gas a little with the accelerator. The best is to start the engine and let it heat up moderately, rather than letting it heat up by idling or running the engine at full load and/or at high RPMs. Most users prefer a 1-tank system because it is easy to use and does not require changes in habits or give any inconveniences. For these reasons it is often recommended to realize 1-tank system if possible.



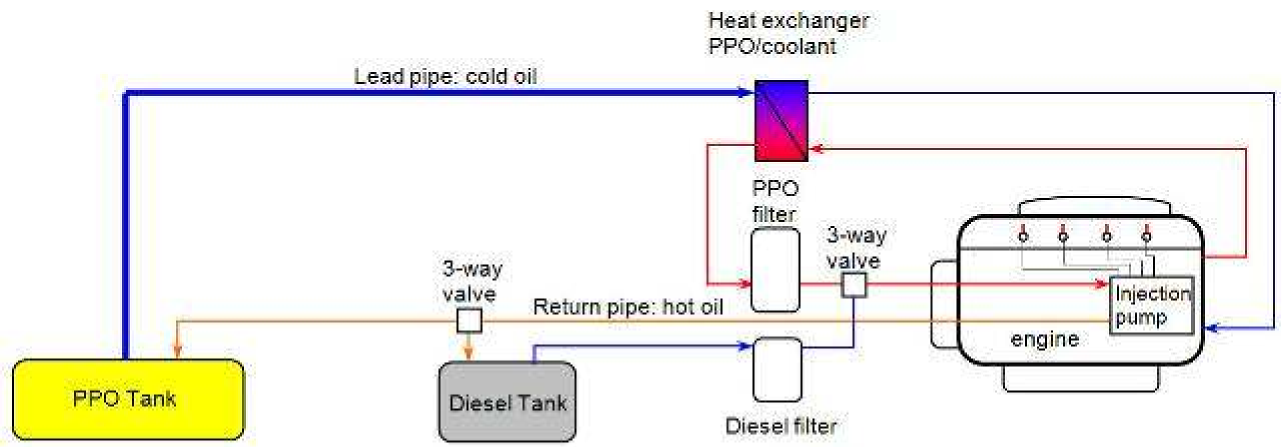
The diagram shows a typical configuration of a 1-tank system, including larger fuel pipes, heat exchanger, electrical fuel heater, injectors, glow plugs relays etc.

3.2.7 2-tank system

Direct Injection engines(DI) are typically converted by a 2-tank system, where the engine starts on diesel as usual, and is switched to heated PPO when the engine has reached operating temperature – either manually by the operator or automatically via a control system, e.g. using a thermo switch in combination with 3-way solenoid valves. Before stopping the engine for cooling down, the operator must remember to switch back to diesel in due time, so the injection system will be purged with diesel and be ready for the next start. The purging time depends on the specific engine and the design of the 2-tank system.

Realizing and operating a 2-tank system is relatively simple, nevertheless there are some challenges to optimize the system, with respect to minimize the diesel consumption and to avoid PPO from being flushed to the diesel tank when purging the fuel system from PPO to diesel.

For DI engines it is often advised to switch to diesel when idling or running on very low load for long time. If the engine has many starts/stops, idling/low load or only running for a short time, the 2-tank system is not suitable because the engine will run most of the time on diesel. The 2-tank system is a little more inconvenient for the user because it's necessary to switch back to diesel in due time before stopping, and to keep an eye on the fuel level in 2 different tanks. For mobile applications the extra tank for diesel takes up space, typically inside the cabin if it's a passenger car or a van, where it increases the risk of spilling when filling up. And of course there will still be a consumption of fossil fuel for the start and stop – typically 10-20% of the fuel consumption.

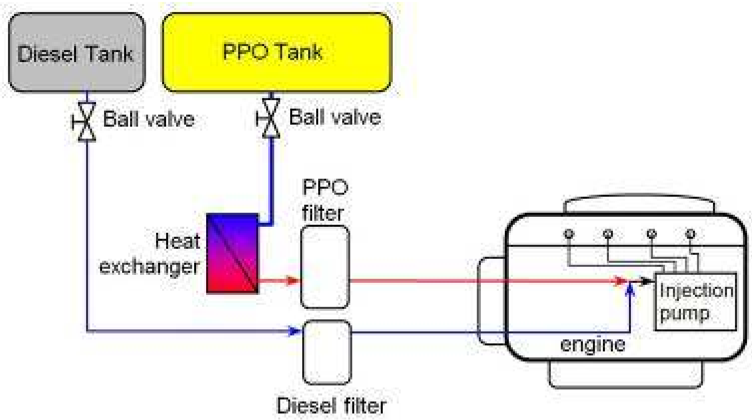


The figure shows a typical configuration of a 2-tank system on engines with the lift pump integrated in the injection pump. It includes larger fuel pipes, heat exchanger, extra fuel tank and fuel filter for diesel, electrical operated 3-way valves for switching between PPO and diesel, etc.

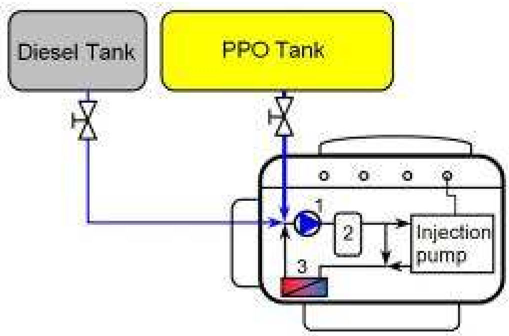
For more basic engines, as often used in Africa for example, with no battery for electric starting, and preheating, it is not possible to realize an electrical controlled automatic fuel switching system, and the conversion system typically consist of the following parts: an extra fuel filter, fuel tank and fuel heating system for PPO, two ball valves (one for each fuel tank), and some hoses and fittings to connect the two fuel lines at the injection pump, and eventually to realize a loop of the return fuel from the injection system.

Challenges are to design the system so that purging time is minimized, and to ensure that PPO is not mixed with diesel in the diesel tank during purging process. The purging time is minimized by minimizing the volume of the common part of the fuel system, from the valve controlling the fuel flowing to the engine and the other valve controlling the return flow. Therefore it is best to use separate fuel filters for diesel and PPO. It will require an extra control valve on engines with external lift pump, because it is usually placed before the fuel filter.

Mixing PPO to the diesel tank can be avoided by delaying the return valve, so that the return fuel will continue flowing to the PPO tank during the purging process, but this will increase the diesel consumption. Another way is to loop the return fuel back to the injection pump instead of the diesel tank, when running on diesel. This will minimize the diesel consumption but will increase the purging time considerably because the fuel in the common part of the injection system is replaced only as fast as the engine consumes fuel. With return flow to the fuel tank, the fuel in the injection system is changed much faster, because the total amount of fuel displaced by the lift pump though the supply and return lines can be up to 5 times as much as the actual consumption.



Simple 2-tank system for engines without electric system and fuel lift pump. The fuel is fed to the engine by gravity, and the switching between diesel and PPO is done manually by 2 valves. The heat source for the heat exchanger depends on the options available for the specific engine, e.g. coolant, lube oil, hot air or exhaust.



Another variant of a simple 2-tank system for engines without electric system, but with original fuel lift pump (1). The original fuel filter (2) and a heat exchanger (3) are installed within a loop of the return fuel from the injection pump. By looping the fuel the fuel heating can be realised by a low capacity heat source, e.g. a fuel hose turned around the cylinder of the air cooled engine. With only 1 fuel filter in the loop, the purging time between diesel and PPO is longer, which is not suitable for an engine running only for a short time, but for an engine running permanently for many hours it is not a problem.

3.2.8 **Important technical issues for PPO conversion**

3.2.8.1 Glow system

A glow plug in the combustion chamber is used to preheat the combustion (pre) chamber before the cold start of the engine. This is an important device for realizing a 1-tank system. Typically glow plugs are a few mm longer than the original glow plugs that are installed, in order to add more heat to the combustion (pre) chamber before the start, and so that the fuel spray from the injectors reaches the hot tip of the glow plug. It is also an advantage to combine longer glow plugs with a post glow system, which means that the glow plugs are activated also a few minutes after the cold start, and thereby improve the combustion of the cold engine. It requires a special kind of glow plugs designed for post glow applications – otherwise the glow plugs will burn out rapidly.

There are other kinds of glow systems, such as a glow coil placed in the air intake manifold, which will ignite a small amount of diesel fuel. Such a system will not work with PPO as fuel, and cannot work with post glow. So the best is to convert such an engine with a 2-tank system. If there is no glow system, the engine should always be converted with a 2-tank system. If the engine is equipped with a fuel-based pre- heating system, typically placed in the air intake manifold, care should be taken that this system will be supplied with diesel.

3.2.8.2 Injectors

There exist many different injectors, and there might be several suitable solutions for the same engine. 1-tank systems require special injectors and increased injection pressure, but for a 2-tank system, usually the original injectors are used, and therefore not replaced unless they are worn. Eventually the injection pressure is increased on 2-tank system depending on the original configuration. Change of injectors might seem complicated and expensive, but often it will improve the performance of a used engine, and even extend its lifetime due to cleaner combustion.

A general rule is that higher injection pressure gives a better atomizing of the fuel and therefore a better cold start and a cleaner combustion. Therefore, the injection pressure should be increased, at least to the maximum within the range specified by the engine manufacturer, or slightly higher. If the injection pressure is increased much higher than the original pressure, it can result in a delay of the injection start and a decrease in the injected fuel amount. So it might be necessary to compensate for this by advancing the timing and increase the fuel quantity respectively.

Another general advantage is to use injectors that inject a small pilot injection before the main injection. That makes the combustion of the main injection faster and more complete. Pilot injection can be realized by the shape of the injector needle, or by a 2-spring injector configuration. This relation was also found by the ACREVO study [7].

3.2.8.3 Injection Timing

Correct injection timing is critical to the performance of the engine, especially the cold start. In general, "early" injection increases the combustion temperature and makes the engine sound harder, and gives a better cold start, higher torque and more efficient combustion. Late injection can lead to bad cold start, high exhaust temperature and inefficient combustion, which also can be noticed by grey smoke with an irritating bad smell of unburned PPO.

When adjusting the timing it's good to aim for the earliest value in the range specified by the manufacturer, or even to advance the timing a bit more, e.g. 2° crank shaft compared to the original setting.

Many engines are equipped with an automatic or a manually activated cold start adjustment, which advances the timing and increases the idle speed, thereby improving the cold start. It's important that this function is working and adjusted correctly.

3.2.8.4 Fuel system

Due to the higher viscosity and density of PPO compared to diesel, there will be higher resistance for the fuel flowing from the fuel tank to the engine. Therefore it is important to minimize the pressure drop, typically by increasing the diameter of the fuel lines, to eliminate critical restrictions in the fuel system, and/or to install an electrical lift pump. Usually increasing the diameter of the fuel lines and eliminating restrictions is enough. Critical restrictions can be pre filter in the fuel tank or on the fuel line, or different kind of junctions or connections of the fuel line, with reduced cross section area. Suction of air into the fuel system is also a common troublemaker, so it's essential to be careful with the assembly of all junctions and connections of the whole fuel system, especially on the suction side of the injection pump/lift pump. For trouble-shooting it's a good idea to install a short piece of transparent fuel pipe just before the injection/lift pump, to see if there are any air bubbles in the fuel.

3.2.8.5 Materials

The materials used in the fuel system should be selected to prevent any interaction between the material and the PPO.

Copper should be avoided due to its catalytic effect on PPO, leading to decreased oxidation stability of the PPO. Zinc-coated steel surfaces (except if electro-coated) also reacts with PPO, which forms solid fat with a high melting point. The fat forms a coating which can release in smaller pieces and flow with the PPO and block fuel filters. Use stainless or carbon steel instead.

The photo shows an inline pre filter which was partly blocked by small particles of solid fat, released from a small piece of zinc coated steel in the PPO tank.

Many modern fuel hoses are resistant to PPO. Typically PA12 hoses are used for hard hose connections, and fat resistant rubber hoses for the soft flexible connections, e.g. NBR or VITON rubber. Special hoses have been developed to resist biodiesel, which are also suitable for PPO.

3.2.8.6 Lift pump

On most diesel engines a lift pump is used to suck the fuel from the tank and supply the correct fuel pressure to the injection pump. It's typically mechanical pumps, either integrated in the injection pump or an external device attached to the engine or the injection pump. Some engines have no lift pump, so the fuel pressure is generated by gravity due to a lifted fuel tank. On several newer vehicles, an electrical lift pump integrated in the fuel tank generates the fuel pressure. When converting the engine to PPO, the system should ensure that both suction and fuel pressure are kept within the limits originally designed for that engine.

A vane type lift pump integrated in the injection pump usually works within a range of 0.2-0.3 bars suction. If the suction increases, e.g. to 0.4-0.5 bar or more, the injection pump can have insufficient fuel pressure and fuel quantity, leading to malfunction of the injection and loss of power. There is also an increased risk of damaging the injection pump. For the conversion and for trouble-shooting later on, it is useful to measure the vacuum in the fuel line before the injection/lift pump , using a vacuum meter with scale 0-1 bars.

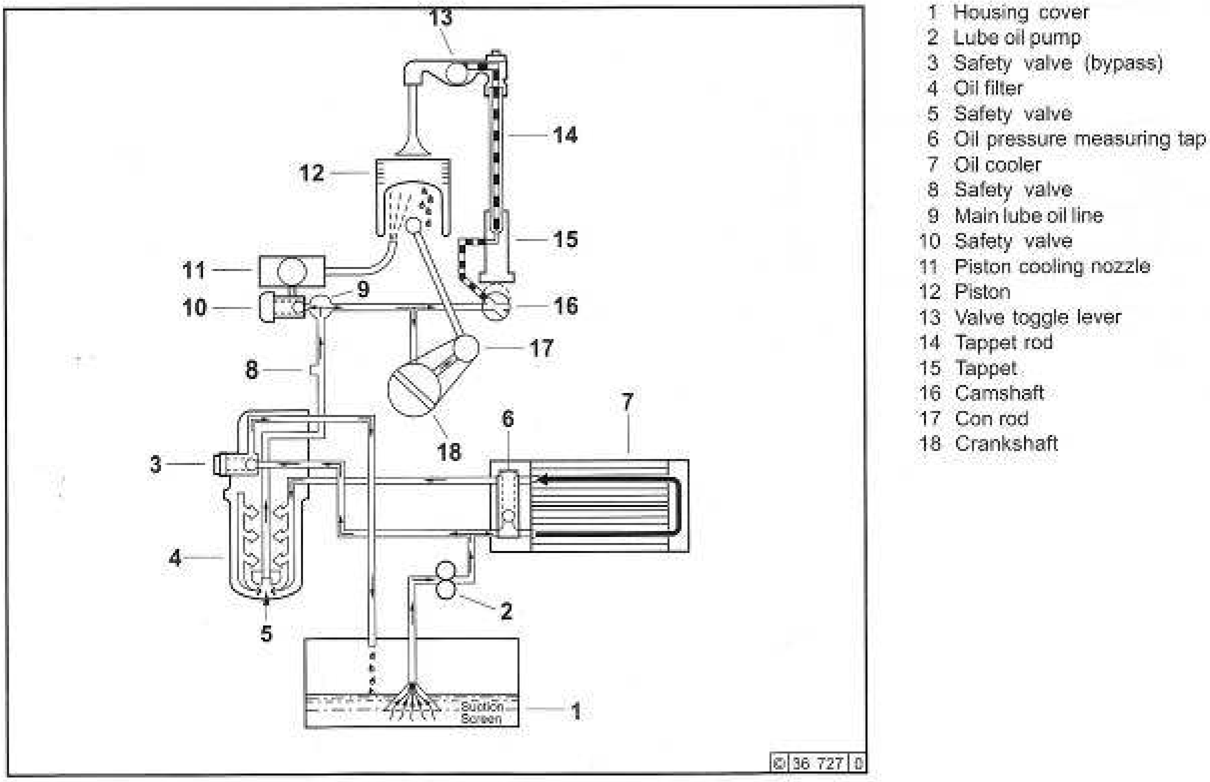
External / mechanical membrane type lift pumps are usually installed before the fuel filter, and should overcome the pressure loss through the fuel filter, and still maintain a positive pressure at the injection pump – typically 0.1-0.5 bars overpressure. The membrane material may not be suitable for PPO, and therefore requires being changed more frequently. Some pumps cannot supply enough positive pressure with cold and high viscous PPO. This situation could be avoided by a 2-tank solution, or modifications could be made to the lift pump, or an external electrical lift pump could be installed either to assist or replace the original lift pump. Keep in mind that the supply pressure at the injection pump should be within the originally specified limits.

