**Mission report**
**for mission to Guinea Bissau August 25$^{th}$ – September 2$^{nd}$ 2013**
**a Consultancy carried out**
**for**

# ADPP, Guinea Bissau

Project tittle
"Renewable Energy for Local Development Bissorã Sector, Oio Region, Guinea Bissau"

Supported by the
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# 2 Introduction

## 2.1 Project background

The activities in this report relates to the Action:

"Renewable Energy for Local Development, Bissorã Sector, Oio Region, Guinea Bissau", a project of 48 months duration – November 2011 to October 2015 – agreed in a contract between Fundacion Pueblo para Pueblo Spain and the European Union in contract number: FED / 2011/ 232-430, and with ADPP Guinea Bissau as implementing local organisation.

**The Action has as its overall objective:**

"Improve the living standards and local economic conditions in rural, low-income areas of Guinea-Bissau"

**The Action has as it specific objectives:**

Introduce and establish renewable energy systems for local development in Bissorã Sector, Oio Region in Guinea-Bissau. O1: Increase in solar and sustainable bio-fuel energy supply in rural areas.. O2: Increased human capacities to encourage renewable energy uptake in rural areas, wherever cost-effective. O3: Reduce environmental impact by promoting sustainable sources of energy.

**The target groups are:**

First level: 24 extension workers, 4 technical extension workers.

Second level: 14.274 community members of 24 communities in Bissorã Sector including 2.600 poor rural smallholder households.

**The specific tasks for DAJOLKA/Niels Ansø on this mission are:**

to install 8 gensets which can operate on Pure Plant Oil(PPO), and train local extension workers, technical extension workers as well as local staff at ADPP and the vocational school in Bissorã in modifying the gensets to PPO, and to install, operate and maintain the gensets.

The communication about these tasks started in May 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 at DAJOLKA within Renewable Energy Technologies.

## 2.3 Mission Terms Of References

The expected specific results and tasks for the mission are, as quoted from the ToR:

According to the local circumstances, technical and human recourses available:

(1) secure the correct installation, setup and operation of the 8 bio-fuel generator sets;

(2) design functional and manageable control, maintenance and repair systems;

(3) train the local staff in executing the responsibilities and tasks mentioned under (1) and (2) and follow systematic observation and report systems;

(4) elaborate an operation cost estimate for running the generators;

(5) suggest an on-line technical assistance system;

(6) at the end of the training elaborate a capacity evaluation of the trained staff, indicating strengths, weaknesses and recommendations for further capacity building;

(7) forward other suggestions, he finds useful, to secure sustainability of the installations;

The following tasks are included:

a) Install 8 generator sets with conversion kits;

b) Design maintenance schemes;

c) Train 10 local participants in the work of setting up the generators and do the maintenance;

d) Train the 10 selected participants in how they train other community members to do the fault detection and maintenance of the units;

e) Design any training material / manuals and maintenance systems and schedules necessary to secure the sustainability of the installation;

f) Design and train in an oil quality control system, including recommendations for how to select and store seeds before extraction and eventually how to "adjust" for not so good oil quality;

g) Elaborate a fuel consumption estimate for the engines, including recommendations for how to operate them most economically;

h) Design and perform together with the ADPP project management team a final "examination" of the people participating in the training;

The work is expected to be concluded with the delivery of a report in English.

# 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 more than 100 years, 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 exhaust gas 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

As mentioned above the diesel engines need to be modified in order to handle and burn PPO satisfactory, in order to minimize emissions and fuel consumption, and to ensure normal life time of the engine.

### 3.2.1 Usefull gloses

| **English** | **French** | **Portuguese** |
|---|---|---|
| Heat exchanger | Echanger de chaleur | Trocador de calor |
| Glow plugs | Les Bougis de preschauffage | Velas de incandescência |
| Lift pump | Pompe alimentation | Potência da bomba |
| Diesel fuel | Gazoil | Gasóleo |
| Pure Plant Oil | Huile végétale pure | Óleo vegetal puro |

### 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, and only at this moment it starts to open and let the coolant pass the radiator to release heat. 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.

Besides entirely water cooling or air cooling, there exist some combinations of air-water cooling and air-lube oil cooling.

### 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 an external fuel-coolant heat exchanger
d) Lube oil from air cooled engines, passing through an 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 the 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 several Chinese diesel engines and the typical old Lister engines, 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 some other stationary engines equipped with a lift pump, the fuel return flow is large, which together with a 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 or push the fuel it through the fuel filter and deliver the fuel to the injection 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 (below atmospheric pressure). 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 has limited force because the membrane is actuated mechanically by a cam in one direction, and returned in the opposite direction by a spring. Therefor some membrane lift pumps have difficulties to pump 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 enters 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 was tested and found to be strong enough for pumping cold PPO with very high viscosity.

#### 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 than the engine and the injection pump, and the gravity will push the fuel though the fuel filter, and deliver it to the injection pump at a small positive pressure. 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 PPO 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 too long. Some engines are less sensitive to idling or low load, e.g. IDI engines(InDirect Injection), like the Perkins 400D, but many DI engines(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 lube oil and 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 it is 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, or 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.

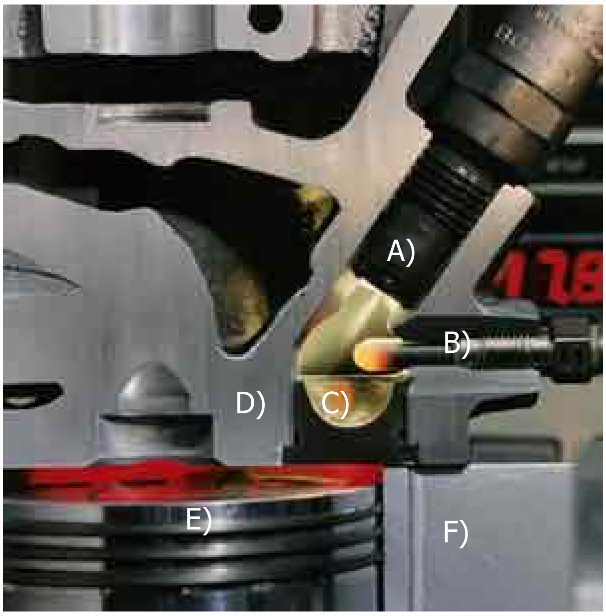
Generally any warm diesel engine will run fine on heated PPO. The main challenge is to get the engine started and run it with satisfactory clean combustion until it reaches normal operating temperature, typically about 80-90°C for a water cooled engine.

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.

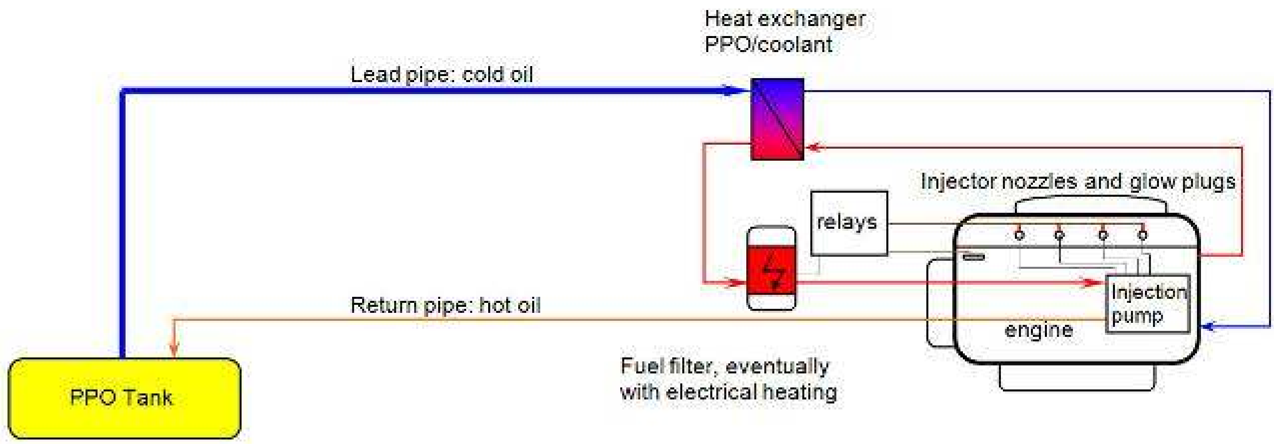
### 3.2.6 1-tank system

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.