3.2.8.7 Fuel heating

Heating the PPO is commonly used to reduce the viscosity and eventually melt solid or semi-solid fats flowing in the liquid part of the cold PPO. The heat is typically introduced before the fuel filter in order to reduce the pressure drop through the fuel filter, and to prevent the filter from being blocked with solid fats in the PPO. The reduced viscosity also enables the injection pump to handle the PPO, and it improves the performance of the injectors (atomizing). The PPO is typically heated with excess heat from the engine, which always is available from an internal combustion engine (60-70% of the energy content of the fuel). Fuel temperatures around 60-70°C are typically reached by water cooled engines, using the coolant as a heat source, and is self limiting due to the thermostat controlled coolant temperature. If the engine after the conversion is meant to run on diesel from time to time, it's wise not to heat the fuel above 70°C due to the lubricity properties and lower boiling point of diesel, which can lead to decreased lubricity and fuel steam bubbles in the fuel, causing wear and mechanical stress in the injection system, and malfunction of the fuel injection. If the fuel temperature can exceed about 70°C, e.g. using the lube oil or exhaust gas as heat source, the fuel heating system should be disabled when running on diesel. As long as the PPO is liquid, heating the fuel tank and the fuel lines is not necessary – and it is better for the stability of the PPO in the tank.

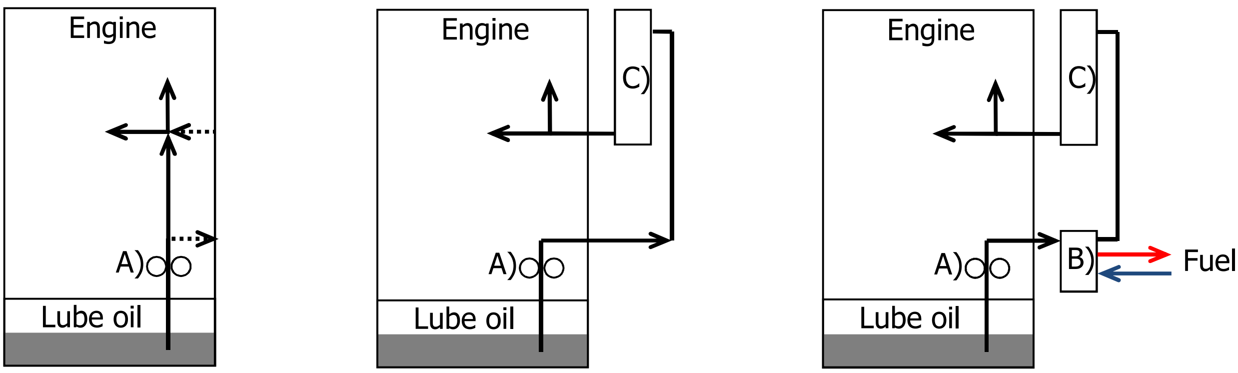
Water-cooled engines usually reach operating temperature around 80-90°C relatively fast, and the coolant is a good heat carrier. An easy and good way to heat the PPO is by a coolant-PPO heat exchanger. It can be homemade, but there are many suitable plate-heat exchangers already used in automobile industry that are designed for fuel cooling in modern diesel engines. These are made from aluminium, and typically have a heat transfer area of 300-600cm^2 for passenger car engines. If a homemade heat exchanger is considered, it must be realized that it needs quite some contact area and hence may not be too small to be effective.

On air-cooled engines the heat source can be the lube oil, the hot air stream and radiation from the engine or the exhaust gas. The lube oil heats slower than the coolant in a water-cooled engine, and oil is a less efficient heat carrier than water, but still is it a good solution to heat the PPO by a lube oil-PPO heat exchanger. Due to lower flow and heat capacity of the lube oil compared to a coolant system, the heat exchanger should have a larger heat transfer area than in a coolant-based system.



The figure shows the lube oil circuit on an air cooled Deutz 910 L03 engine (Source: Deutz AG)

If the engine has an external oil cooler, e.g. like a Deutz 910 (see figure), it is possible to connect the heat exchanger to the hot lubrication oil flowing to the oil cooler. Or the engine might have plugs for connecting external devices to the lubrication system, e.g. external oil filter or cabin heater. It is necessary to get detailed technical documentation for the engine, showing the lube oil circuit, including data for oil pressure in order to study how the lube oil system is designed, and to figure out which maximum pressure can occur where the heat exchanger is connected to the lube system, to avoid blasting the heat exchanger. It is also important to fit the heat exchanger so that it cannot disturb the function of the original lube system.



Three variants of a simplified lube oil circuit of an air-cooled engine. Left: the engine is prepared for connection of external oil cooler, oil filter or cabin heater (C). Centre: External oil cooler is installed. Right: a heat exchanger (B) has been connected to the lube oil pipe between the lube oil pump (A) and the external oil cooler (C)

Using the exhaust as heat source is also an option, which might seem attractive, but it also has disadvantages. There exists a technical risk that the PPO is overheated because of the high temperature of the flue gas (up to 500°C) leading to cracking of the fuel, and a fire risk, especially if diesel fuel is leaking inside or near the exhaust system. Due to very high difference between fuel and exhaust gas temperature, the system cannot be self-limiting. The fuel temperature should be controlled by precise design and control of the fuel flow. If the injection system includes a return line to the fuel tank, the fuel flow will be much higher than the fuel consumption, and vary a lot depending on the engine speed, load, fuel temperature, condition of fuel filter etc.

Fuel heating can also be realized electrically, or combined with one of the solutions described above. Some car brands have electrical fuel heater for diesel, and retrofit solutions exist, but many of these will switch off before the fuel has reached a temperature suitable for PPO. Therefore an electrical fuel heater should be well selected and eventually modified for PPO. Heating PPO with a glow plug may seem attractive, but there is a high risk that the PPO will crack/burn due to the concentrated heat transfer of high power and a very small area. Generally it is advised not to use electrical PPO heating alone (or at all) but to use coolant or lube oil as the main source of heat.

3.2.9 Service and maintenance after conversion to PPO

After the conversion, the engine should generally be serviced and maintained as if it was still running on diesel.

3.2.9.1 Fuel filter

Just after the conversion of a used engine, the *fuel filter* can quickly become blocked because the PPO can release dirt and deposits in the fuel tank, and due to the higher density, PPO can lift and move more dirt than diesel fuel. If the PPO fuel is clean, the fuel filters can last as long as with diesel. Nevertheless, a blocked fuel filter makes more problems with PPO than with diesel, so it is a good idea to change the fuel filter at least once a year, e.g. before a cold season.

3.2.9.2 Lube oil and filter

Regarding change of *lube oil and filter*, it can be kept on the same service interval as for diesel for IDI engines. For DI engines it is usually recommended to halve the change interval compared to operation on diesel (change the oil twice as often). That is because DI engines have a stronger tendency to get PPO diluted in the lube oil, which can lead to polymerization (see figure 5.7). To prevent this from happening, it's important to regularly check the level and consistency of the oil in the engine. If the level has increased it's a clear indication that the lube oil has been diluted with PPO. The oil should be changed and the reason for the increased level should be found. Reasons could be the many starts on PPO or a lot of idling/low load operation, or it could be caused by inefficient combustion due to low temperature of the engine, wrong adjustment, bad quality PPO or a defect injector. On some engines the injection pump is attached to the engine in a way that enables fuel from a defect gasket to leak into the lube oil.

If the engine consumes some lube oil, it's possible to get increased PPO concentration without an increase in oil level, so it is important also to view the consistency of the lube oil when checking the oil level of the cold engine. If the oil suddenly seems more viscous and sticky, it's a sign of beginning polymerization, and the oil and filter should be changed immediately after running the engine warm.

3.2.9.3 Injectors

With a good quality, clean PPO the *Injectors* will last at least as long as with diesel – e.g. 150-200.000km, or a corresponding amount of operating hours, e.g. 3500-5000h.

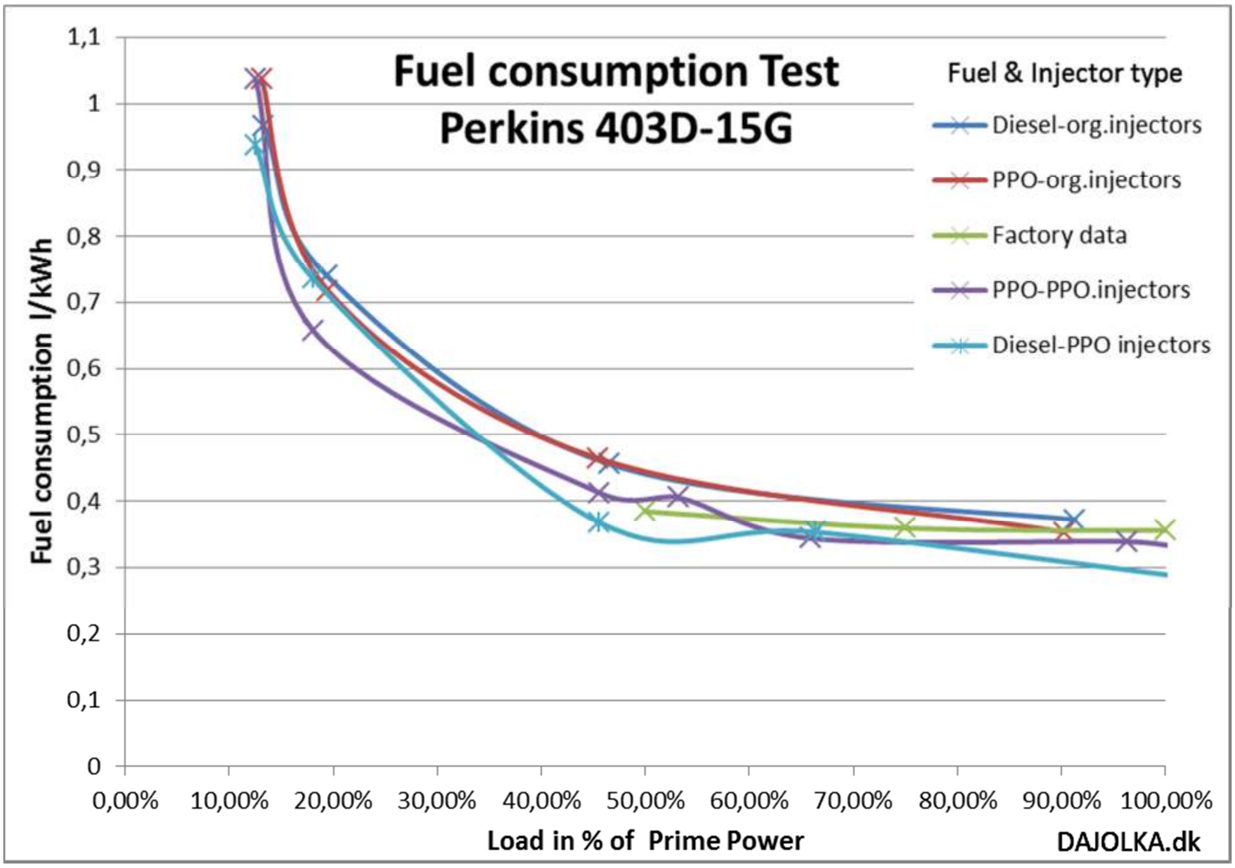
3.2.9.4 Glow plugs

Glow plugs in a 1-tank application will typically last shorter because they are used more. Typically for a passenger car, good glow plugs last 2-4 years. For 2-tank system, the wear on the glow plugs are unchanged.

3.2.10 Fuel consumption

The fuel consumption when operating a modified diesel engine on PPO is comparable to the fuel consumption as when operating the same engine on diesel. Theoretically PPO contain 5% less energy per liter, but because PPO have other advantages, mainly that is contain 11-12% oxygen, where diesel contains zero oxygen, the PPO is often combusted more efficiently that diesel.

In 2013 we converted Perkins 403D genset in our workshop, and I took to chance to make some detailed test of the specific fuel consumption, both on diesel and PPO, and both with original injector nozzle and the PPO injector nozzles.



The results of our test is shown on the diagram above.

The conclusions are:

- that the measured fuel consumption matches well with the factory data, but factory data are only available above 50% load.
- that the fuel consumption on PPO and diesel are very similar
- that the fuel consumption with PPO nozzles seems a little lower both for diesel and PPO compared to the fuel consumption with the original injectors.
- That the genset preferable should be operated on loads above 40-50%

3.3 Fuel quality

It is generally accepted that the German norm for rape seed oil as fuel, DIN51605, should apply to pure vegetable oil used as fuel in converted diesel engines. The norm specifies 8 natural parameters, which are more or less specified by nature, and 7 variable parameters, which are influences by harvest, handling and storing of the oil seeds, and by the process, handling and storing of the oil. For other vegetable oils than rape seed oil, the DIN51605 can be used as reference, but each crop might have different natural and variable parameter relevant to PPO as a fuel.

The purpose of the quality standard is to ensure that the vegetable oil do not contain components and impurities which will weakening its own stability, and to limit the level of "strangers" in the fuel, which can negative impact on the combustion efficiency, leading to increased emission level and deposits in the engine.

3.3.1 DIN V 51605(2011) – Quality Standard for Rape Seed Oil as engine fuel

The limits specified in DIN V 51605 (2011)[3)] is displayed in the table below. As indicated this is the version of the standard which was valid until December 31st 2011. These are limit are relevant to most engines found in developing countries, since the new and current version of the standard specifies limits which are relevant modern European vehicles with particulate filters in the exhaust system, and which should meet the newest emission norm for vehicles in Europe.

Parameter	**Limit**	**Unit**
Characteristic/natural properties [1)]		
Density at 15 °C	900 - 930	kg/m³
Flashpoint Pensky- Martens	min. 101	°C
Kinematic viscosity at 40 °C	max. 36,0	mm²/s
Calorific value (incl. H2O –Correction)	min. 36.000	kJ/kg
Cetane number	min. 40	-
Carbon residue CCR (from Original)	max. 0,40	% (m/m)
Iodine number	95 - 125	g Jod/100 g
Sulfur content	max. 10	mg/kg
Variable properties [2)]		
Total contamination	max. 24	mg/kg
Acid number	max. 2,0	mg KOH/g
Oxidation stability	min. 6,0	h
Phosphorus content	max. 12	mg/kg
Earth alkali content (Ca + Mg)	max. 20	mg/kg
Ash content	max. 0,01	% (m/m)
Water content	max. 0,075	% (m/m)

1) The natural properties which are independent from the process, handling and storing.
2) The variable properties which are influenced by the process, handling and storing
3) A new version of DIN V 51605, with reduced limits for ash building components, were introduced by January 1.st 2012, especially to meet requirements for the newest type diesel engines with particulate filter installed. The limits in the table above are from the DIN norm before January 1st, and are suitable for diesel engines without particulate filter.

The following parameters are the most important for a safe operation of diesel engines on PPO.

3.3.2 Water content

Water can emulsify in PPO up to approximately 0,1% (1000PPM). Above this limit, water can separate from the PPO as free water which can damage the injection system, and which can lead to increase acid no. of the PPO due to Hydrolysis [2]. In order to avoid free water in PPO fuel, the limit is set at 0,075% (750PPM), to keep some distance to the saturation point of emulsified water in PPO.

In Crude Palm Oil(CPO) we have measured up to 0,5% (5000PPM) water, which is far too high to use in an engine, and far too high for the stability of the CPO during storing, while the acid no. can increase due to that. A reason for the high water content can be that phosphor lipid and other unwanted ingredients acts like an emulsifier between water and vegetable oil.

3.3.3 Acid no. / content of Free Fatty Acids (FFA):

The Acid no. expressed the amount of Free Fatty Acids in the vegetable oil, and is one of the most critical parameters when using vegetable oil as fuel in diesel injection system. One major problem is that vegetable oil with high level of FFA becomes abrasive to sensitive component in the fuel injector nozzles and to the fuel injection pump, which can generate permanent problems for the engine performance - very rapidly if the Acid no. is high, which means more than approximately 4 mg KOH/g. Another problem is that vegetable oil with high acid value reduces the stability of the lube oil, due to dilution of the lube oil by unburned vegetable oil. If the injection system is damaged the engine will burn the fuel less efficient, and more unburned PPO will dilute the lube oil (and generate deposits in the engine), so the problem will emphasize itself.

Its not possible to see, smell or taste on the vegetable oil if the acid no. is too high.

The Acid no. is determined by titration, where it is possible to measure the amount of FFA. There exist a stoichiometric relation between the acid no. and FFA level. 1% FFA corresponds an acid no. of 2,0 mg KOH/g PPO, or 2,85 mg NaOH/g PPO, dispending on if the titration solution is based on KOH or NaOH. Titration can be done in the field to get a good impression of the level, but it is advised from time to time to have the results confirmed by an professional laboratory.

The Acid no. is influenced by hydrolysis (by presence of free water)[2], enzymes[3], catalysts like cobber(Cu)[2], oxidation by contact to atmospheric air, light/sun radiation, fungi's etc.

3.3.4 Phosphor content

Phosphor is a stranger in the combustion process, and lead directly to an increase emission of P related particles and P deposits, which has an abrasive behavior, and indirectly to increase of unburned fuel duel to a reduction in the combustion temperature. The limit in the DIN51605 v2011 fuel standard is 12 PPM.

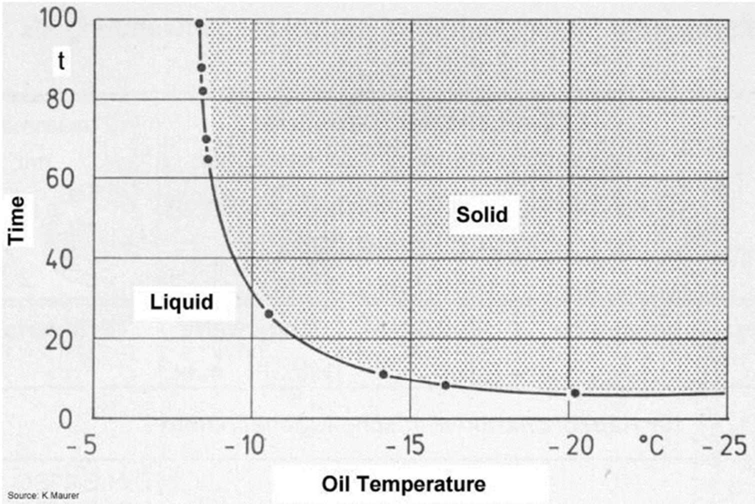
3.3.5 Alkali content (Ca+Mg)

As with phosphor, alkali components Ca and Mg, are strangers in the combustion process and should be kept at a low level. We have very often experienced that low alkali contents is found together with low content of phosphor, so therefor we normally only test the oil for phosphor, and only if it is very important for the documentation of the quality, we also test it for alkali content. The limit in the DIN51605 v2011 fuel standard is 20 PPM.

3.3.6 Melting point

The melting point of PPO depends on the source of the vegetable oil, and is normally only relevant to care about if the application operates at temperatures below the melting point of the fuel, e.g. approximately 5-10 °C for Jatropha oil, or around 35-40°C for Palm oil.

The phase shift from liquid to solid vegetable and back happens as a function of both temperature and time. The following curve shows this relation for rape seed oil. The tendency will be the same for other kinds of vegetable oil, but the temperature at which the phase shift start to happen, will be different for each kind of oil.



Solid/liquid phase shift of rape oil as function of temperature and time.

3.3.7 Contamination

The limit for contamination with impurities is 24mg/kg (24PPM), which is quite low. The purpose is to avoid blocking of fuel filter, but also to avoid unnecessary wear on injectors nozzle and injection pump. PPO can easily contain 4-6 times more impurities, which are not visible for the eye, and which will not sediment in a sample. Therefor it is highly recommended always to pass the PPO though a fine filtration system to be sure that the limit for contamination is not exceed. From German research we have learned that cartridge filters with cartridges made from cotton string is the most efficient. Its best to do the filtration in 2 steps, with a 5 micron cartridge first, followed by 1 or ½ micron for the last step.

3.3.8 Alkaline metals(Na,K)

The content of Alkaline metals(Na,K) in vegetable oil is not mentioned in the DIN51605 standard, while it is normally not relevant for PPO as fuel. But it is relevant for this project because the CPO to PPO process includes a saponification process to remove Free Fatty Acids(FFA), using NaOH to neutralize the FFA´s. The FFA´s are converted to soap, which should be removed by gravity separation and filtration.

Alkaline metals(Na,K) can be present in the vegetable oil as free NaOH or KOH left from the saponification process, or as integrated part of soap created from the same process.

Since standards for Biodiesel (trans esterified vegetable oil) includes limits for alkaline metals(Na,K), we suggest to use these limits. Several Biodiesel standards from different countries are published in Gelbes Heft 69(page 34)[4], specifying 5-10 PPM as limit, and the ASTM standard for biodiesel specifies 5 PPM as limit [6].

We suggest to use 5 PPM as limit for Alkaline metals(Na,K).

3.3.9 Soap content

The soap content in vegetable oil is not mentioned in the DIN51605 standard, while it is normally not relevant for PPO as fuel. But for this project it is relevant because the CPO to PPO process includes a saponification process to remove Free Fatty Acids(FFA), using NaOH to neutralize the FFA´s. The FFA´s are converted to soap, which should be removed by gravity separation and filtration.

The soap content is relevant for Biodiesel (trans esterified vegetable oil) quality, because saponification processes are a part of the biodiesel manufacturing process. Nevertheless we have not found limits for soap content mentioned directly in Biodiesel quality standards.

A limit of 50 PPM (0,005%) soap is mentioned in the ALINORM 99/17 in Gelbes Heft 69(page 39) [4]. And soap limits can be calculated according to the ASTM limits for Alkaline metals(Na,K) [5]. If NaOH is used to neutralize the FFA´s, the limit for soap is calculated to 41PPM.

We suggest using 40 PPM as the limit for soap.

4 Training Sessions

During the mission was planned several training sessions, on one side working on the CPO to PPO process, including the fuel quality, and on the other side working on the conversion of diesel engines to operate on PPO. My main task was to conduct training on the engine conversion, but also to contribute to the training issues regarding the fuel process and quality.

Initially I had planned to start with the engine conversion, because that part was well defined, materials and tools was brought for that, and because we have a lot of practical experience in this kind of training. But unfortunately 1 off the 2 bags, which I brought with tools and materials from Denmark, was delayed 4 days in the domestic flight from Kinshasa to Gemena. Therefor the whole group started to work on the CPO to PPO process and the fuel quality issues.

4.1 Training in CPO to PPO process

These training sessions were conducted by the SNV team. Many preparations had been done already. Initially suggestions and guidelines for the CPO to PPO process had been prepared by J.J.Lanting and H.D. Pérez Canales in the report "Small scale crude palm oil refining for rural electrification" [2]. Based on that the SNV team had prepared a practical guide for the process; "GUIDE PRACTIQUE: LA TRASNFORMATION DE L'HUILE DE PALME BRUT À L'HUILE VEGETAL PURE POUR UTILISER COMME CARBURANT DANS UN MOTEUR DIESEL".

I participated mostly in the sideline, and tried to compare the planned CPO to PPO process with a similar process I had seen realized with cotton oil by a farmer in Mozambique in 2009. That process impressed me, while the raw cotton oil had far too high values for FFA, phosphor etc, but the treated oil had very good properties, except for too high remaining's of NaOH and Soap. So my idea was to make a controlled lean FFA reduction process, dosing NaOH according to the actual FFA level measured – but not aim for 100% neutralization, but aim for approximately 0,5% FFA lest in the oil.

A test reaction was carried out to compare the DRC process with the process from Mozambique.

4.2 Training in PPO quality assurance

These training sessions were also mainly conducted by the SNV team. Nevertheless, I were asked to play a more active role in some of the disciplines.

Initially I was supposed to show how to do titration to determine the content of Free Fatty Acids(FFA) in the CPO. I knew already some brief theoretical back ground about the titration, but this was the first time to do titration practical by myself. Therefor my performance in this discipline was honestly not very convincing to anybody, including myself. It was not because the topic was very difficult, but more because the situation occurred suddenly and unexpected, because of the delayed bag with the tools and materials for the engine conversion. Later during this mission I got more confident about the titration theory and practice, and now understand it more thoroughly, and thanks to the project experience I have used it in the field several times after this mission.

I have noticed that the field test of FFA level in Gemena as well as field test I have carried out after that, gives lower FFA results than compared to the ASG laboratory. I suppose that there can be several reasons for that, which should be taken into consideration in the future:

- inaccurate concentration of the NaOH titration solution
- inhomogeneity in the NaOH titration solution -> the bottle should be shaken before every use
- Inhomogeneity in the mixture between PPO, Alcohol and titration solution during the titration process. It might be necessary to try to mix it better, eventually using a fast spinning magnetic mixer.

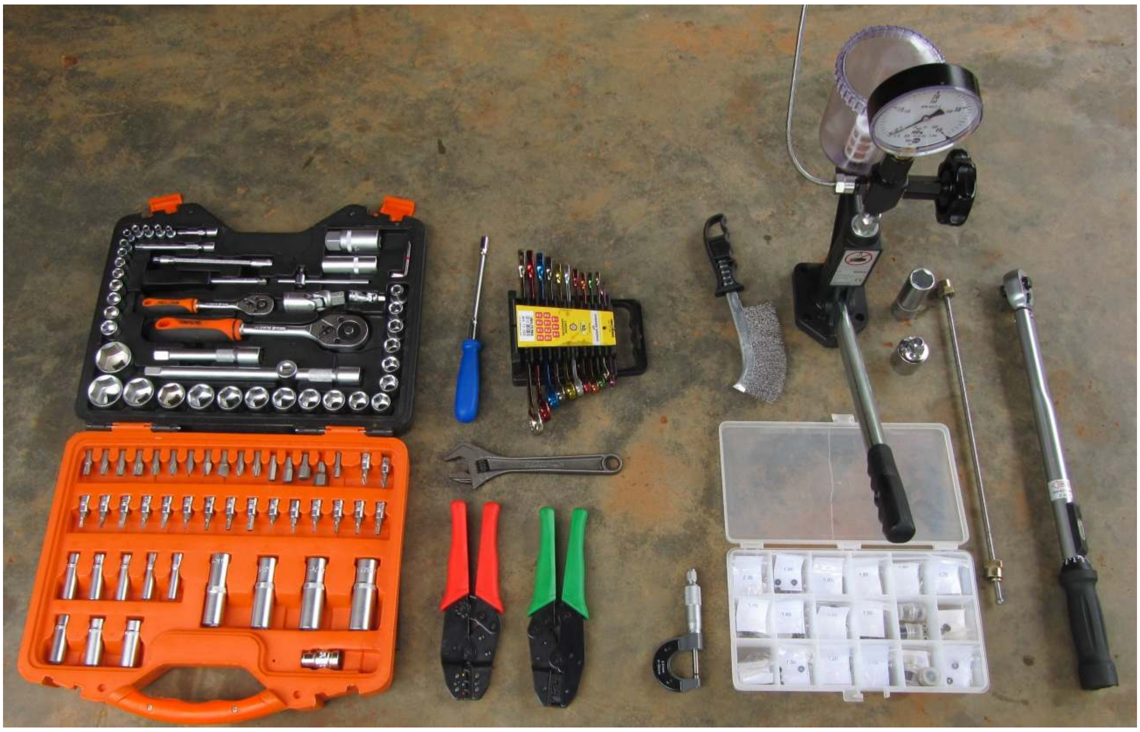
4.3 Training in engine identification and conversion

Before the mission 4 possible engines were identified for conversion, and it was planned to convert 3 of them. For the electricity production for the community, a new Perkins 400 serial genset was purchased. We appreciate and find it very important that the project management had followed our advice to by this kind of engine, which was very suitable for the conversion.

2 others engines were operating in genset at to local partners, George and Jose Augusto, and the last engine was supposed to run the new developed oil press.

4.3.1 Tools and materials

I had brought tools and materials for the conversion of the Perkins genset and for 2 other engines, which were still not 100% identified.



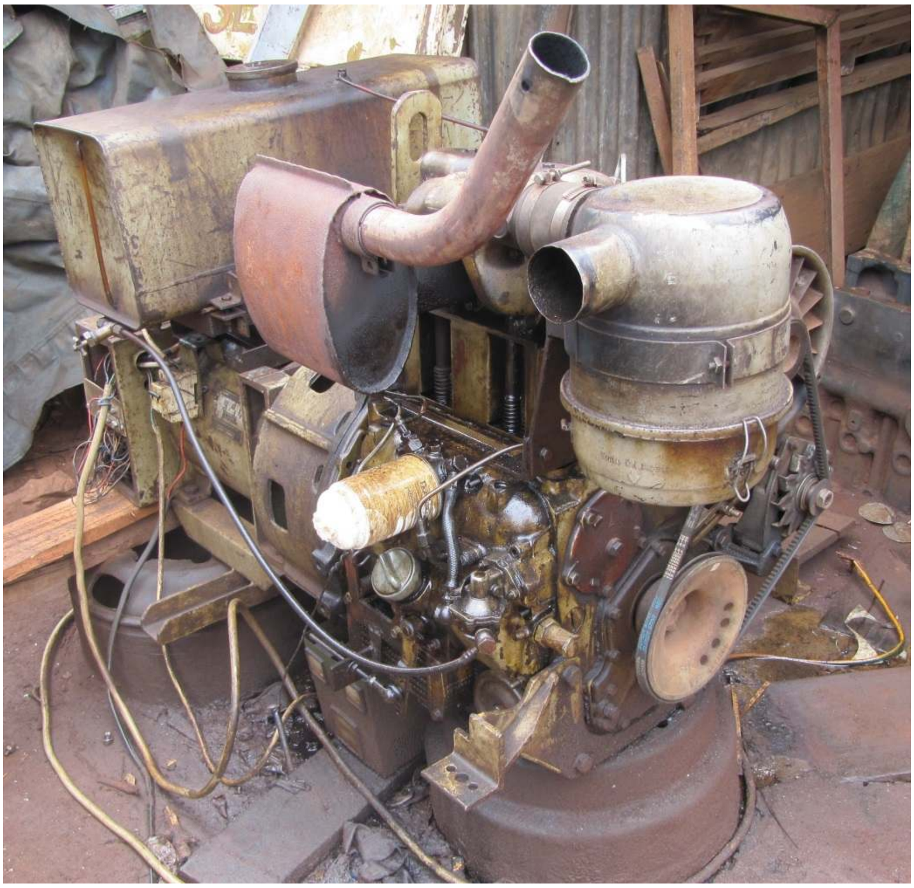
The special tools for the conversion workshop. Including injector tester, torque wrench, adjustment shims and micro meter, crimping tools, Socket set etc.

Some materials for the simple 2-tank conversion systems.

4.3.2 Deutz 912 engine, in genset at George Augusto

George Augusto is running a mechanical workshop where he can repair or manufacture all kinds of machines – including repair of cars and trucks. The genset is supplying power for illumination, refrigerator etc. from sunset to about 24:00 every day.

George is quit a unique person with a lot of practical and technical skills. He has preciously experimented using palm oil in a truck, but faced some problems with blocking fuel filter.

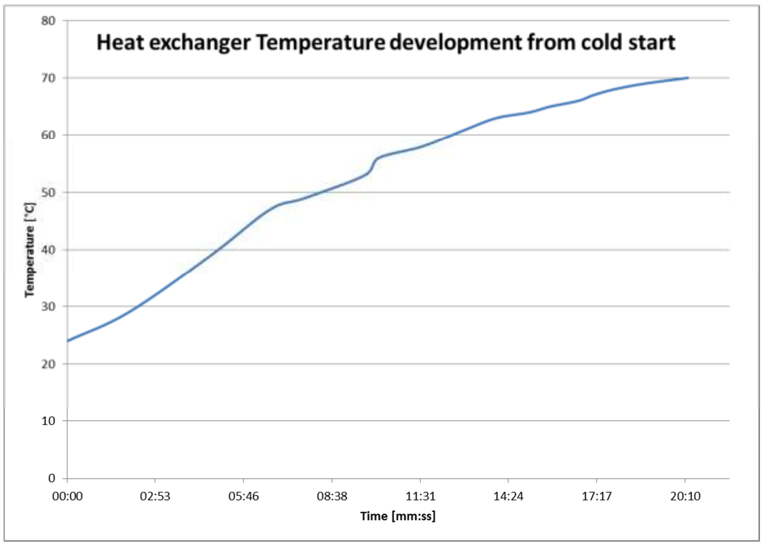


2 cylinder air cooled Deutz 912 engine

George´s Deutz engine is a 2 cylinder air cooled engine with direct injection. The air cooling, the direct injection, and the fact that the engine has already some years behind, doesn´t make it the best choice to convert to PPO, but at George we find it in good hands.

The direct injection system defines that it should be converted with a 2-tank system, starting and running warm on diesel, then switch to heated PPO, and finally switch back to diesel before stopping the engine for cooling down.