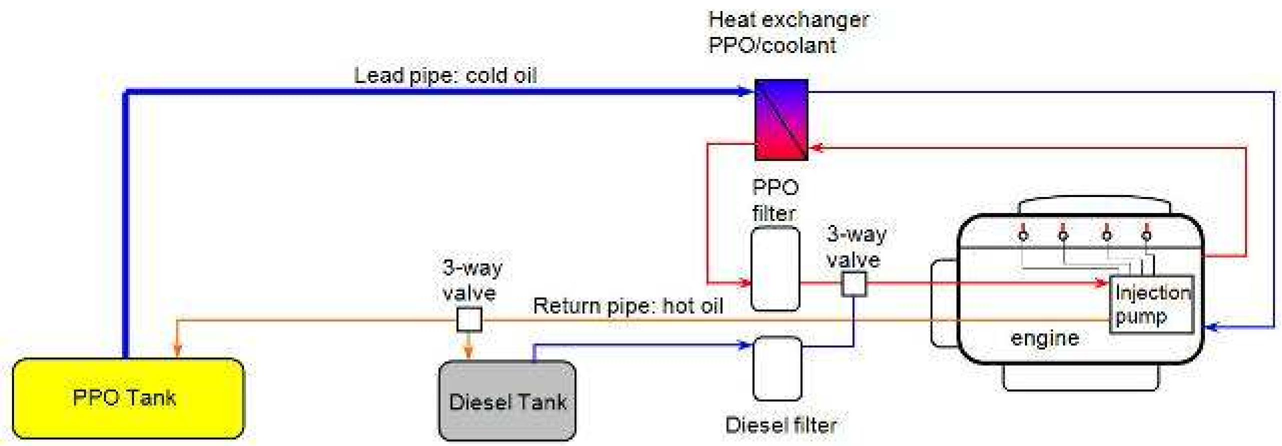

The diagram shows a typical configuration of a 1-tank system, including larger fuel pipes, heat exchanger, electrical fuel heater, injectors, glow plugs relays etc.

### 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. The fuel switching is done 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.

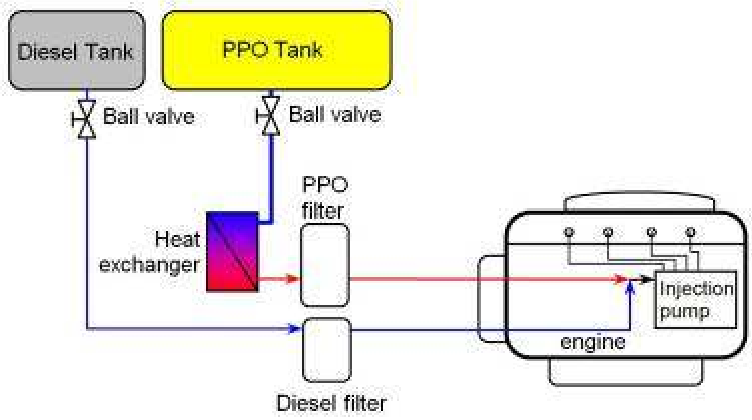



The figure shows a typical configuration of a 2-tank system on engines with the lift pump integrated in the injection pump. It includes larger fuel pipes, heat exchanger, extra fuel tank and fuel filter for diesel, electrical operated 3-way valves for switching between PPO and diesel, etc.

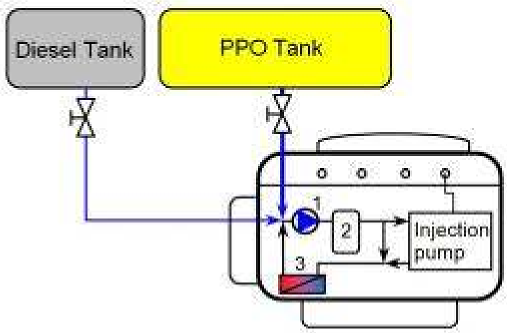
For more basic engines, as often used in Africa for example, with no battery for electric starting, and preheating, it is not possible to realize an electrical controlled automatic fuel switching system, and the conversion system typically consist of the following parts: an extra fuel filter, fuel tank 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 for PPO 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 out. 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 begin and a decrease in the injected fuel quantity. 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 at approximately 65°C. The fat forms a coating which can release in smaller pieces and flow with the PPO and block fuel filters. Use stainless, carbon steel or plastic materials 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 elevated 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.

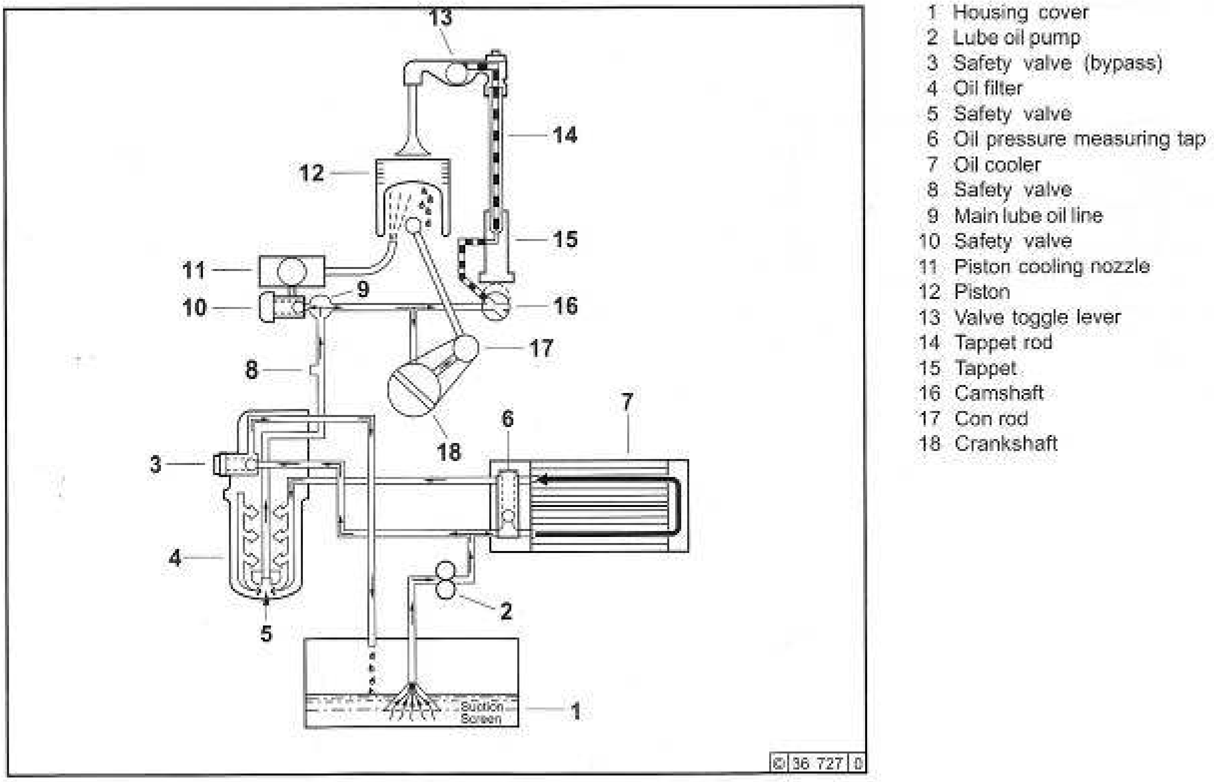
External / mechanical membrane type lift pumps are usually installed before the fuel filter, and should overcome the pressure loss through the fuel filter, and still maintain a positive pressure at the injection pump – typically 0.1-0.5 bars overpressure. The membrane material may not be suitable for 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 durability of the PPO in the tank if heating is avoided.

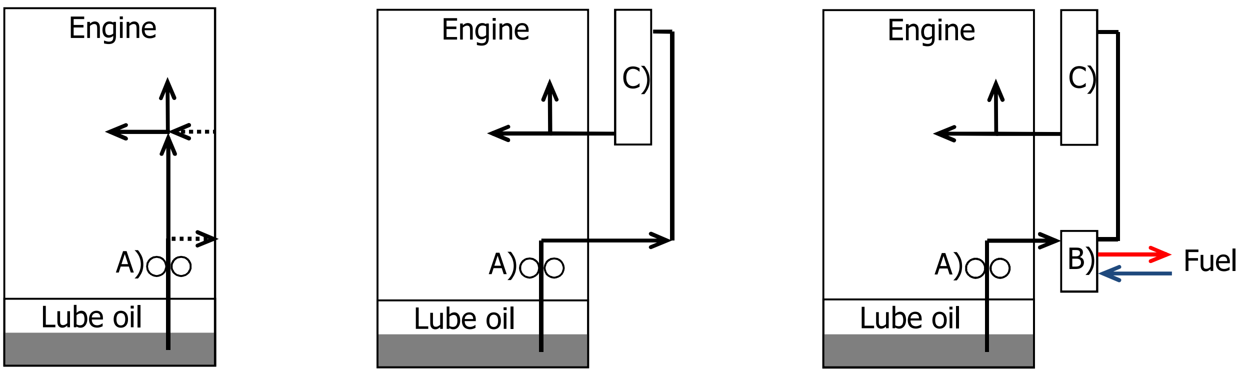
Water-cooled engines usually reach operating temperature around 80-90°C relatively fast, and the coolant is a good heat carrier. An easy and good way to heat the PPO is by a coolant-PPO heat exchanger. It can be homemade, but there are many suitable plate-heat exchangers already used in automobile industry that are designed for fuel cooling in modern diesel engines. These are made from aluminum, and typically have a heat transfer area of 300-600$cm^2$ 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 dirt accumulated in the fuel tank. 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. But for DI engines it is usually recommended to halve the change interval compared to operation on diesel. That is because DI engines have higher tendency to get unburned PPO diluted in the lube oil, which by time can lead to polymerization of the lube oil (see figure in previous chapter). To prevent this from happening, it's important regularly to check the oil level and consistency of the oil in the engine. If the level has increased it's normally 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 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 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 and 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.

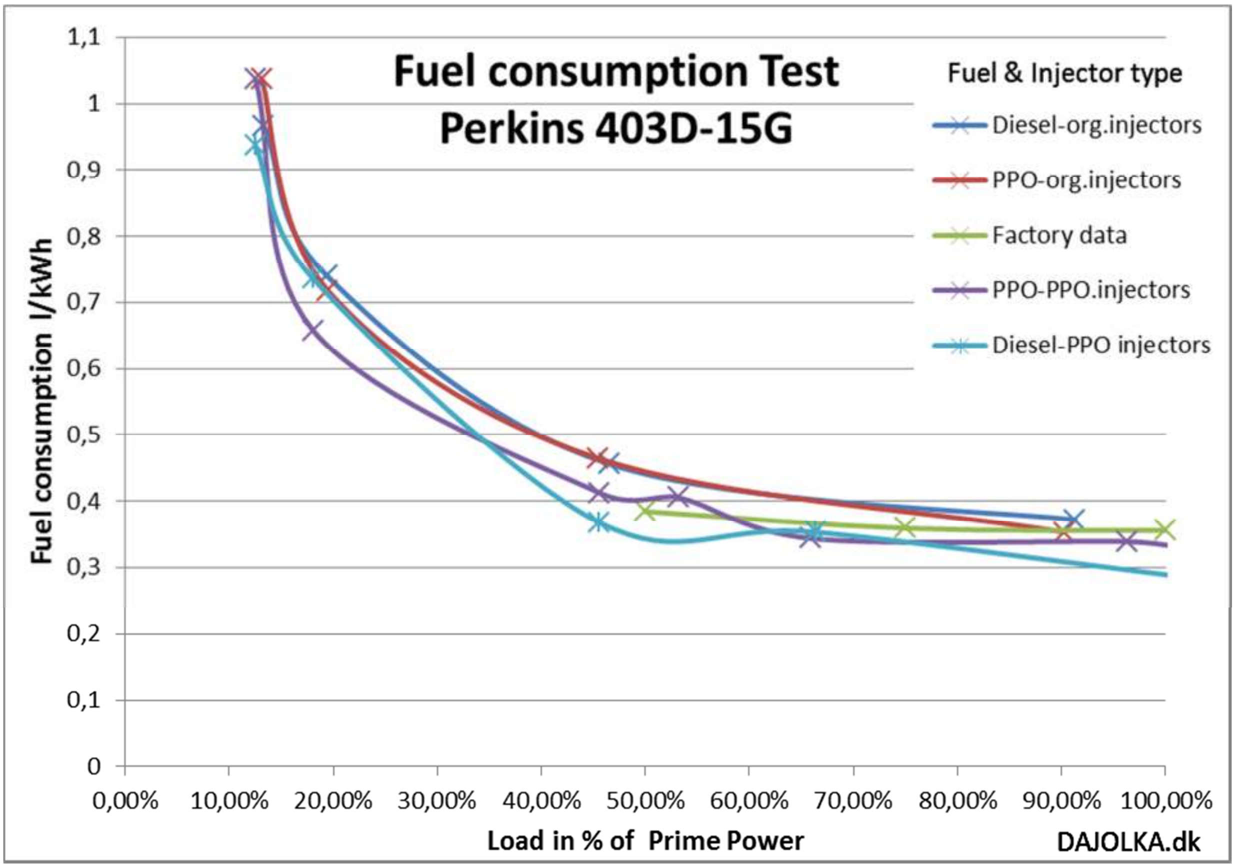
#### 3.2.9.4 Glow plugs

*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 compared to operate on diesel.

### 3.2.10 Fuel consumption

When operating a modified diesel engine on PPO, the fuel consumption 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 no oxygen, the PPO is often combusted more efficiently that diesel.

In 2013 we converted the prototype Perkins 403D genset for this project in our workshop, and we made 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 fuel consumption test are 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 engine 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 general 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 storing stability, and to limit the level of "strangers" in the fuel, which can have a negative impact on the combustion efficiency and leading to increased emission level and deposits in the engine, as well as avoid properties which can damage the injection system.

The norm has been updated several times – the latest version came into force from January 1st 2012, taking into account the newest European emissions norms, and the fact that most new passenger diesel cars on the European market are equipped with particulate filters, which make the engines very sensitive to contents of ash components like Phosphor(P), Calcium(Ca) and Magnesium(Mg) in the fuel. As a consequence of the latest update, rape seed oil produced by cold pressing and filtering alone, can no longer meet the limits for these parameters – its necessary to reduce the level of P, Ca and Mg by additional semi refining. But for engines without particulate filter, which in Europe are most engines produced before around year 2005, and most engines in rural areas in developing countries, the previous version of DIN 51605, valid until 31/12 2011, can be used. This quality can normally be achieved just by careful cold pressing and filtering.

### 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.

| **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 51605, with reduced limits for ash building components, were introduced by January 1st 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 by corrosion, and degrade the storage stability of the PPO, leading 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 most cases the water content is in vegetable oil is low, and if free water is found, the reason is most likely water contamination from outside coming sources. Sometimes the water limit is exceeded due to high amount of phosphor, while the phosphor lipids acts like emulsifier between water and vegetable oil.

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

The Acid no. expresses 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 a 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 and ripeness of the seeds etc.

### 3.3.4 Phosphor content

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

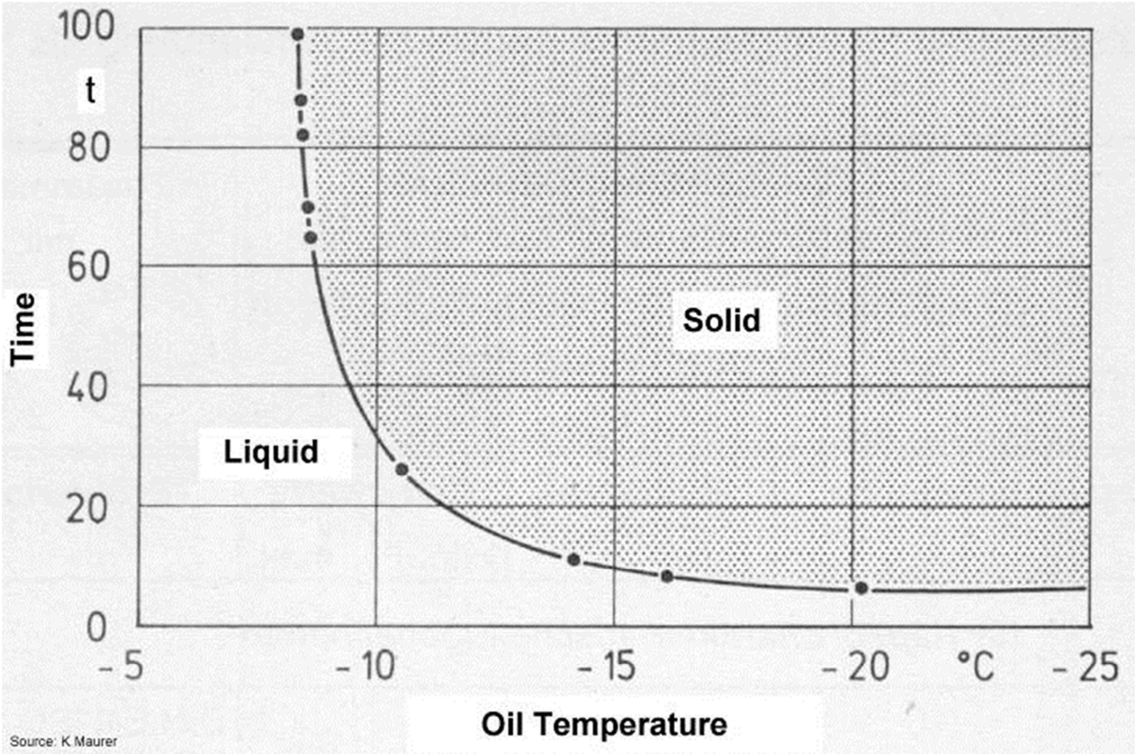
### 3.3.5 Alkali content (Ca+Mg)

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 for Ca+Mg 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 range at which the phase shift happens, will be different for each kind of oil.