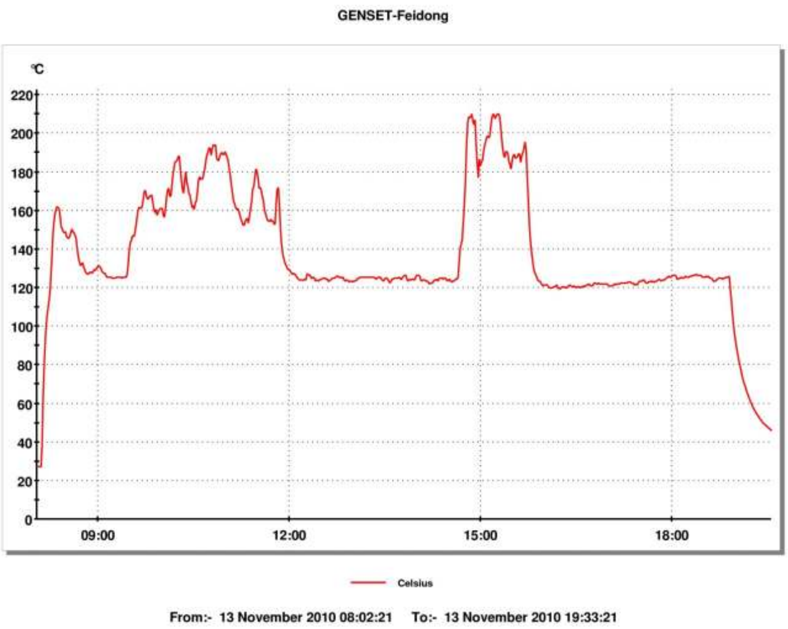
The air cooling is a challenge, while the cooling system is not regulated but cooling at full capacity as soon as the engine is running. Therefor it takes a lot of time for the engine to heat up to normal operating temperature, where is can be switched to heated PPO. Another challenge with the air cooled system is that it is hard to use the waste heat from the engine to heat the PPO.



The curve shows the temperature development on the surface of the air-lube oil heat exchanger, from an air cooled engine similar to George´s Deutz engine, running on 50% load. It reached 60℃ after 12,5 minutes, and 7 0℃ after 20 minutes.

It was clear that several of the participants in the training sessions had already considered the possibility to heat the PPO using the exhaust gas. The general idea was to pass the exhaust gas though the fuel tank. But we do not recognize the exhaust gas as a good solution for that, for the following reasons:

- The temperature of the exhaust gas fluctuate a lot and very fast depending on the load of the engine. At idle its typically at 100°C, but a ½ minute later the temperature can increase to 200℃ when the engine is loaded. And by 200℃ there is a high risk to “coke” the PPO on the hot surface, to initiate polymerization of the PPO, and in other ways to have a negative impact on the PPO fuel.
- It is theoretical possible to design a heat exchanger system which will limit the final fuel temperature, as long as the fuel is moving by pumping But in reality that it close to impossible to realize, especially in a 2-tank system, where the fuel is only moving in the active part of the fuel system.
- Having the fuel in close contact to the exhaust gas increases the risk fire, especially having diesel in the fuel lines.
- For the stability of the PPO it is better not to heat the entire fuel tank, but only heat the PPO coming to the fuel filter and injection system.



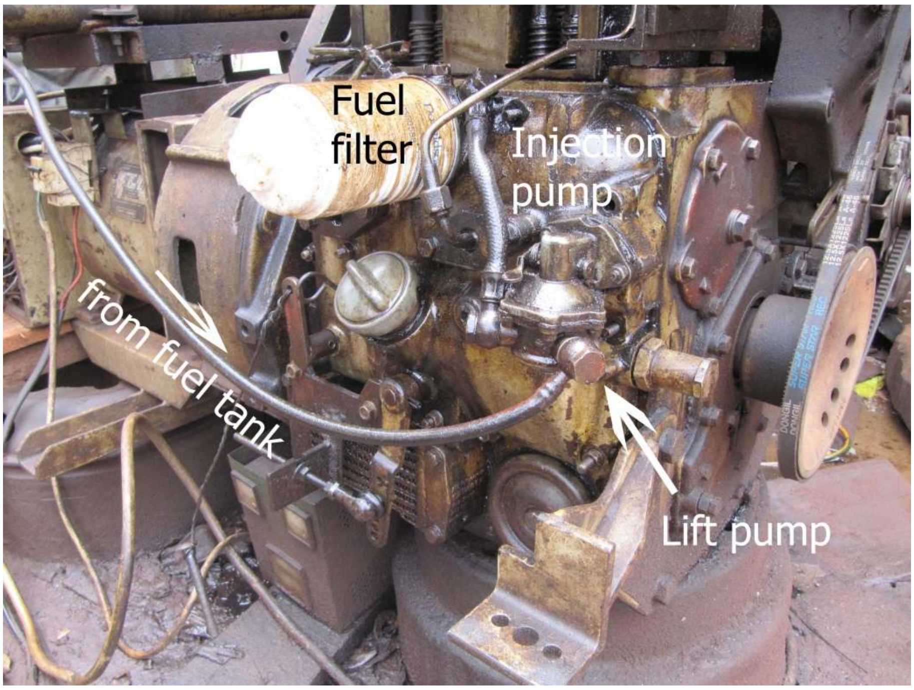
The curve shows the temperature measured on the exhaust pipe from an water cooled engine on a genset. At idle the temperature is around 125°C, but as soon as the genset is loaded, the temperature increases up to more than 200°C.

We have previously worked with several similar engines with air cooling. One way to get access to the waste heat is to use the hot lube oil – which often is cooled down in an external air-lube oil heat exchanger. One challenge is that the lube oil pressure is relative high, around 5-6 bars, so it requires good materials suitable for hydraulic systems. If the system is not realized using suitable materials, the consequences can me loos of the engine, due to loosing lube oil from the system.

The photo shows a PPO-lube oil heat exchanger (left), being connected in serial with the air-lube oil heat exchanger (right) on an air cooled engine.

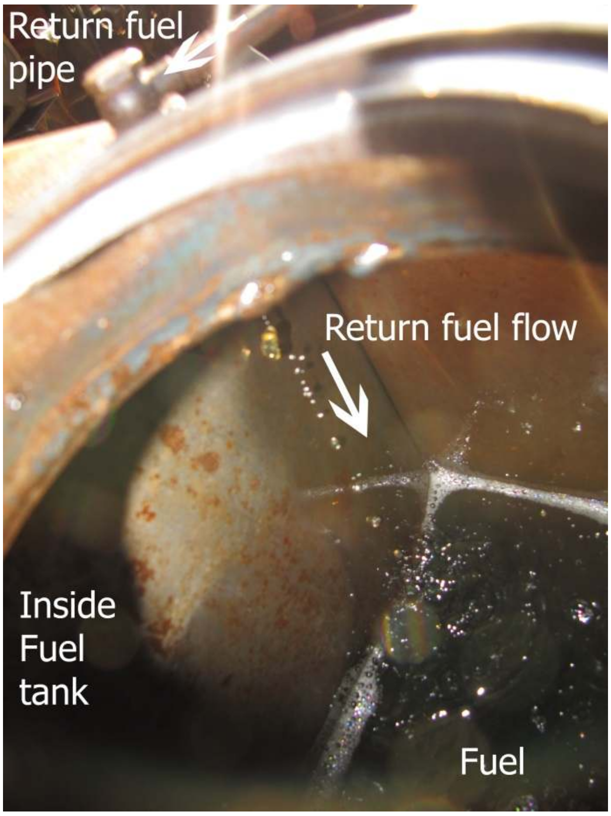
George's Deutz engine has an external air-lube oil heat exchange, and he actually also suggested that himself as en solution. But due to limited availability of time and suitable materials, we decided to realize the fuel heat in a different ways.

The idea was to use the injection pump as heat source, while it was integrated in the engine block, and therefore being heated by the engine block and the lube oil. And also to let the fuel pass though the hot air coming from cooling the cylinders. Both heat sources are not enough for heating the cold fuel coming from the fuel tank, but combining the heating system with a loop of the warmer return fuel, which normally flow back to the fuel tank, but instead let it back to the injection pump, allows the PPO to heat up enough – close to the temperature of the engine block.

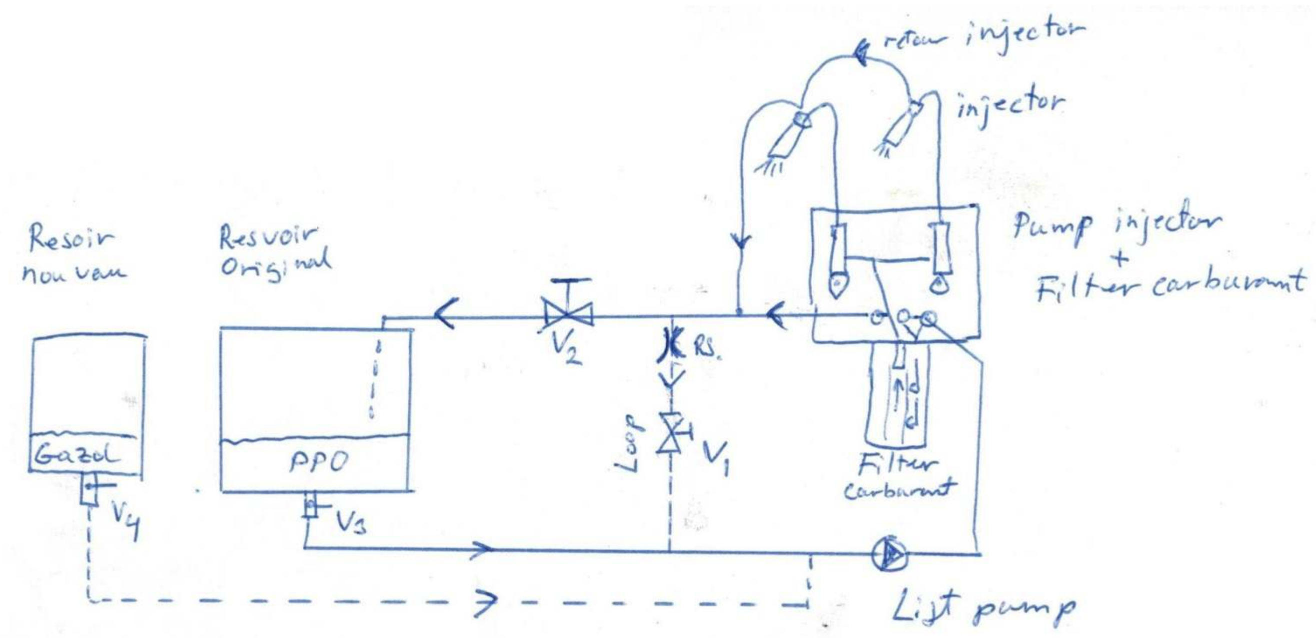


The efficiency of the heating/loop system depends of the fuel flow in the fuel lines. The higher flow the better heat transfer and the better heat transport inside the loop.

This engine has a lift pump and originally the access fuel is returned to the fuel tank. But we realized that return flow was very limited because the fuel had to pass a long and very thin pipe from the injection pump to the fuel injectors, where the return fuel joined with the leak fuel from the injectors. Therefor we moved the junction between return fuel and leak fuel to the injection pump, which increase the return fuel rate a lot, and improved the heat transfer and heat transport in the loop system.

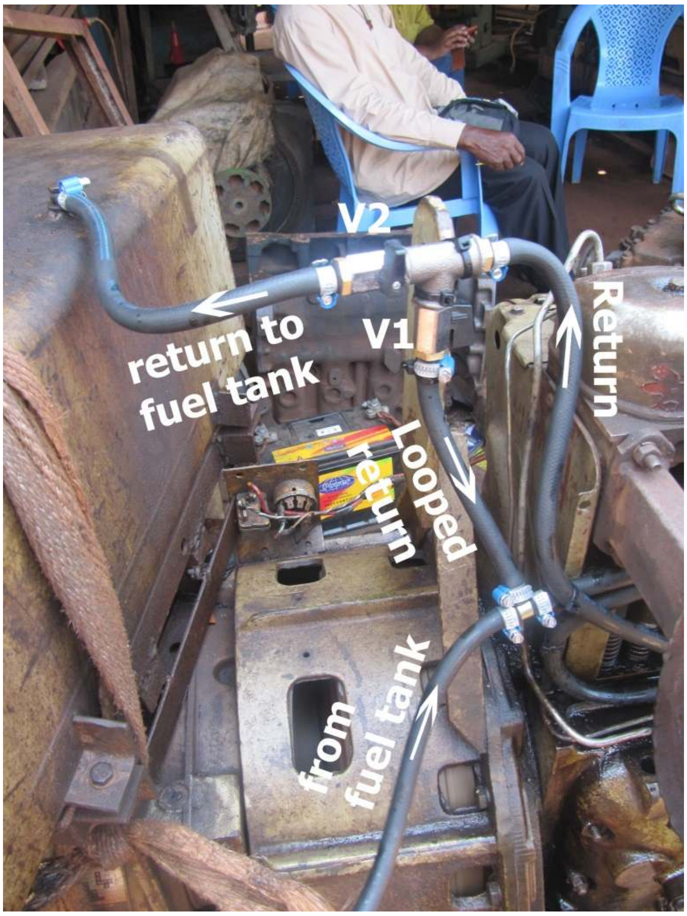


Return fuel flow increase after modifying the fuel cycle.

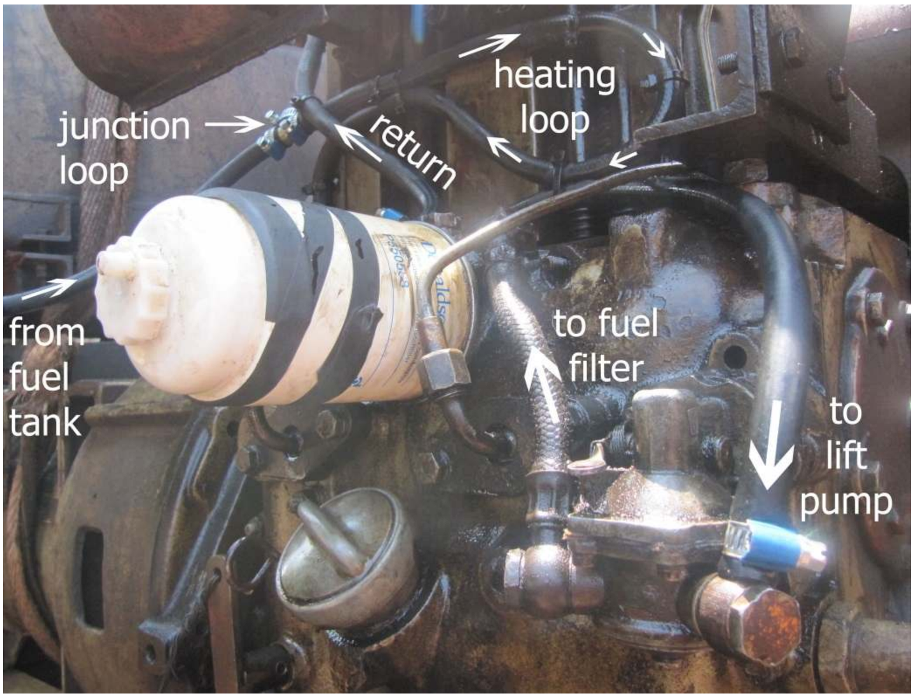


Drawing of fuel cycle for the 2-tank system designed for George Augosto´s Deutz 912 engine.

An extra fuel tank was installed for diesel fuel, and the original fuel tank should be used for PPO. Each tank has a stop valve, which are used to control if the engine is supplied by diesel or PPO. Another 2 stop valves was installed on the engine to control if the return fuel from the injection system should return to the PPO tank(original), or if it should be lopped back to the lift pump for further heating (PPO mode).



Details for fuel cycle after conversion.



Details for fuel cycle after conversion.

The engine seems to smoke a little with grey smoke permanently, both on diesel and PPO. It might be because of wear on the injector nozzles. Therefor we have sent 2 new injectors nozzles and a set of Ø11,5mm adjustment shims for this size of nozzles, for George Augusto, to replace the old injector nozzles, to see if it improve the combustion and reduces the smoke. I have also advised George to increase the injection pressure a little, and to advance the injection begin timing by approximately 2°, in order to further improve the combustion efficiency.

Daniel and Eduard checking the smell from the exhaust, after switching to PPO.

4.3.3 **Perkins 404D in Genset at the cooperative**

The Perkins 404D-22 engine is a 4 cylinder natural aspirated diesel engine with indirect injection. We have advised the project to purchase such engine because it is very suitable for conversion to 1-tank system for PPO operation.