Solid/liquid phase shift of rape oil as function of temperature and time.
Jatropha oil has a similar characteristic, but the curve is parallel offset about 10°C to the left.

### 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 for filtration of vegetable oil. 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 could be relevant for this project in case a high acid no. has to be reduced by 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 could become relevant if a saponification process is applied 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 water washing and gravity separation, followed by 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 Preparations

## 4.1 Purchasing gensets

At a very early stage of the project DAJOLKA was contacted by Joe Grove, who asked which engines we could recommend for PPO operation in gensets. One of the recommendations was the Perkins 400D series(2,3 and 4 cylinder), and for the specific capacity needed for the project, the Perkins 403D was suitable.

The Perkins 403D-22 engine is a 3 cylinder natural aspirated diesel engine with indirect injection, which makes it very suitable for PPO operation and it can be converted by a 1-tank system. With respect to emission norms, this engine has been approved according to the EU Stage III A and the US Tier 4.

From our side it is highly appreciated, that this project has chosen engines which are specifically suitable for PPO conversion.

## 4.2 Converting first genset in Denmark

### 4.2.1 Conversion

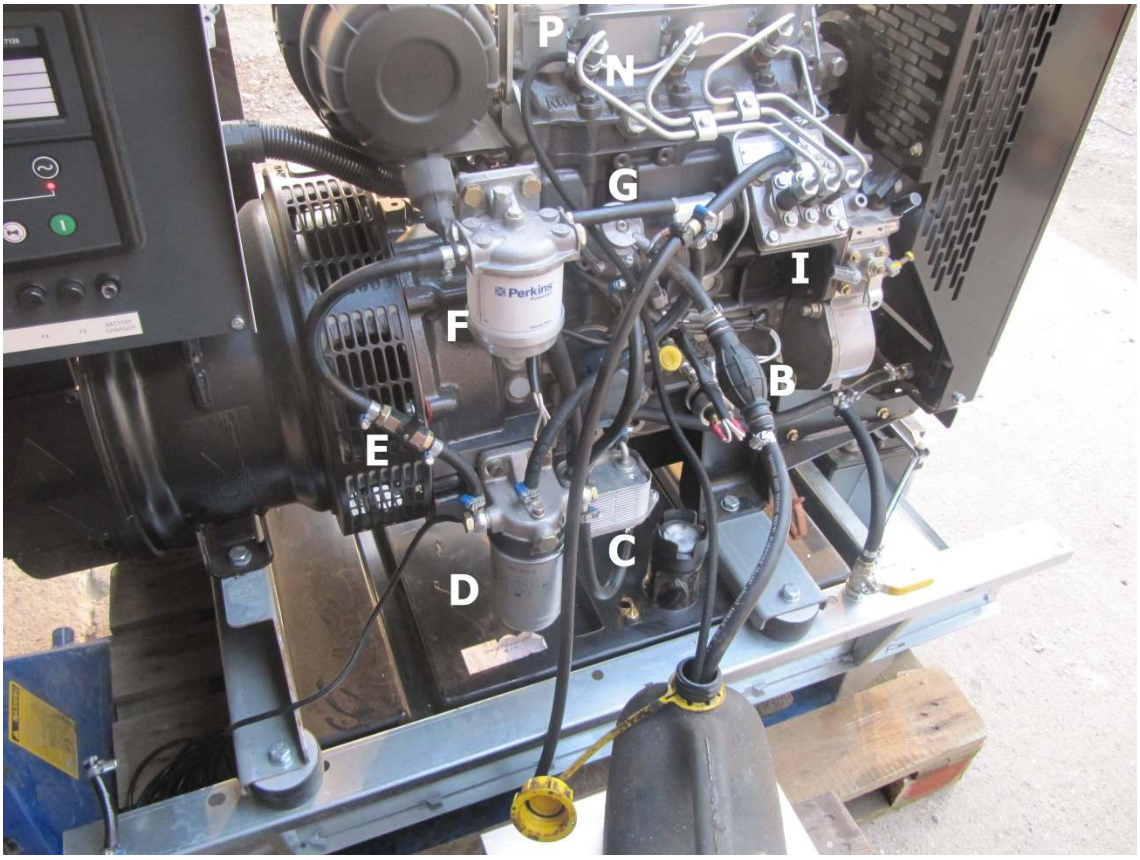
The first genset was shipped from the UK supplier to our address in Denmark for conversion and test. The purpose of this was to select the best and suitable component for the conversion kit, and find all parts which are necessary for this specific conversion, so all parts, even small details like special bolts fitting into existing hole on the engine, could be purchased and shipped to Guinea Bissau. In this way the conversion of the remaining 7 gensets could go fast and smooth without need to spend valuable time searching for materials on the local market, which might even not be available.

Since the Perkins 403D engine has a new upgraded design to meet stronger emission limits than the previous model 403C, we decided initially to test the original injectors with PPO. But with the original injectors the engines had big problems to start on PPO, and the combustion was incomplete even when the engine was hot.

The original injectors after just 1 cold start and approximately 1h operation on PPO.

Then the injectors was changed as planned, and after this the engine got very good cold starting properties

(Left)Special bracket designed for holding the heat fuel exchanger. (Right) Heat exchanger and bracket being installed on the genset.




The main components for the conversion of the Perkins Genset.
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)**, **G)** original lift pump(internal pre filter removed), **I)** injection pump, **P)** Glow Plugs, **N)** Injectors


The fuel feed pressure from the original lift pump was measured both before the conversion running on diesel, and after the conversion running on PPO. In both cased we measured around 0,55bars, which indicates that the lift pump has no problems to handle PPO with higher density and viscosity.

### 4.2.2 Load test

For the load test we used electrical air heaters, which we could adjust in various steps between 1kW and 10kW