4.3.3.1 The conversion kit

- Injector nozzles
- Glow plugs
- Heat exchanger
- Extra fuel filter
- Electrical heater for fuel filter
- Glow plug controller

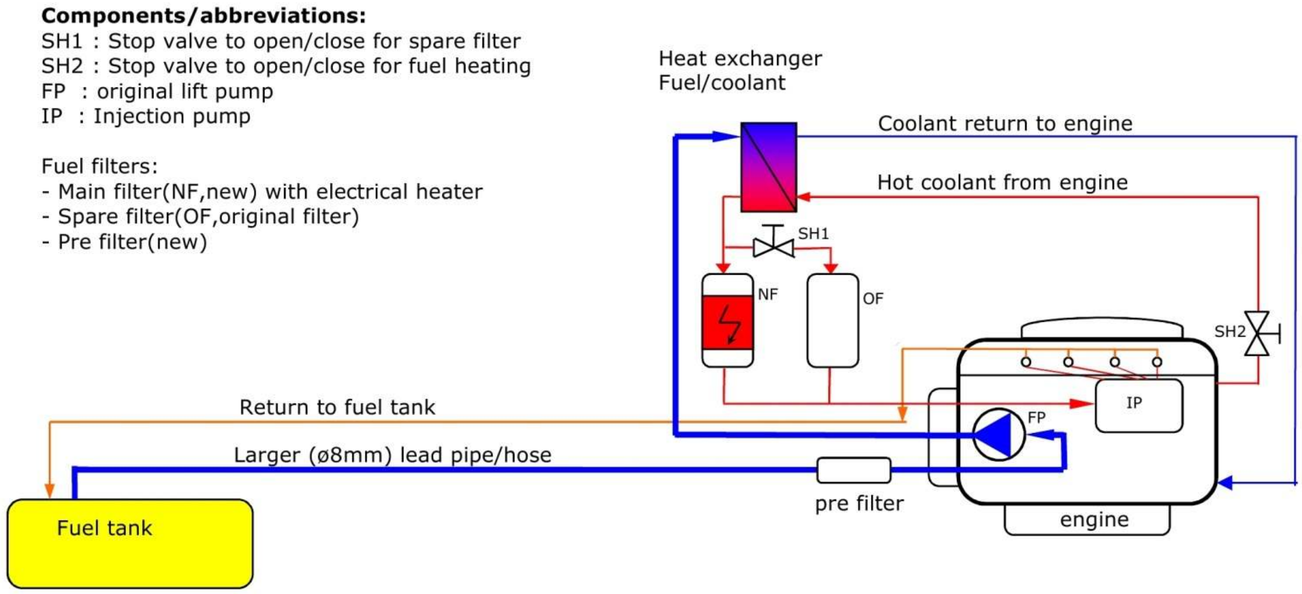
- Thermo switch
- Fuel hoses & coolant hoses
- Hose clamps, fuel fittings, fittings for coolant system.
- Wires, fuse holders, wire fittings, cable ties, etc.
- Pre filter

4.3.3.2 Start and operating procedures

After modification with the 1-tank system, this engine can start directly on cold PPO with a cold engine. Before cranking the engine it is necessary to pre heat the combustion chamber for 10-15 seconds using the glow plugs. Then the engine is started and the glow plugs are kept energized for another 3 minutes, and simultaneously the electrical fuel heater integrated on the fuel filter is energized, in order to preheat the PPO before passing the fuel filter. That is to ensure that the pressure loss though the fuels filter is on acceptable level so that the engine will get enough fuel.

Its better to add a moderate load to the engine shortly after started, than to let it idle, because it heats up faster and burn the PPO better.

4.3.3.3 Modifying fuel cycle



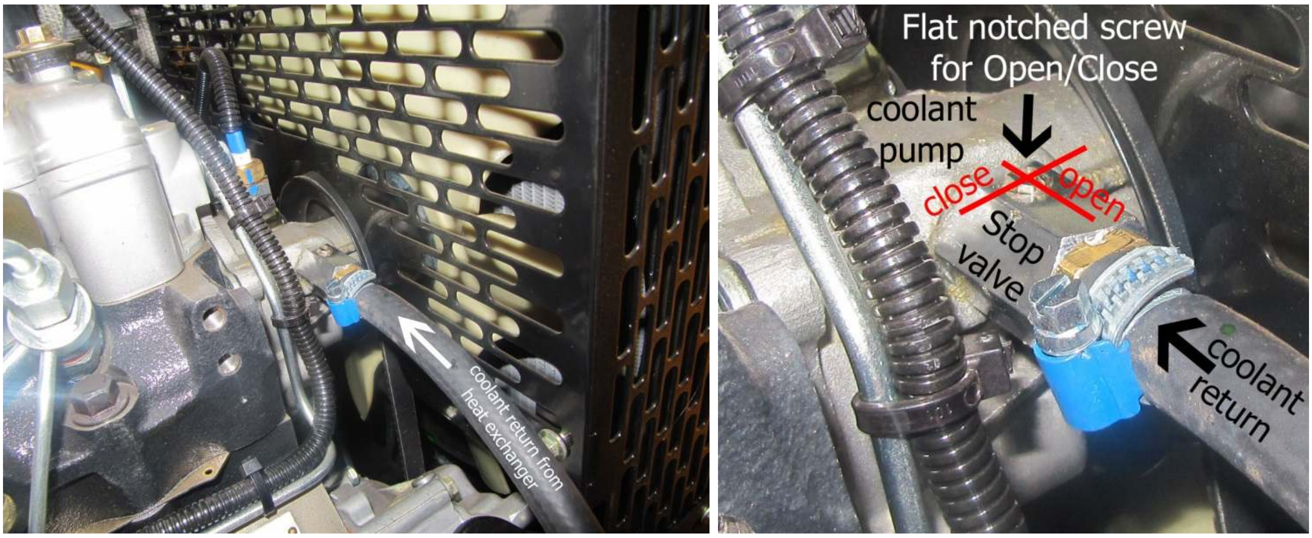
The diagram shows the modified fuel cycle including 2 fuel heating system.

A new fuel filter is installed parallel to the original fuel filter. The main purpose to install the new filter is to install the electrical fuel heater, which will heat the fuel for the first 3 minutes of operation after cold start. The original fuel filter could be removed, but it is left there just to have a spare filter in case the new filter will be blocked. A stop valve is installed to close the fuel flow though the original filter. The valve should only be opened if the new filter is blocked.

4.3.3.4 Installing coolant-fuel heat exchanger

A plate heat exchanger is installed between the lift pump and the fuel filters. Coolant is taken out from the engine at the hottest points in the cooling system, just before the coolant thermostat, and then passed though the heat exchanger and return to the suction side of the coolant circulation pump.

The hot coolant is taken out from the coolant thermostat house (left photo), just before the thermostat, then passed through the heat exchanger(right photo, left side) and returned to the engine at the suction side of the coolant pump (right photo, right side).



From the heat exchanger the coolant is return to the engine at the suction side of the coolant pump(left photo), where we installed a stop valve(right photo), which can be used to close for the coolant flow to disengage the fuel heating.

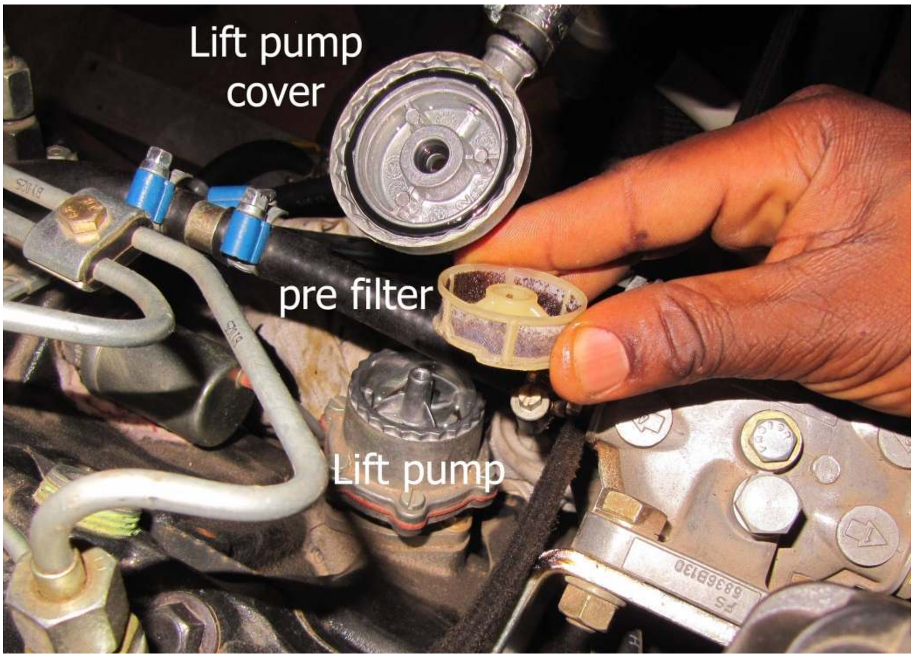
That is a very efficient fuel heating system, and it gets warm already approximately 3-5 minutes after starting the engine. A stop valve is installed on the coolant circuit, so the fuel heating can be disengaged, just in case the user want to operate on pure diesel for long time. It is actually not a problem to run the modified engine on pure diesel, but on the other hand the fuel heating has no advantage.

4.3.3.5 *Remove pre-filter from lift pump*


The manufacturer of the genset has installed an advanced combined pre filter and water separator between the fuel tank and the lift pump.

The water separator is usually not necessary for PPO applications, but is will not make any problems. But regarding the pre filter we decided to remove the filter element because it might block because the cold and semi-solid palm oil, which is not heated before the pre filter.

The pre filter is to protect the lift pump from malfunction, because larger impurities can disturb the function of the 2 integrated non-return valves. Therefor it is advised to install another rough pre-filter to protect the lift pump from larger impurities. It seems that I forgot to bring the pre-filter which I normally install here.

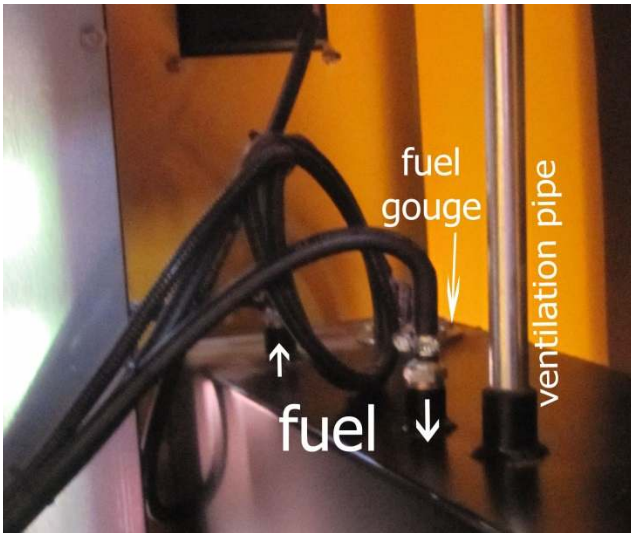


Original pre filter integrated in the lift pump – to be removed for PPO operation.

After this mission to DRC we have realized that the Perkins 400 serial engines have a small pre filter integrated in the lift pump. Because this filter is very small and compact it is likely that it soon can block and make too much resistance for the lift pump – especially with semisolid palm oil. Therefor it is advisable to remove the pre filter, and install a larger pre filter external from the lift pump. Se photo above for how to remove it.

4.3.3.6 Modifying the fuel pickup and return from the fuel tank

The fuel pickup and return was not modified during the training session, and it is usually not necessary to do. But sometime there can be installed a pre filter in the fuel pickup point in the fuel tank, which can block the fuel supply after some time: Such filter should be removed or Ø6mm holes should be drilled in the filter to avoid it from blocking.



The fuel pickup and return lines at the top of the fuel tank.

For this project, using semi solid palm oil, it might also be necessary to change the point of fuel return, while the warm return fuel should help to heat up the cold palm oil, initially around the fuel pickup point, and by time also the entire fuel tank.

The capacity of the heat exchanger many times larger than needed for heating the fuel before the fuel filter and injection pump, so heat is available for heating the fuel tank. The amount of energy which is return to the fuel tank also depends on the flow in the return pipe.

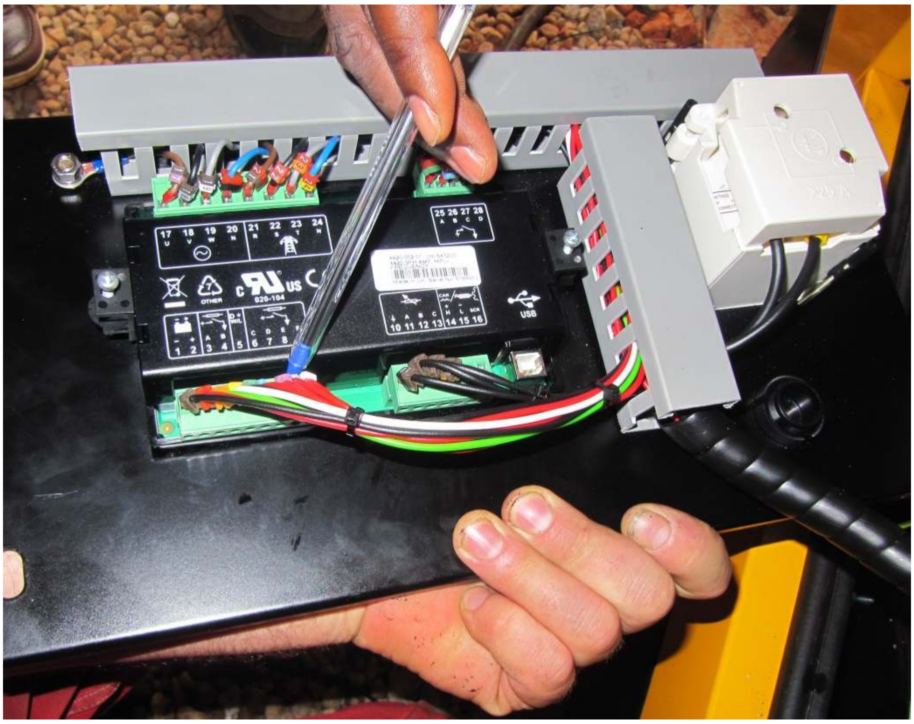
Modifying the Control system

The genset is equipped with a DSE4420 control system, which controls and monitors the engine and electrical grid system. The control system can be configured for many different types of gensets, and if offers also from extra functions which can be configured. The configuration of the control system can be modified using a lap top computer, an USB cable and the software from the manufacturer of the controller.

The engine has glow plugs installed for pre heating the combustion chamber before cold starting, but they are not connected electrically and no glow relay has been installed from the manufacturer’s side – probably because it was configured to work in tropical climate where the engine can start on diesel without pre heating with glow plugs.

But for starting on PPO is it necessary to pre heat before cold starting. A suitable glow plug controller relay is a part of the conversion kit. In order to automate the start procedure, the relay needs to get signal an "ignition" signal from the genset control system – equivalent to the "ignition" signal in the diesel car, which will start the pre heating before cranking the engine for starting.

Therefor the original configuration of the DES4420 controller was modified, in order to make the ignition signal available for the new glow relay. The digital out E was free and available for this purpose.



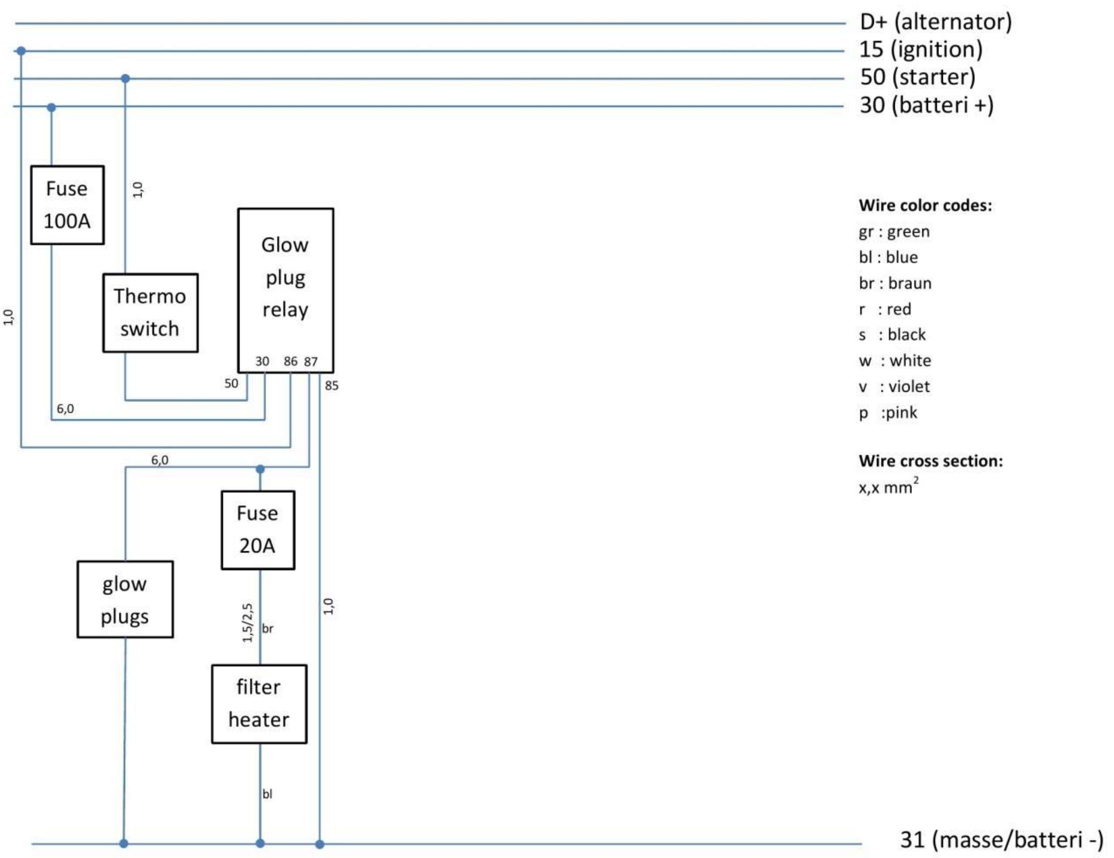
The rear side of the DSE4420 control panel. Digital output E configured for pre heating.

Initially it seemed like the output E was occupied, but it was just connected to a free terminal (PIN no. 120) elsewhere in the control board.

Besides changing the output E, the starting timer for pre heating was changed from 0 to 15 seconds, which means that the control system automatically will start cranking the engine 15 seconds after the operator pushed the start bottom, or 15 seconds after the control system would make an automatic start e.g. in case for mains fault. 15 seconds pre heat in tropical climate is more than we normally find necessary, but because this genset should start directly on cold palm oil, we find this better.

4.3.4 **Installing electrical system for preheating**

The new glow plug controller relay was installed according to the following diagram.



As described previously, the ignition signal for the glow relay was taken from the genset control system. The ignition signals activate 20-40 seconds pre heating before cranking the engine.

Another control signal for the glow relay is no. 50 from the starter, which is the same signal as activated cranking of the engine. On the glow relay signal 50 activates 3 minutes post heating. The post heating is necessary to have efficient combustion of PPO in the cold engine.

The electrical fuel heater is connected parallel to the glow plugs.

After operating 3 minutes, the engine has reached satisfactory temperature to operate without post heating and electrical fuel heating.

4.3.4.1 Electrical fuel heater

The electrical fuel heater is the only part which we sometimes take out of the conversion system for tropical climate configurations. But because this genset is going to operate on palm oil, which is semi solid at ambient temperature, the fuel heater is important for safe operation of the engine during the warming up phase.

The electrical fuel heater is integrated on the new fuel filter, between the filter top and the filter element. So the fuel is heated efficiently by direct contact the heated surfaced inside the heater. The power of the heater is 130-260W – depending on the fuel temperature and the flow. With cold fuel and large flow, the power is at maximum 260W. The heater has a hot spot protection system which limits the surface temperature of the heating surface to 130°C for safety reasons and to avoid coking the fuel. Initially the heater draws close up to 20A current for a short moment when it is connected, but the current rapidly drops to around 10A.

4.3.4.2 Glow plugs

The glow plugs used for PPO configuration are normally 2-3mm longer than the original for diesel operation. But we have carried out detailed test of Perkins 400 serial engines in our workshop in Denmark, and in other African projects, and found that the original geometry of the glow plugs works fine with PPO. The other issue with the glow plugs is that they should resist working with 3 minutes post heating, which means that they are energies 3 minutes after starting, where the supplied voltage is close to 14V, because the alternator is charging, or about 3V more than the voltage supplied for pre heating. Therefor the glow plugs should be designed for post heating. The glow plugs supplied with the conversion kit are designed for post heating, but we do not know if the original Perkins glow plugs are designed for that.

A typical life time of glow plugs for 1-tank systems are 1-4 years, depending on the number of cold starts and some other details, which sometimes can be difficult to predict. If one of more glow plugs are worn out, it is usually recognized by difficult cold start, and the engine can misfire on the relevant cylinders.

The performance of the glow plugs can be checked in several ways. The easiest is to measure to the current in the supply wire for all the glow plugs, using a DC A clamp meter. Each glow plug consumes around 15A initially when energized, but the consumption rapidly drops to around 10A. So if you initially measure 45A which will drop to around 30A, that means that 3 glow plugs are working. Another way is to measure the resistance though each glow plug individually. To do that the bridge connecting the supply current parallel to all the glow plugs has to be removed. Then measure the resistance between the engine body and the power supply connection on the glow plug. A normal working glow plug will have an resistance of approximately 1,2 Ohm, but if you measure e.g. 20 kOhm, the glow plug is worn out. Finally, the performance of the glow plugs can be checked visually by taking them out and testing them by direct connection to a 12V battery. Approximately the first 5mm of the tip should glow orange after a few seconds. Sometimes a glow plug can draw normal current, but the entire tip will heat up instead of only the first 5mm. In that case the glow plug should be changed.

4.3.4.3 Installing injector nozzles

The conversion kit included new injector nozzles for PPO operation. The special nozzle makes the engine start promptly on PPO and run smooth after cold start without misfiring. The best results are when used in combination with the right glow plugs and glow plug control. In general these injector nozzles are characterized by making a small pilot injection into the combustion chamber, before the main fuel injection. But otherwise the nozzles are selected for specific engines. The nozzles we supplied with this conversion kit are purchased from ANC/Elsbett in Germany.

The injector nozzle is installed in an injector holder, which contains also a spring and adjustment shims(washers). The original nozzle is replaced by the new one, and the injection opening pressure is adjusted by changing the shims. Other necessary tools are a torque wrench and sockets for dismounting and opening the injector holders.

The injector adjustment training session, under a Mango three at George Augusto´s place.

The training in injector change and adjustment is normally very exciting for the participants, especially the BOSCH tester which is used to check the opening pressure of the injector.

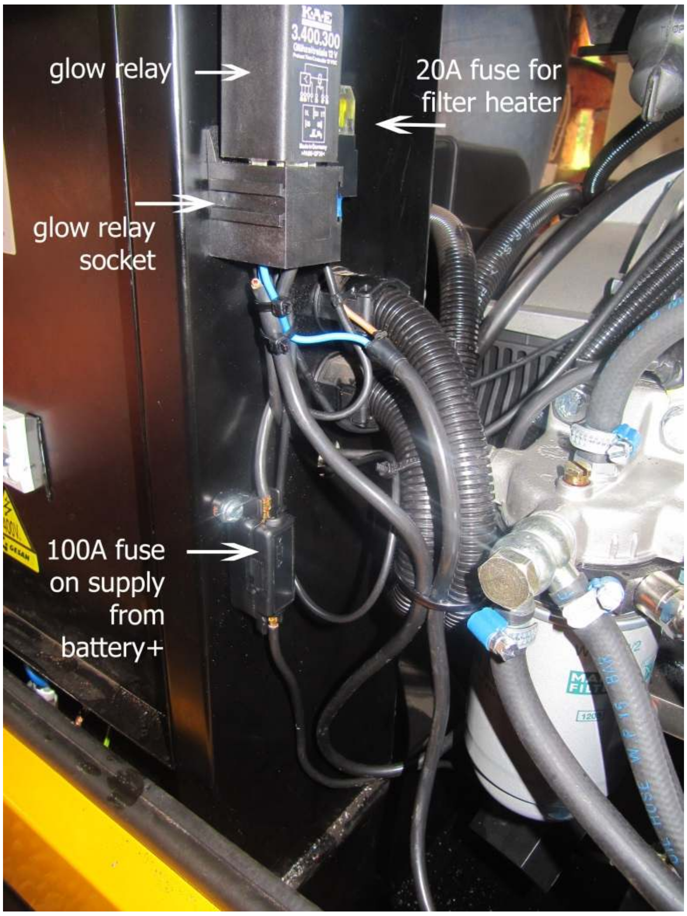
For this new Perkins engine we found the original opening pressure to fluctuate from 125-135bars, and we found similar opening pressure on 8 other Perkins gensets which we converted in another project. The higher injection pressure the better atomizing of the fuel, but you cannot just increase to pressure too much without to consider also readjustment of the injection pump etc. For these engines we recommend to adjust the new opening pressure to 145 bars, which is satisfactory for good atomizing of the fuel, but without to require readjustment of the injection pump.

The lifetime of the injector nozzles mainly depends on the quality of the fuel. With good PPO quality the injector nozzles will have at least the same life time as injector nozzles used with diesel. We have many good examples where injector nozzles are still performing well in vehicles after more than 200.000 km on PPO. That could be equivalent to 4000 hours of operation or more.

The adjustment of the injector spring(left) and the test of the opening pressure(right)

4.3.4.4 Conversion completed and testing

The main components for the conversion of the Perkins Genset.
A) original pre filter (filter element removed), B) original manual lift pump(for bleeding air after change fuel filter), C) new coolant-PPO heat exchanger, D) New fuel filter with electrical heater, E) stop valve to close the parallel connection of the original fuel filter F).



The glow plug relay and fuses

Test run after conversion with refined palm oil from the shop.

4.3.5 Poussa engine for the oil press

The Poussa engine is a small Chinese type water cooled Direct Injection engine for mechanical power take off. The engine is started manually by hand, and there is no electrical system. There is no lift pump and the fuel is fed just by gravity. The original fuel filter is integrated in the fuel tank. The conversion was carried out during a separate training session at the SNV office. The direct injection system requires a 2-tank system.

4.3.5.1 Cooling system

The cooling system included a water tank on the top of the cylinder. When the engine is operating, the water will heat up until it starts boiling at 100℃. The temperature will remain around 100℃ as long as the engine is operated and as long as there are water left for evaporation. There is a level indicator on the water tank showing when the level is low, and it's time to refill water. The engine is designed to operate at this temperature level controlled by the natural "thermostat" called phase shift from water to vapor. That is actually well suitable for PPO application. The question is just how to design the fuel heating system.

4.3.5.2 Fuel feeding system

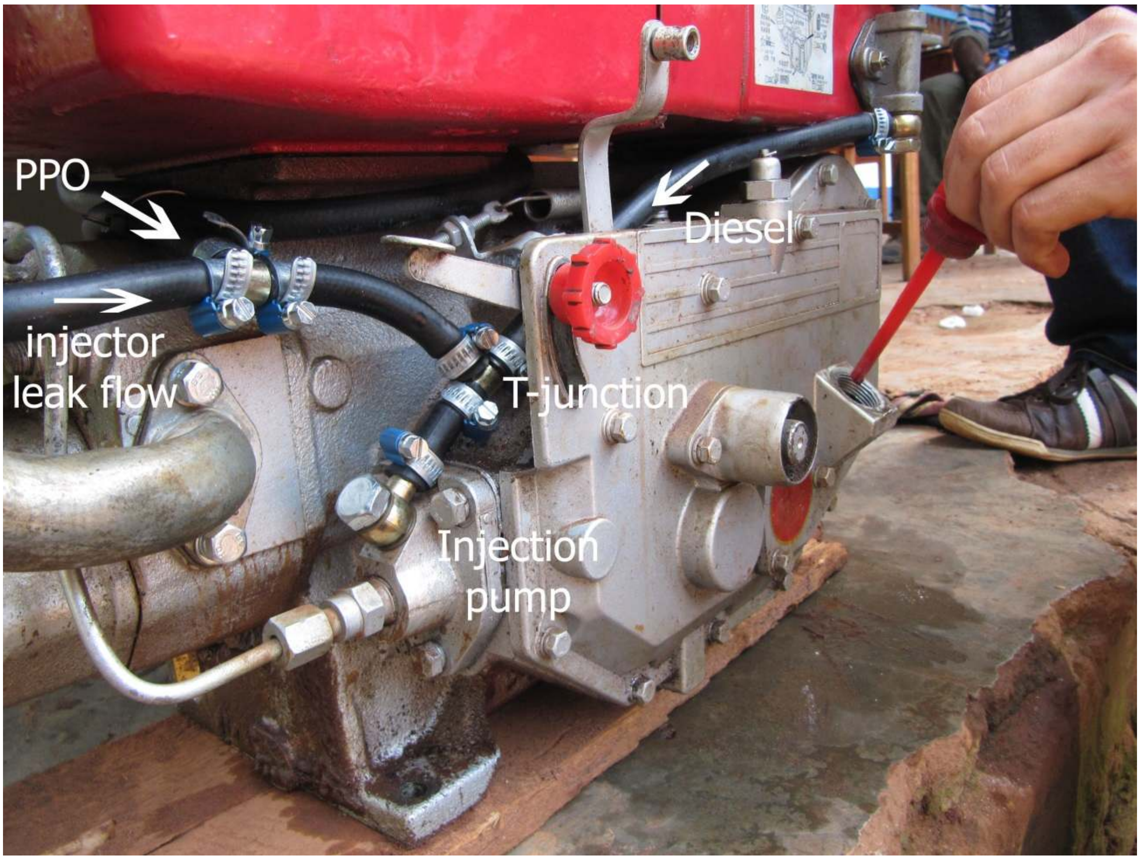
As mentioned the fuel is fed just by gravity. That means that there is no return flow to the fuel tank, except from the leak flow from the injector, which is close to zero on a new engine. That also means that the flow in the fuel line is very low, only as much as the engine instantly is consuming. That also means that if you heat the fuel with a separate heat exchanger before the fuel filter, the fuel temperature can drop a lot on its way through the fuel filter and the following fuel line to the injection pump. Therefor a special solution for fuel heating is required. The fuel feeding with a 2-tank system is easily realized by installing a T-junction as close to the injection pump as possible. A new fuel tank for PPO should be installed and the fuel supply line should have its own fuel filter in order to switch fast from one fuel to the other and back. The PPO fuel tank should be elevated about 1 meter to generate a little more pressure from gravity. The fuel flow is controlled by a stop valve in each fuel tank.

4.3.5.3 Fuel heating

A new idea came up to install the PPO fuel filter directly in the hot water tank, so the entire fuel filter would be heater to around 100°C when the engine is operated. After the fuel filter the hose will turn around the warm cylinder head, before it reached the T-junction right at the injection pump.

To prepare the PPO fuel filter for the hot environment in the boiling water, the plastic drain screw at the bottom was removed and replaced by a sealed metal screw.

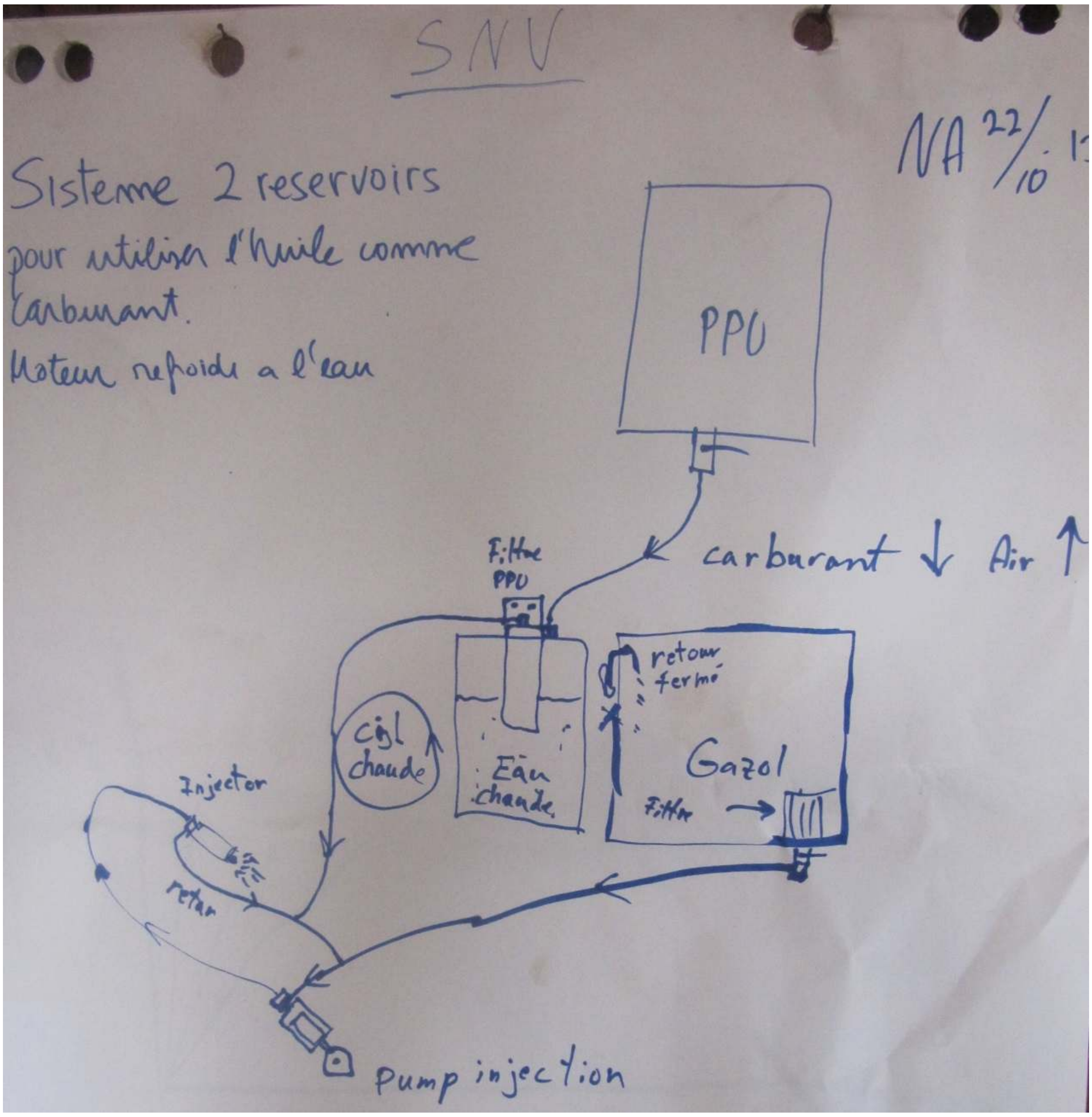
The fuel filter fitted well directly into the water tank. Just needed a little grinding to remove edges on the water tank, to cut some of the plastic cover, and finally to make a bracket for fixing the filter safely to the water tank.