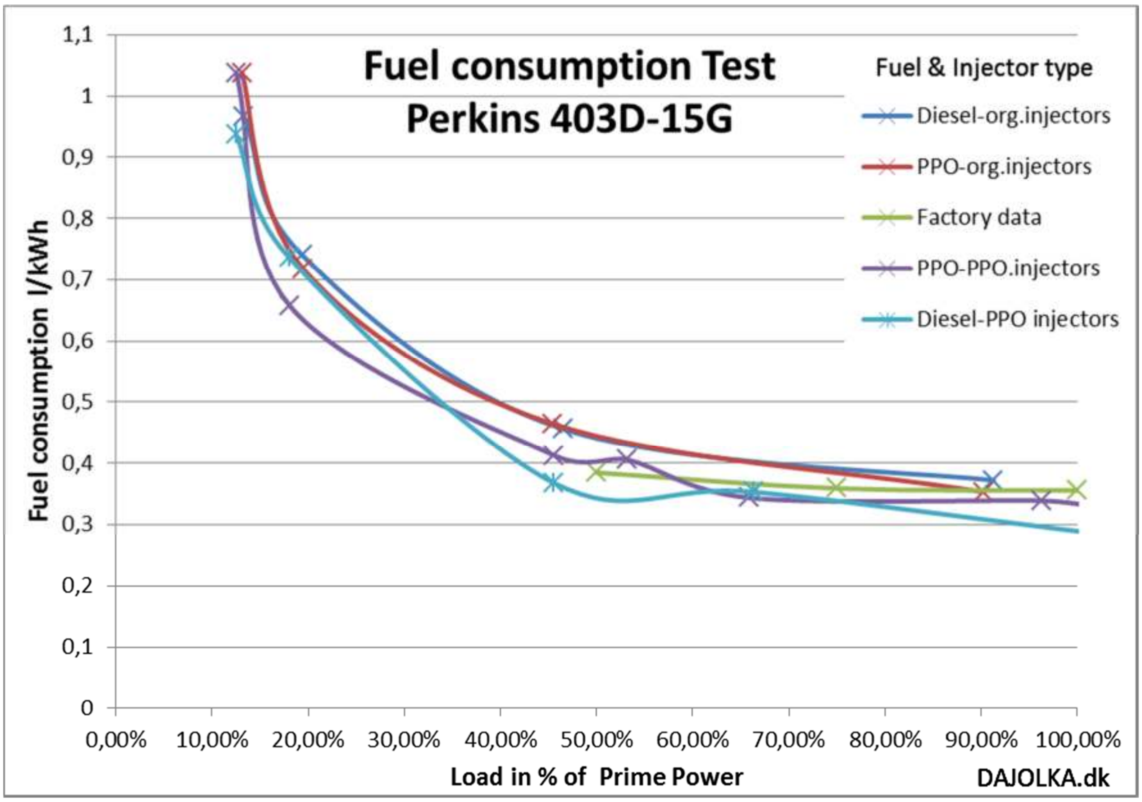

Load test with electrical air heaters and measurement of the consumed power.

### 4.2.3 Measurements of fuel consumption

We made series of load test and simultaneously measured the fuel consumption and the energy production from the generator.

The fuel consumption was measured by weighing the fuel tank on a digital balance.


The power consumed by the load was measured by an accurate 3phase electrical meter.
On the photo the load was 9,38kW – close to full load.




The curve shows the results of the load tests measuring the specific fuel consumption, both on diesel and PPO, and both with original injectors and with the PPO injectors.

From the curves it is clear that the specific fuel consumption is very high at loads below 50%, and it is probably the reason why the manufactory only informs numbers for fuel consumption above 50% load. But the specific fuel consumption is very high for all internal combustion engines at low load.

It seems like the fuel consumption is less with the PPO injectors than with the original diesel injectors, and that the measured fuel consumption matches well to the numbers given by the manufactory.

From the curves it is obvious that its always better to run the engine at loads higher than approximately 40% equivalent to approximately 4kW.

### 4.2.4 Shipping parts and tools


All conversion kit parts and tools packed on the genset to be shipped back to UK, from where all 8 gensets will be shipped to Guinea Bissau.

# 5 Training Sessions

10 participants had been invited to participate in the training.

A meeting was held Monday morning right after Niels and Joe´s arrival to Bissora. And the practical training started right after that.

At the end of each day there was held an evaluation, where all participants should evaluate their own performance as well as they could comment on the performance of the other participants. We found that evaluation very useful and constructive.

Evaluation at the end of each day of training

## 5.1 Training in engine conversion

The participant were divided in 5 groups each of 2 persons, who should work together, and each group should specialize in one of 5 main disciplines in the engine conversion (see workplan in appendix)

The first 3 days was used to prepare the new gensets in Bissora, and to design and manufacture mounting bracket for the heat exchanger and the PPO fuel filter etc.

The first engine was ready and started on SVO on Thursday at 12:00.

The next engine was converted more rapidly the same day, and field missions were prepared in order to convert the remaining 6 gensets which already had been installed in the villages. The preparation included to take out injectors from one the engines and install the PPO injectors, which required the special tools. Then at the same day we went to a village in the afternoon – the team was very excited. The conversion went very well and took only 1h20m.

### 5.1.1 Details of the conversion of Perkins genset

The Perkins 403D engine is a 3 cylinder natural aspirated diesel engine with indirect injection. We had advised the project to purchase such engine because it is very suitable for conversion to 1-tank system for PPO operation.

#### *5.1.1.1 The conversion kit*

The 1-tank conversion system for this kind of engine is well defined already and have proven to work on 1000´s of engines during around 15 year.

The main components in the conversion kit is:

- 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

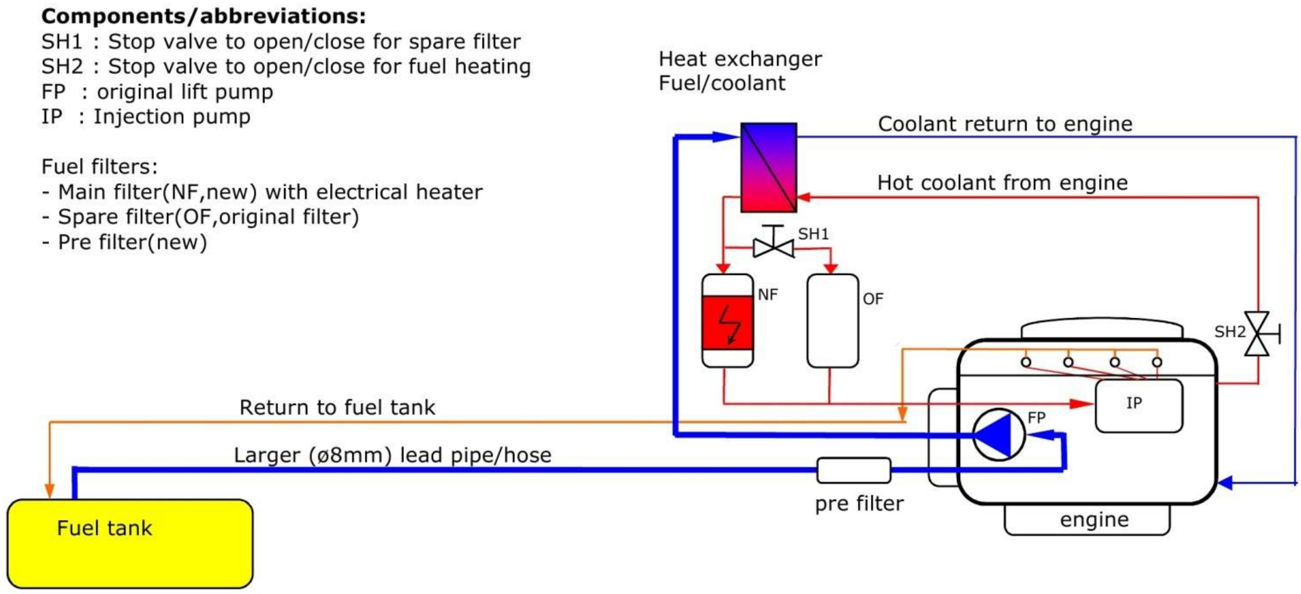
Example of 1-tank conversion kit

#### *5.1.1.2 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 8-15 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 fuel 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.

##### 5.1.1.3 Modifying fuel cycle

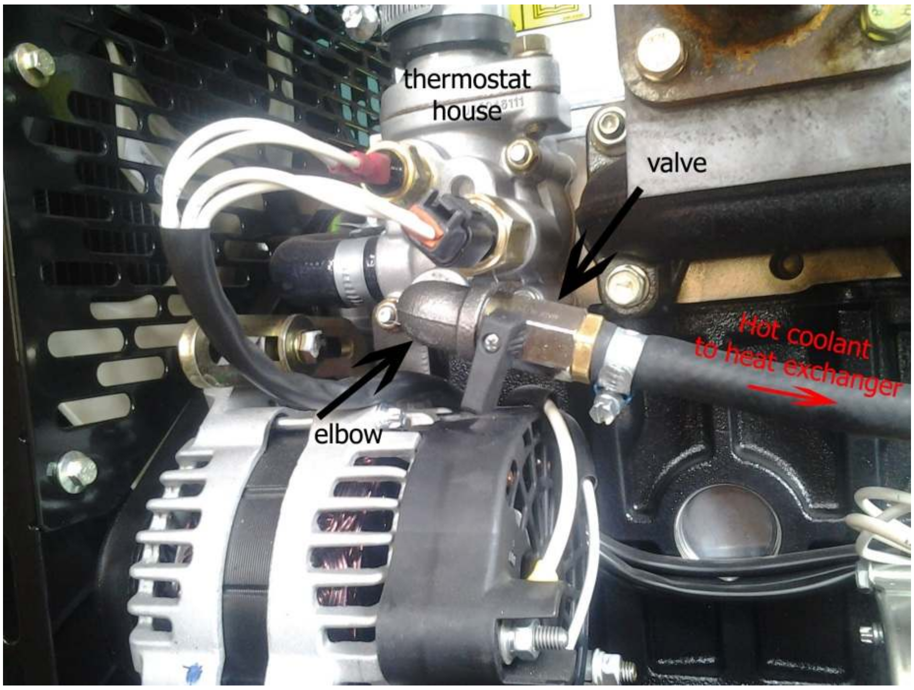



The diagram shows the modified fuel cycle including 2 fuel heating systems.