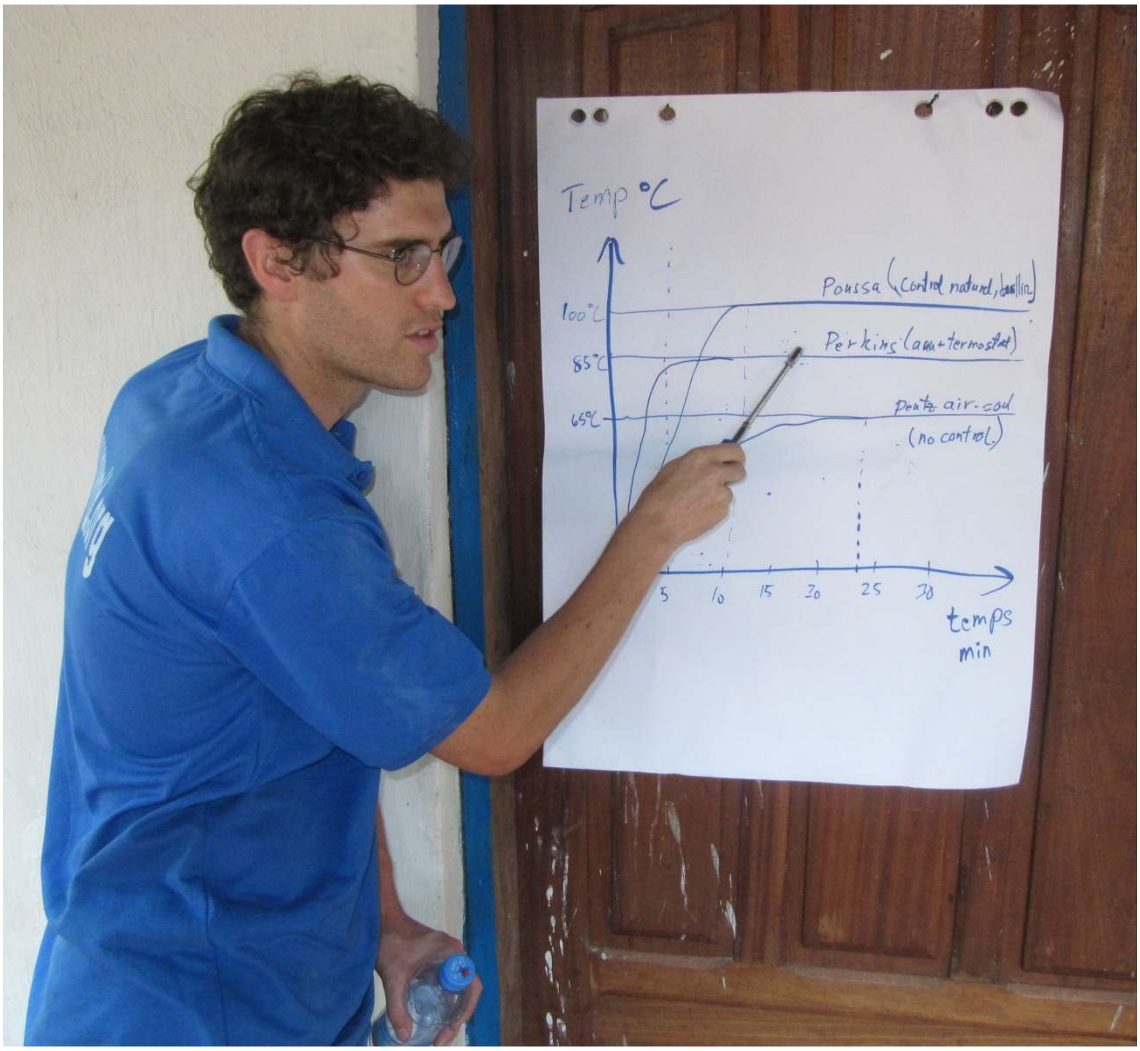
Fuel cycle for the Poussa 2-tank system.

The PPO tank elevated approximately 1 meter above the engine.

The conversion system was test without any load and work very well. Because of the system with separate fuel filters and a junction very close to the injection pump, the fuel switching from diesel to PPO and back happens very fast. The engine heats up even without load. All in all the outcome of the conversion was very good and promising. Very simple and very cheap system which can be made from local materials.



The conversion system was explained by this drawing made during the training session. Considerations included how to bleed air from the system.



Xavier translating and explaining the poster showing the temperature development of all 3 kinds of engines, which had been converted during the last couple of days. from the worth one, the air cooled Deutz, which need to operate on load for 15-20 minutes before it can be switched to PPO, to the Perkins which starts directly on PPO and reach operating temperature within 5 minutes.

4.3.6 Lister engine in genset at Jose Augusto

The Lister engine on Jose Augusto´s genset is a 2 cylinder air cooled Direct Injection engine.

It is quite similar to George´s Deutz engine, but has another challenge that the fuel is fed by gravity. That means no return flow to realize a loop system. On the other hand the gravity feed system allows to make a very compact fuel system with a junction from the 2 fuel tanks directly at the injection pump. The big challenge is to heat the fuel. There was not enough time also to convert this engine, but there were materials enough. And I believe that Jose can convert this engine together with his brother George.

5 Other technical issues

5.1 Grid system at the cooperative

The grid system has been installed at the cooperative, and it was briefly inspected on the day of arrival to Gemena (16/10). Both the design documentation and the installation work carried look very professional. Nevertheless there are a few points which could be improved.

5.1.1 Connection from generator to main electrical board

For this connection was installed a 4 core armed installation cable (3x10 mm^2,1x6 mm^2(gray)), same as used for the main lines in the grid. Due to vibrations from the genset, we had recommend to use a flexible rubber cable, which is more resistant to vibrations. But since the connection box on the genset is fixed to the frame which is fixed to the floor, we think it is not necessary to change. On other gensets, where connection box is attached to the generator, and therefor vibrating, it is important to use a flexible cable.

5.1.2 Serial connection of fuses

In the main board the power is separated in 2 lines which go in each direction on the Avenue. There installed a C16 automatic fuse from where the power splits out in the power house, to protect the main line, and another C16 aut. fuse, when it enters the connection box to the houses, and immediately after that an C10 aut. fuse before the supply separated to each house connection which is protected by a C2 aut. fuse. In our point of view the C16 at the entrance to the connection box is not necessary. Its maybe a good idea to repeat that the purpose of a fuse is to protect the cable downstream, and the capacity of the fuse should never be larger than the capacity of the cable.

5.1.3 Extra junction box

Due to shortage of the main cable in L1, a junction box has been constructed about 10m distance from the power house. It is placed in the ground, with housing from brigs, but not water proof. Penetrating water might easily make connection problem in this place, so we suggest looking for options to join the cable with moisture prof connections, and bury the junctions instead of leaving it open. It has also an extra benefit that the junction box will not be damaged by cars or other traffic which passes the road.

5.1.4 Voltage drop in line 1

Also due to shortage of cable for the main lines, and not even distribution of load (no of houses) between L1 and L2, and alternative solution was suggested by Bart Frederiks, using 6x2,5mm2, totally 15mm2, for the first part of the L1 from the power house to the first connection box. But we understood that this solution was not applied, so this part of L2 is still made by the 3x10mm1+1x6mm2 cables

5.2 CPO to PPO process

5.2.1 Gravity system

Gravity is used several times in the CPO to PPO process to separate different components like water, gums (water & phosphor lipids), soap, etc., but during the training session it became clear that the solidification of the palm oil in ambient temperature (typical morning 20°C and afternoon 30-32°C), solidifies obstructing the gravitation to take place, as well as draining of the bottom layer from oil drums is difficult, because the layer of semisolid palm oil grows from the bottom.

Process tank with conical bottom.

Dried fibers from the palm fruits could be used as insulation for the process tank.

Therefor it is suggested to improve the gravity system by insulating the gravitation tank, in order to keep temperature as constant as possible above ~50°C, giving the gravitation time to work over the night. The oil is already hot after the treatments, either with phosphoric acid or NaOH. The issue was discussed at the training site, and Xavier Castellvi (XC) told that insulation material already had been searched, but so far without result. One idea could be to use the dried fiber material from the oil fruits as insulation material, by building a wooden box around the oil drum, leaving 200-300mm space between the wood and oil drum for compressed dried fiber material from the oil fruits.

Having a conical bottom with minimum 1" ball valve in the bottom in the center of the cone, for easy drain off the bottom layer.

5.2.2 Filtration system

A filtration system had been designed for filtering the oil several times during the CPO to PPO process. The construction of the filter system was completed the day of arrival to Gemena.

An initial rough filtration using a filter membrane attached to a half cut oil drum.

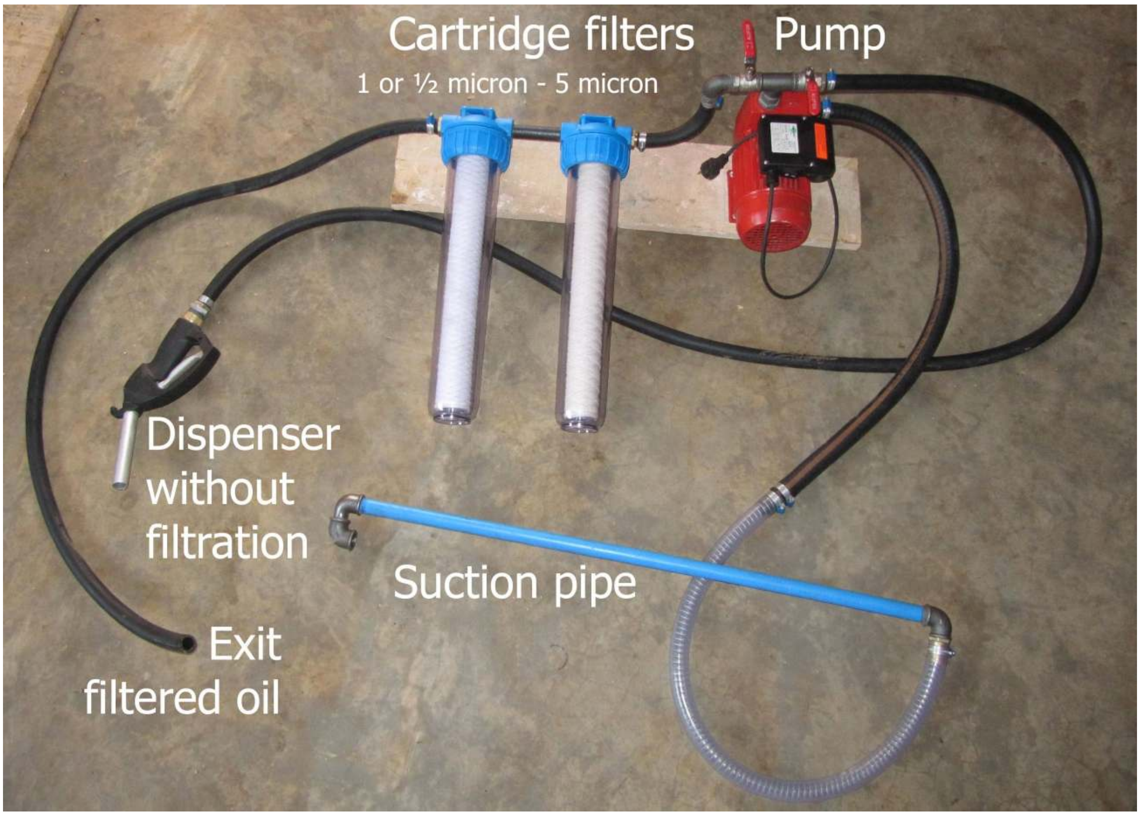
A finer filtration using filter bags hanging in a support frame, designed for the purpose.

We recognize that the designed filtration system can be used for rough filtration of large particles, because rough filtration is fast and will limit the time in which the vegetable oil is exposed to atmospheric air(oxygen) and sun radiation(light), which haves an negative impact on the oil stability and quality.

But for filtration of fine particles we find it problematic for the same reasons, while fine filtration with filter bags in a gravity system with hardly any pressure, max ~ 0,45 meter oil column equivalent to 0,041 bar, will take extremely long time. Besides the filter bags are designed to be used in closed filter houses where they are supported by a metal mesh.

Therefor we suggest using a closed pressurized filtration system for the fine filtration, and to use cotton wound filter cartridges (candle filters), which has proved to work very efficiently with vegetable oil. The pressure shouldn´t exceed approximately 2 bars, to avoid dirt penetrating the filters. Impeller pumps, which are often used for domestic water pumping in households, are suitable while they allows small impurities to pass, and they are self-limiting the pressure to about 2,5 bars, which is acceptable, but still about 60 times higher pressure than achieved by the gravity system.

Plastic filter houses for 20” cartridge filters(left) and impeller pump (right)



Example of pump-filter system, which can be used both for fine filtration, as was well as moving oil from storage tanks to canisters etc.

5.2.3 Removing water

Water evaporation from palm oil in Gamena

5.2.4 Process heat

The diesel engines used for gensets and for mechanical power take off(PTO) produces a lot of waste heat, approximately 2/3rd of the energy input, or the double of the electrical/mechanical output. It is suggests to consider this considerable waste of heat as en heat source for the CPP to PPO processes.

5.2.5 Oil press

Including this project is the aim off improving oil quality and increase yield from the same amount of oil seeds, and this include construction of an oil expeller based on a proven design for palm oil expeller. The function of the expeller is to drain the oil out of the fruit flesh, but not the brake the palm oil kernels, and expel the oil from them. The force needed to press out oil from the fruit flesh requires much less pressure than traditional oil seeds expellers, which DAJOLKA has much more experience.

A visit to Debo was carried out early in the mission to Gemena. The oilpress was tested in August but some parts in the gear exchange system got broken, and the problem seems still not to have been solved. The gear exchange system was constructed using gear wheel from moped transmissions. Initially these components seems week to an oil expeller transmission, but it is not possible to conclude on that without some few measurements and calculation – e.g. using the power and torque from the Poussa engine as input. Another week point in the transmission system seems fixation between the gear wheel and the transmission shafts – they we fixed only with a point screw and not a key way.

Another similar oil press was seen later at another mechanical workshop, but there the transmission system was made by more rigid chain and gear wheel transmission parts, and all gear wheels was attach to the transmission shafts using key ways. This oil press was still under construction, so it was also not possible to test.

6 Other practical and organization issues

The following issues are mentioned for consideration for future mission and daily work in Gemena.

6.1 Workshop facilities

During the mission we carried out engine conversion training sessions in 3 different locations.

The first was a George Augusto´s place, which were the best equipped regarding tools and materials.

The second with on carried out on the site of the Perkins genset. Under the conditions it was OK, but I had understood that we could use the nearby workshop belonging to one of the community members. But was absent, so it was not really possible to other things than what we could do with the tools I had brought.

The last training session was held at the SNV office. For that one felt much more comfortable, like to be at home, and I think that also the participants felt more clearly that this activity was conducted by SNV, than compared to the 2 previous locations.

6.2 CPO-PPO Process and Laboratory facilities

Laboratory facilities are necessary for control the CPO to PPO process, and to verify the quality of the PPO before to use as fuel. Laboratory instruments and chemical was already transferred to Jose Augusto, and tested during this mission. But since some uninspected challenges with CPO to PPO process occurred, mainly semi solidification of the palm oil in ambient temperature, preventing separation of the different fractions in the process (soap, gums, water etc.), it was difficult to take out samples for analyzing in the lab.

We expect that a considerable amount of test and improvements are necessary before the process with be finally optimized, and for that also a considerable amount of analysis has to be done. We suggest involving several people to contribute with knowledge experience specifically on small scale Palm Oil production, and practical experience and theoretical knowledge of the chemical process and the laboratory work. It could be a student for longer period accompanied by an expert/consultant for shorter visit to Gemena, and distance support.

We suggest to establish some laboratory facilities in the SNV office in Gemena, for the people to feel more confident "in own house", and not necessary to show all test results and experiments publicly, before conclusions has been made. Also for practical reasons, like communication, and transport (road to Jose August very challenging, and not passable if its raining)

7 Follow-up

There has been very little need for follow up on the specific activities carried out during this mission.