A new fuel filter(NF) is installed parallel to the original fuel filter(OF). 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.

##### 5.1.1.4 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 point 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.

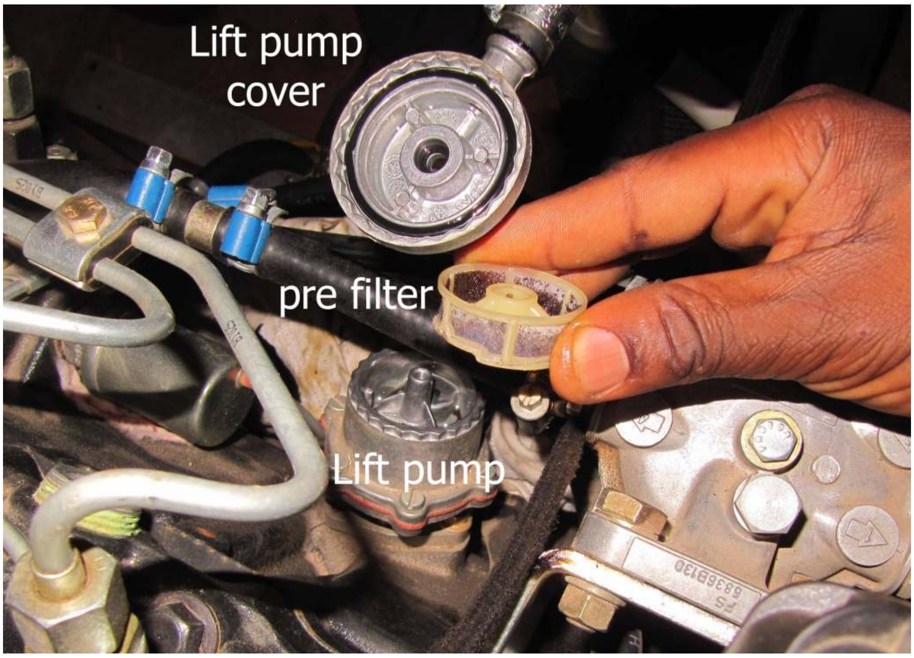


The hot coolant is taken out from the coolant thermostat house, just before the thermostat, then passed through the fuel/coolant heat exchanger, and returned to the bottom om the radiator.

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.

#### 5.1.1.5 Remove pre-filter from lift pump

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.



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

Because this original pre filter is very small and compact it is likely that it soon can block and make too much resistance for the lift pump. 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 the original pre filter on the Perkins.

The original pre filter on the lift pump is replaced by this in-line pre filter, which has much larger capacity in volume, and the larger dimensions reduced the flow resistance (pressure drop). Dimensions filter body: LxD = 125xØ40mm, connections Ø8/Ø10mm hose nippels

#### *5.1.1.6 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 in tank pre filters should be removed or Ø6mm holes should be drilled in the filter to avoid it from blocking.

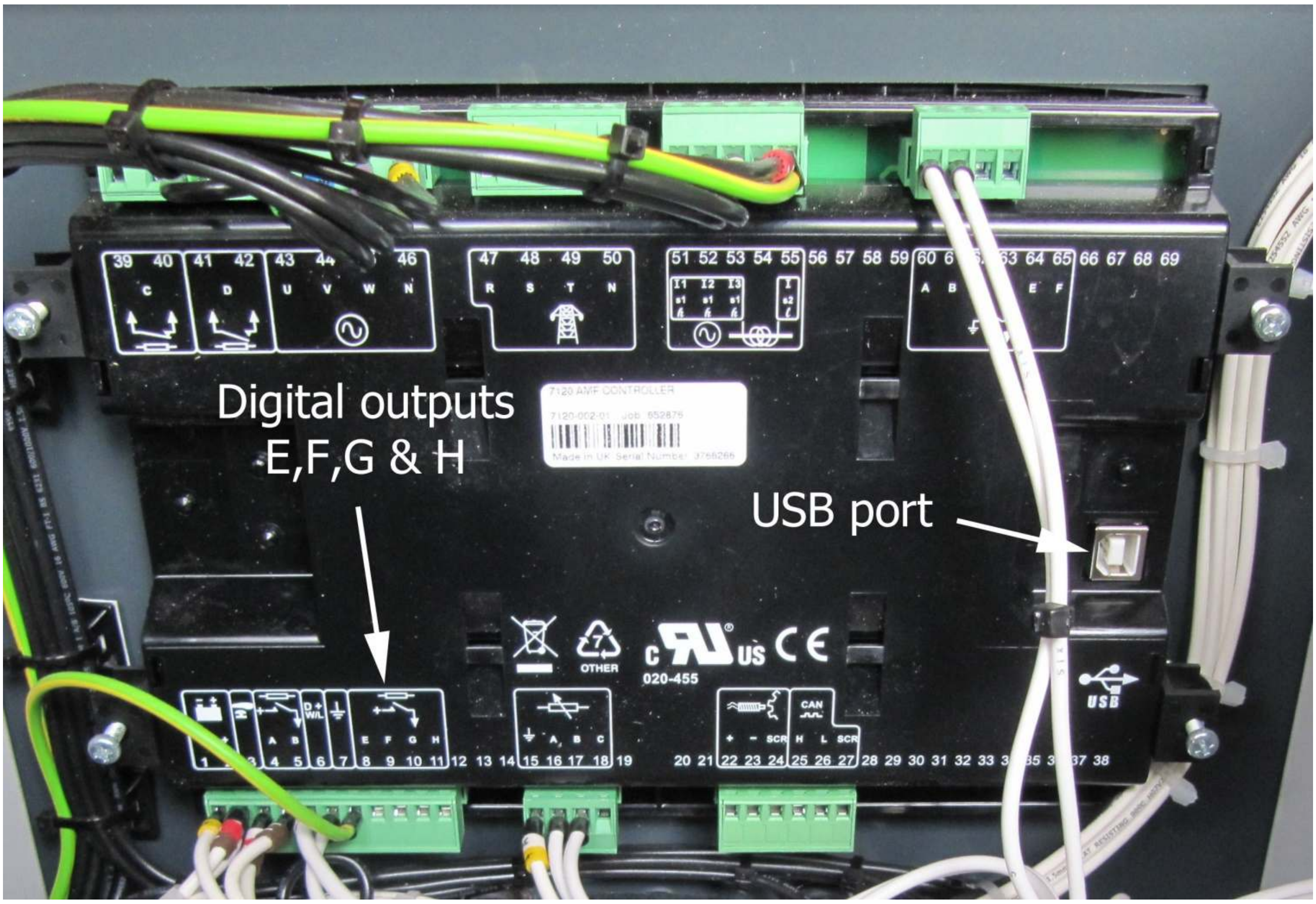
#### *Modifying the Control system*

The genset is equipped with a DSE7120 control system, which controls and monitors the engine, generator and electrical grid system. The control system can be configured for many different types of gensets, and if offers also some extra functions which can be configured. The configuration of the control system can be modified using a laptop computer, an USB cable and the software from the manufacturer of the controller.

The Perkins engine has glow plugs installed for pre heating the combustion chamber before cold starting, but they are not connected electrically and no glow plug controller(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 the "ignition" and "start" signals from the genset control system – equivalent to the "ignition" signal in the diesel car, which will start the pre heating(yellow glow indicator is ON) before cranking the engine for starting.

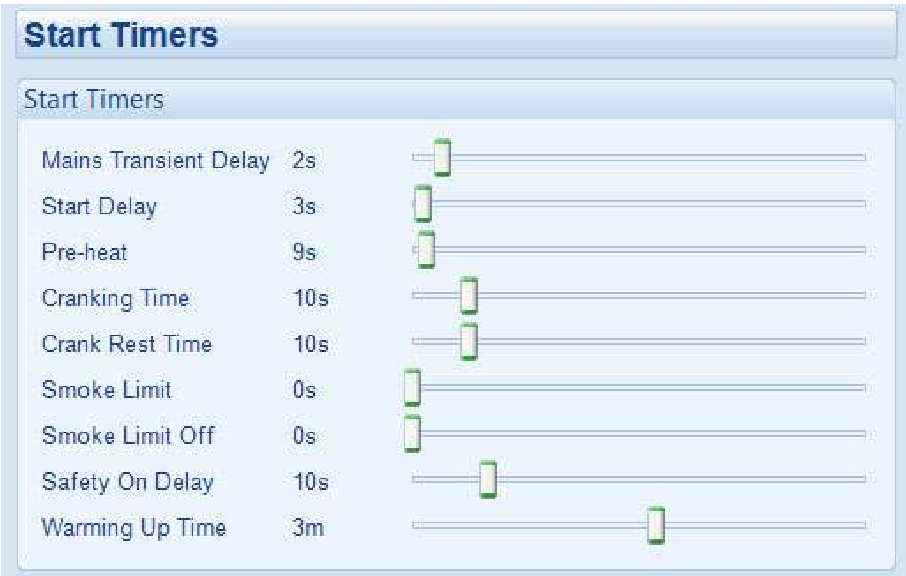
Therefor the original configuration of the DSE7120 controller was modified, in order to these signals available for the new glow relay. The digital output E & F was free and available for this purpose.




The rear side of the DSE7120 control panel. Digital outputs E & F were configured for controlling the pre-heating.


Screen from the DSE configuration software, changing function of outputs E and F.

Besides changing the function of output E & F, the "start timer" for pre heating was changed from 0 to 9 seconds, which means that the control system automatically will start pre heating when the operator pushes the start bottom, or the control system would make an automatic start e.g. in case for mains fault, and then start the engine after 9 seconds pre heat, which is suitable for starting cold IDI engine on PPO in tropical climate.

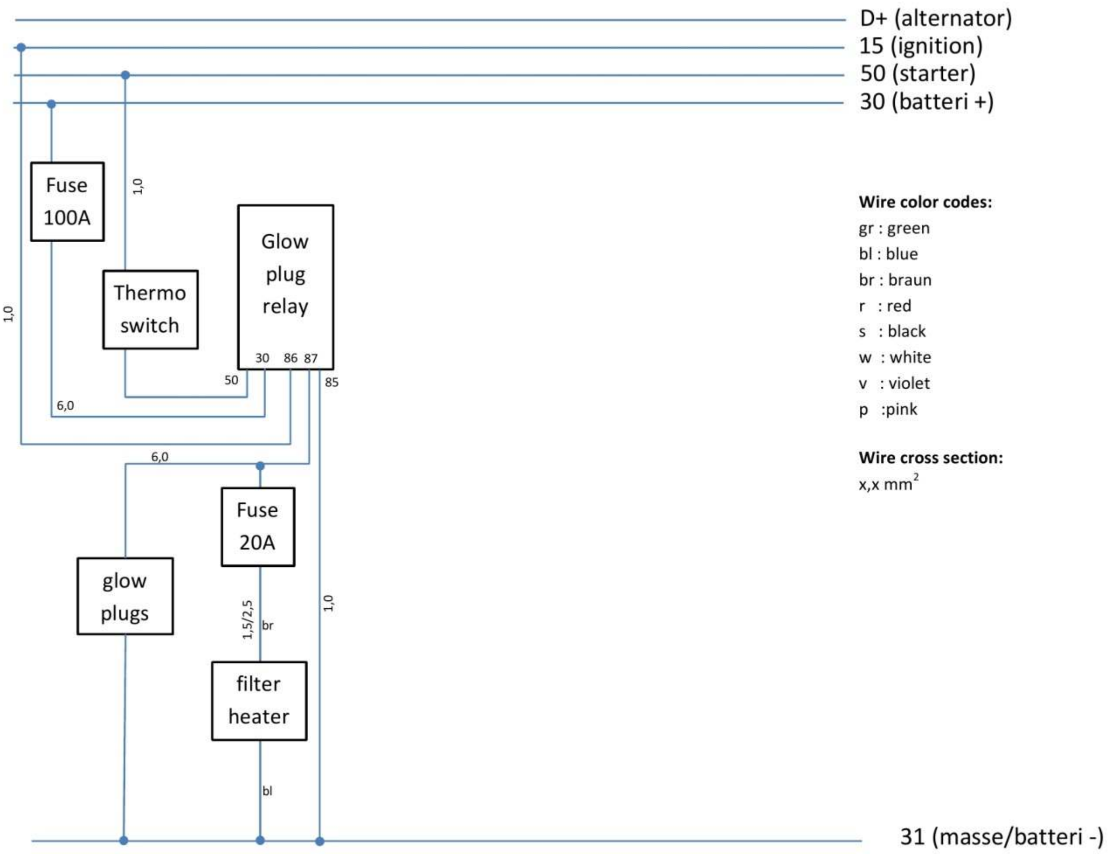



The "start" timers "Pre-heat" and "Warming Up Time" was changed with the configuration software.

The changed settings were saved as a file on the laptop, and was used to change all 8 gensets very rapidly.

### 5.1.2 Installing electrical system for preheating

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




Wiring diagram for glow plug and fuel filter heating controller.

As described previously, the ignition signal for the glow relay was taken from the genset control system(Output E). 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 “start signal” was taken directly at the starter, but

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


New glow plug controller(relay) installed on the read side of the genset controller.

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

#### 5.1.2.1 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 for this project was chosen the full heating system.

The electrical fuel heater is integrated on the new fuel filter, between the filter top and the filter element (see photo). 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.

#### 5.1.2.2 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.

#### *5.1.2.3 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. All other parts we have purchased from various suppliers.

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 …


… where the participants also tried to test the injector opening pressure.

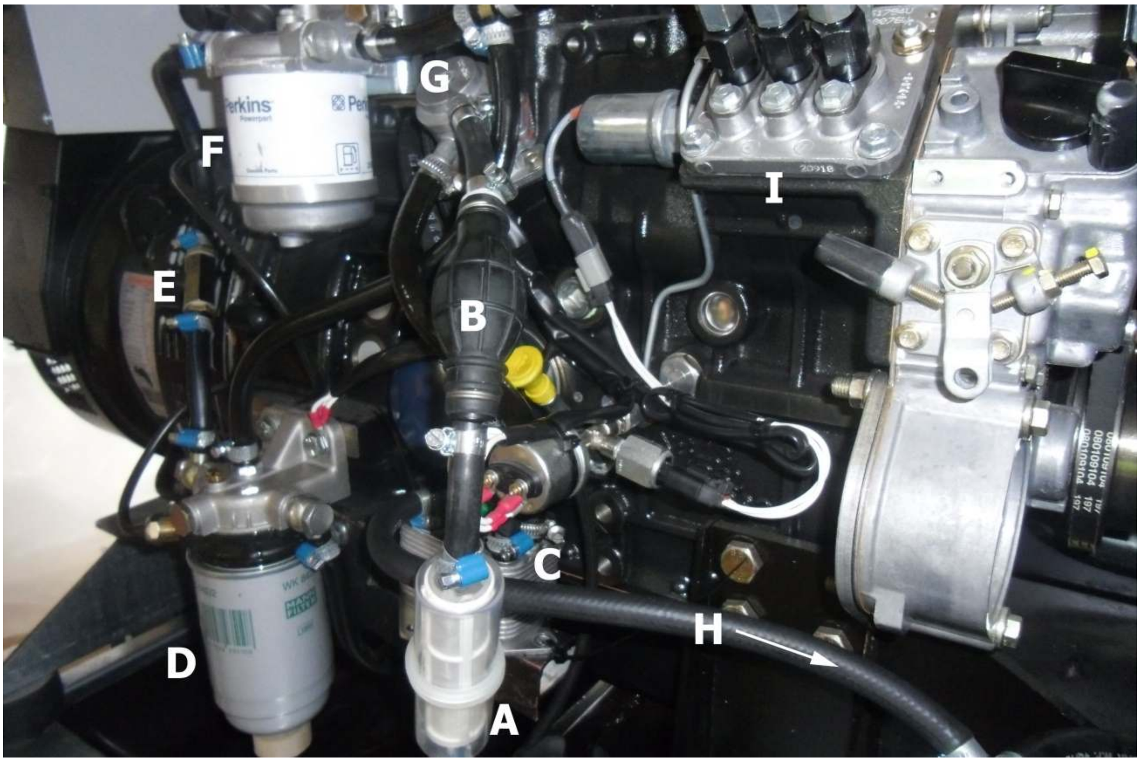
The training in injector change and adjustment is normally very exciting for the participants, especially the BOSCH tester which is used to check the opening pressure of the injector.