8 Conclusion

8.1 CPO to PPO quality

We have seen that quality of CPO has to be improved before it can be used as PPO in diesel engines. The main problems are high water content, which makes the CPO unstable in itself, developing high levels of FFA just by storing, and the free water can lead to corrosion in the injection system of the engine. We prefer that problems are solved at the source, which with respect to high water content might be the extraction method, using water steam for softening the oil fruits before releasing the oil by stirring.

If water level cannot be brought down by improved extraction method, the suggested method of evaporating the water at 120-140°C is necessary.

The FFA levels are too high, but it seems possible to reach acceptable levels even without neutralization. I believe that FFA levels up to 1,5-2% can be accepted, even that it is higher than specified in the norm. I base that on practical experience, and the fact that I know a engine manufacturer who decided their own limit on 2% FFA.

The phosphor level is little too high compared to the limit, but in my opinion not so high that it need to be removed by degumming or neutralization. Nevertheless, if neutralization is applied, the test results shows that the phosphor levels becomes very low.

For the stability of the PPO during storing, I suggest to use a maximum size of 200 liter drums for the storing, including storing at the Perkins Genset power house. Oil canister and oil drums should be totally filled before closing them with an air tight plug. I find the 1000 liter IBC at the power house too big for that purpose.

8.2 Engine conversion

A total of 3 very different engines were converted to PPO during several training sessions on 3 different locations in Gemena. The outcome was general good. Nevertheless the air cooled Deutz engine is smoking and might be suffering from running on PPO. Therefore attention should be paid to engine performance, including checking the lube oil level frequently.

The Perkins engine was converted successfully by a 1-tank system which has been used in many other PPO applications for long time. Nevertheless, the Palm Oil in Gemena gives some extra challenges for the 1-tank system, because the palm oil get semi solid at ambient temperature. If I get another chance to visit Gemena, I would like to perform some more detailed test of the system working on palm oil from Genena.

9 Appendix

9.1 Terms of Reference

General objectives

The objective of the consultancy is to support SNV's advisors and local partners to deliver advisory services on the installation and adaptation of a Perkins 404-22G engine to run with pure plant oil from palm oil and to be connected to an electricity grid.

Specific objectives

The advisor will provide support on

- Conduct 1 training to local technical partners on how to adapt engines to work properly with purified palm oil (PPO), and best practices to assure quality of the production of PPO.
- Connect the generator set Perkins 404-22G engine to the electricity grid set up by the project.
- Adapt the Perkins 404-22G engine to the use of PPO as fuel with optimal performance.
- Adapt 2 other smaller generator sets to the use PPO as diesel substitute.
- Carry out initial tests of the adapted engines.
- Define guidelines for operation and maintenance of the engines to assure proper use from the operators (regular checkups, potential worn parts, test for the upgraded palm oil used, etc.).
- Define engine performance evaluation protocol, compared to regular engines using diesel.
- Define quality control procedures for oil as fuel and train local partner on how to implement these procedures.
- Support the project team to solve technical issues during commissioning and the early stages of use of the generator sets.

Results

The results of the consultancy are:

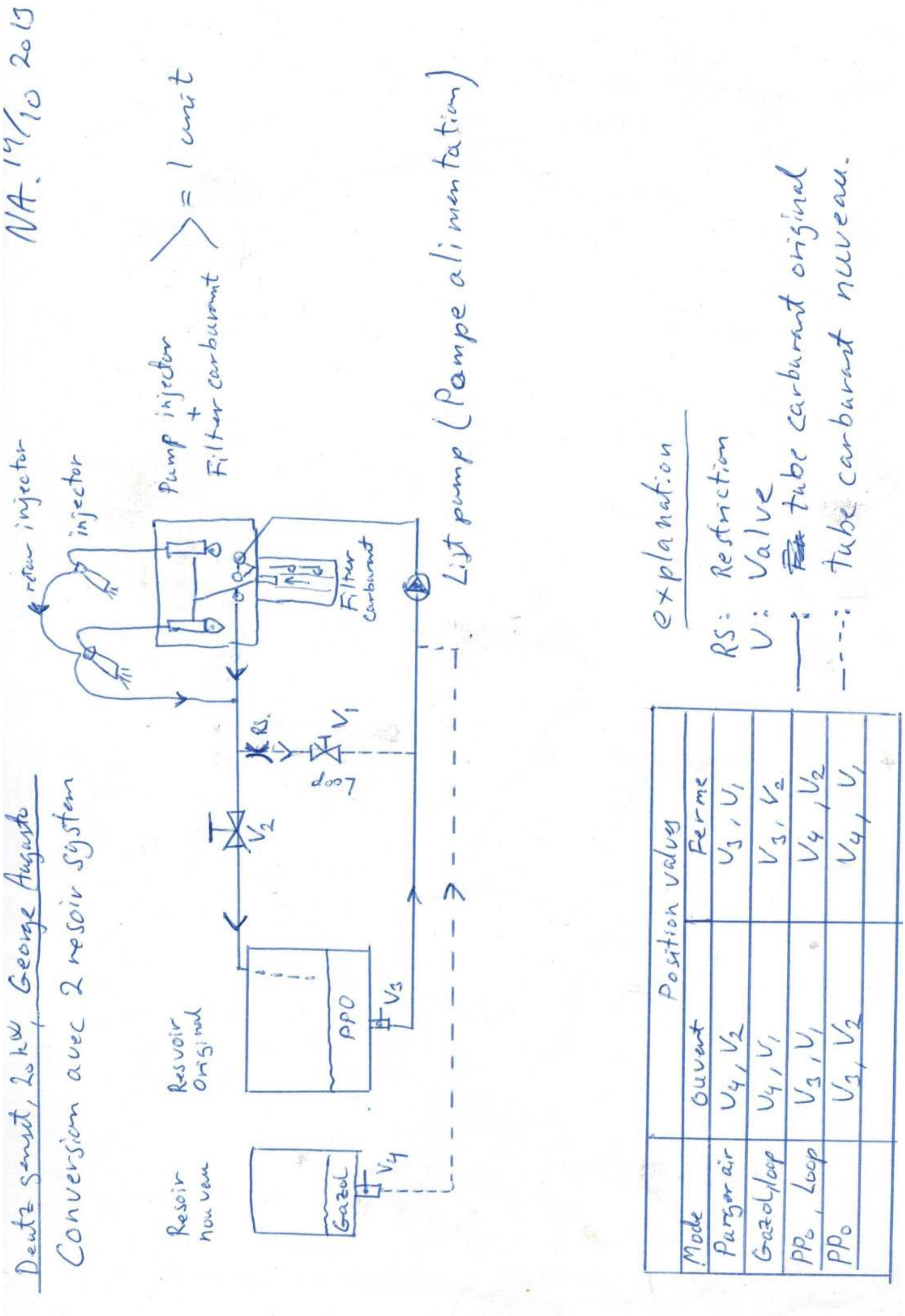
6. 5 to 10 people trained (both theory and hands on) on adaptation of generator sets. The trainees are able to adapt similar size generators and to train other technicians on the matter
7. Perkins 404-22G installed, adapted and initial test done and connected to the electricity grid.
8. 2 small diesel engines adapted and running with PPO.
9. Fuel quality control procedures and protocol elaborated and transmitted to the project. Local partners trained and able to implement these procedures.
10. Technical support in distance given to the Project.

Deliverables

1. One training material on generator sets adaptation[1]
2. One technical manual with the following information:
    a. Generalities of engine adaptation. Types of adaptation and technical description of the adaptation kits.
    b. Operation and maintenance of the adapted engines.
    c. Performance assessment protocols to compare regular engines with adapted engines.
    d. Fuel quality control procedures.
3. One mission report with recommendations for the project including monitoring forms to help the project team to monitor the different trainees and support them adequately in the future.

[1] To send to the project team at least 2 weeks before the training to allow for translation into French and copying

9.2 Fuel cycle for 2-tank system George Augusto´s Deutz 912



9.3 Documentation for Perkins 1-tank conversion system

9.3.1 Fuel cycle

DAJOLKA

DAJOLKA
Dalmosevej 2
DK-9330 Dronninglund
Danmark
niels@dajolka.dk , www.dajolka.dk
Tlf:+45 9885 4220 , Mob:+45 4014 8020
CVR nr. 20448636

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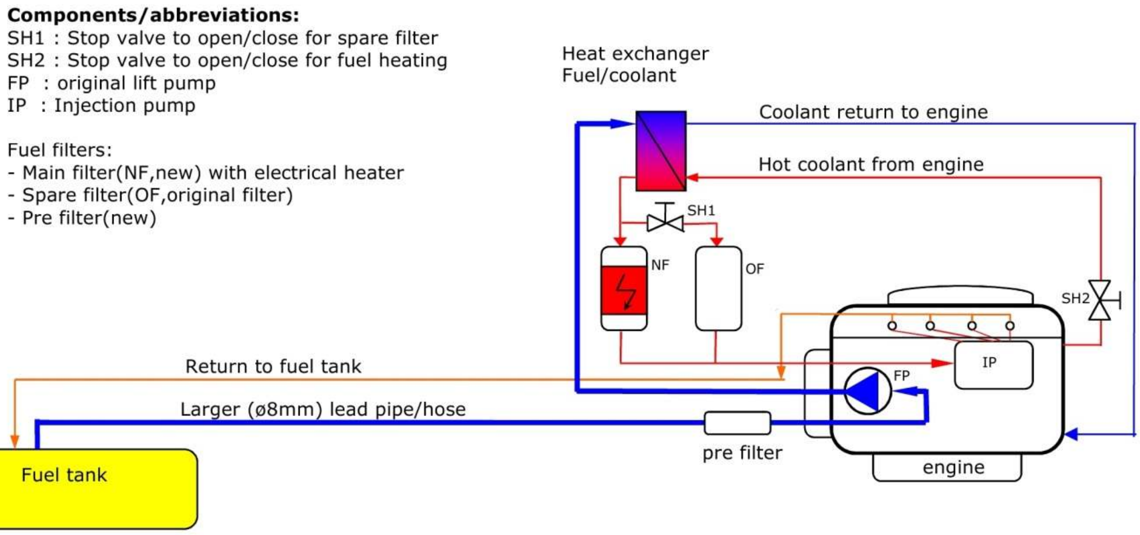
Fuel system for DAJOLKA 1-tank system Perkins 400 IDI, Gensets DRC



The conversion kit contains

- Injector nozzles
- Glow plugs
- Heat exchanger
- Extra fuel filter
- Electrical heater for fuel filter
- Glow plug controller
- Thermo switch
- Fuel hoses & coolant hoses
- Hose clamps, fuel fittings, fittings for coolant system.
- Wires, fuse holders, wire fittings, cable ties, etc.
- Pre filter

For further information's please contact:

DAJOLKA
Dalmosevej 2
9330 Dronninglund

www.DAJOLKA.dk
niels@dajolka.dk
tlf. 40148020

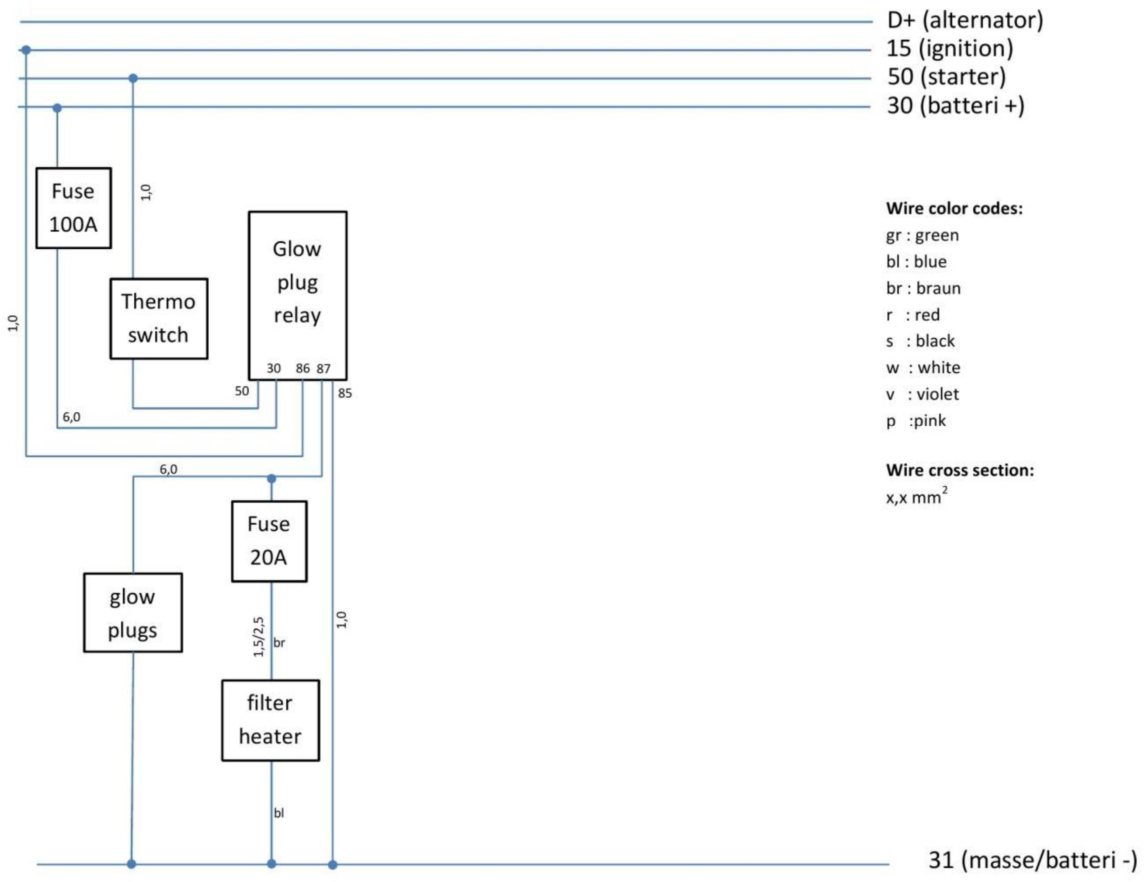
9.3.2 Wiring diagram

DAJOLKA
Dalmosevej 2
DK-9330 Dronninglund
Danmark
niels@dajolka.dk , www.dajolka.dk
Tlf:+45 9885 4220 , Mob:+45 4014 8020
CVR nr. 20448636

NA 10/10 2013

Wiring diagram DAJOLKA 1-tank system for Perkins 400 IDI engine, without original glow plug controller

Gensets, DRC



9.3.3 Workplan

NA 12/10 2013

Work plan for the conversion of Perkins 400 genset, DRC.

1) For new gensets, fill lube oil and coolant, and connect battery etc. in order to make a test run on diesel fuel, before to start the conversion job.
2) The conversion job contains difference disciplines, e.g. fuel system, coolant system, wiring&control system, injector nozzles & glow plugs. The workshop participants can work 2 & 2 together with each discipline, and change discipline when a genset is completed (if more than 1).
    a. fuel system:
        i. Make a new bracket for supporting the new fuel filter and heat exchanger. Use flat steel ~40x5mm. Cut, drill, weld and paint the bracket.
        ii. Install fuel filter and heat exchanger
        iii. complete fuel system according to the diagram
    b. coolant system:
        i. unscrew the 3/8" plug near coolant thermostat house. Install pipe bending and ball valve.
        ii. install T at the radiator drainage hose.
        iii. connect the heat exchange coolant side.
    c. wiring system:
        i. Make wiring system according to the diagram
        ii. Note that signal 15 (ignition) should be taken from the DSE genset control system-
    d. injector nozzles (this job will be conduction by NA)
        i. remove fuel lines from injection pump to injector
        ii. remove leak fuel return lines from injectors
        iii. unscrew the injectors. Care about the sealing rings.
        iv. put pieces of clothes in the holes for the injectors, to avoid dropping dust and other parts into the engine
        v. clean the injector with brush
        vi. test the original opening pressure
        vii. change the nozzle with the new SVO nozzle and adjust the pressure to original pressure +0-10 bars (~ 150bars for these engines)
        viii. install the injectors. Care about cleaning treats and sealing rings. If necessary is new rings.
        ix. install the leak fuel return lines. Use new sealing rings.
        x. install the fuel lines. Don't tight the fuel pipes at the injector before cranking the engines for bleeding air.
    e. glow plugs:
        i. The original glow plugs on these engines are working fine with SVO. Therefor it is suggested to leave them, and only change them when necessary after time. New glow plugs are supplied with the kit.
        ii. when time to change glow plug, remove electrical connection from glow plugs.
        Unscrew the glow plugs. Be careful not to break glow plugs
        Compare the new glow plugs with the old ones. Thread and geometry should be the same, but the new SVO glow plugs might be 2-3mm longer (the hot part which goes into the engine.)

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