For all 8 new Perkins engines we found the original opening pressure to fluctuate from 125-135bars, which is a little low for good atomizing of PPO. 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.

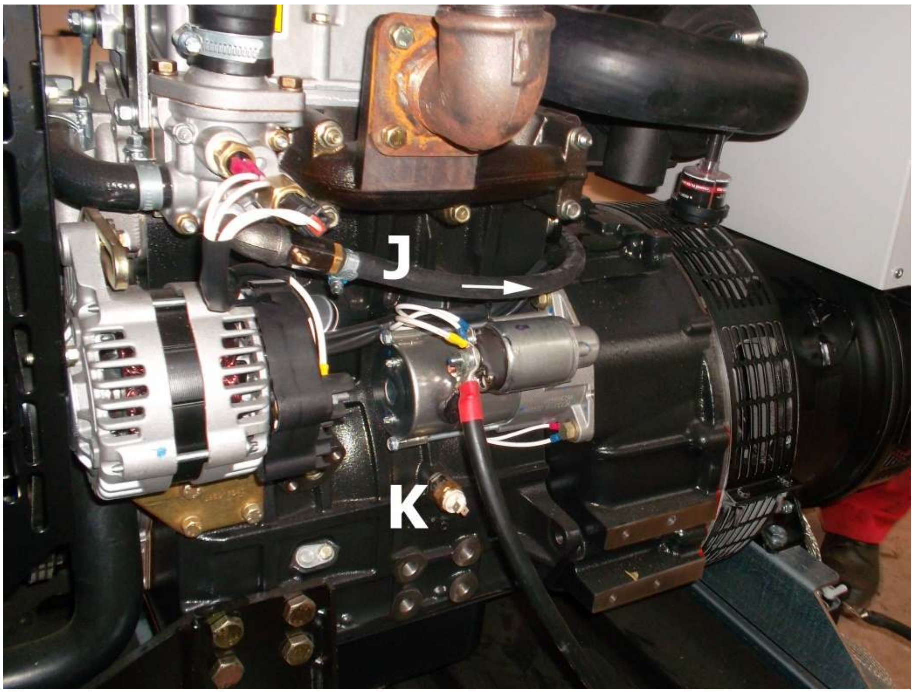
The lifetime of the injector nozzles mainly depends on the quality of the fuel. With good PPO quality the injector nozzles will have at least the same life time as injector nozzles used with diesel. We have many good examples where injector nozzles are still performing well in vehicles after more than 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 spray and opening pressure(right)

#### 5.1.2.4 Conversion completed and testing

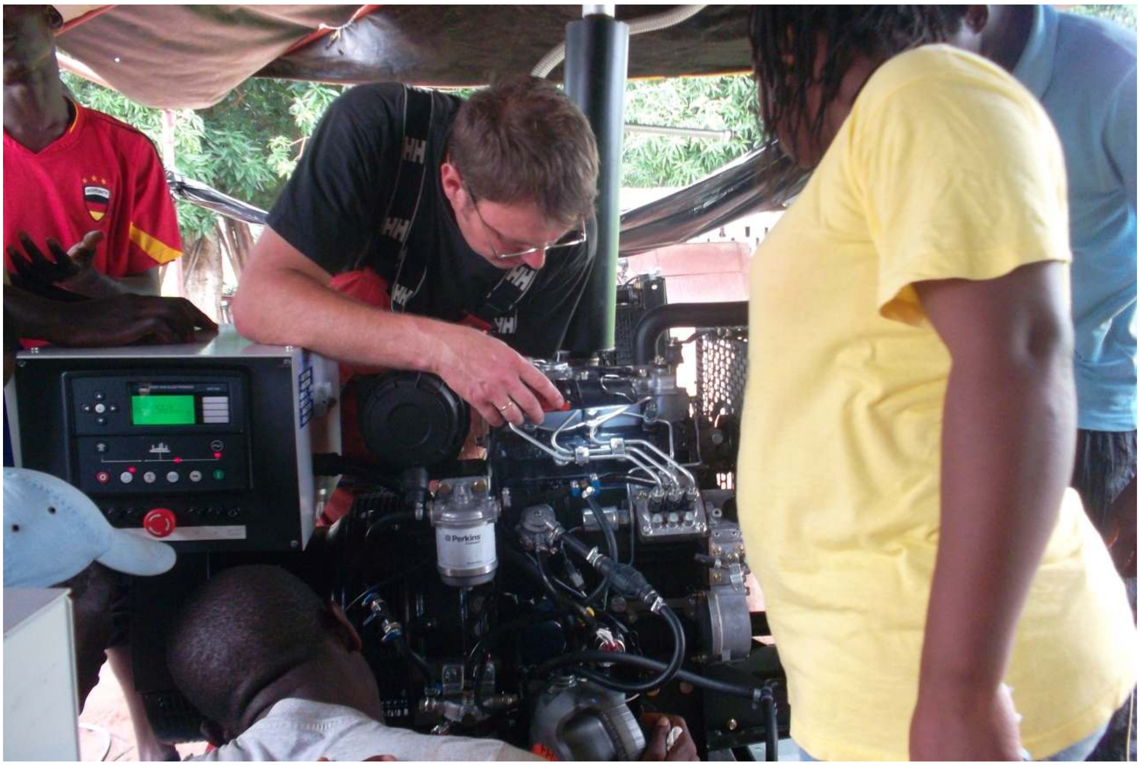



The main components for the conversion of the Perkins Genset.
**A)** New pre filter, **B)** original manual lift pump(for bleeding air after change fuel filter), **C)** new coolant-PPO heat exchanger, **D)** New fuel filter with electrical heater, **E)** stop valve to close the parallel connection of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




On the opposite site of the engine is found the new coolant connection to the thermostat house, stop valve and hose connection **J)** to the fuel heat exchanger, and the Thermo Switch **K)** which detects if the engine body temperature is above og bellow 65°C.

Test run after the 1st conversion with refined cooking oil from the shop.



First test run after the conversion – checking that there are no leakages from fuel and coolant connections, and no leakage from the injectors.

## 5.2 Training in maintenance

During the conversion training was included instructions in how to test and change glow plugs, fuel filters, injectors, and lube oil.

## 5.3 Training in electrical load and connections

### 5.3.1 Measurements of power consumption from different machine

A 3-phase digital electrical meter was delivered together with a small USB data logger, in order to measure power consumption over timer – e.g. measure the power consumption from the machine during 1 hour or during some day, and in this way get experience how much it costs to run each kind of machine, and how much to charge for the energy supply.

Different load test was done using a homemade water heater dump load. The load tests were conduction by Joe Grove, ADPP.

The dump load is made from 3 conductors – 1 for each phase – which are immersed in water-cooking salt(NaCl) solution. The salt makes the water conducting current between the phases, and thereby heats the water.

### 5.3.2 Adjusting genset controller for heavy motors starting loads

The agricultural products processing machines used in the projects are typically equipped with 3 phase 5,5kW electrical motors, which during starting draws approximately 3 times nominal currents, which actually is a 50% more than the genset's nominal capacity.


Therefor starting these electrical motors are triggering the "overload protection" with the default settings in the genset controller, which made the genset stop. So it was necessary to change the

“Generator Transient Delay” limit in the control system from default 1sec to 6sec, allowing the load shortly to exceed the nominal power. This was carried out by Joe Grove (photo above)

### 5.3.3 Parallel connections of 2-gensets for the main center

A test of paralleling 2-gensets for the main center was carried out, conducted by Joe Grove, ADPP. The genset was synchronized using 2 light bulbs, after the direction of rotation (phase order) had been checked by connecting the grinder.

The synchronization when well, but when adding load from the processing machines, the individual mechanical speed controllers (governors) on the gensets were “confused” which gave large +/÷ fluctuations in the load sharing, so initially it was concluded that this didn´t work out well, and the gensets had to be load separately with different processing machines.

## 5.4 Examination

On the last day all participant were invited for an examination. Each team of 2 persons was invited separately to answer questions in 6 categories covering the topics which had been part of the training.

The environment for the examination was around the genset in the workshop tent.

### 5.4.1 Examination questions and correct answers

All participants got the same questions, as in the following table. Possible correct answer and explanations are given in the right column.

| Category | | Questions | Answers |
|---|---|---|---|
| Fuel system | Q1a | Explain the fuel system from the fuel tank to the injection pump? | Show fuel lines and explain the components: Pre filter, lift pump, fuel filters (main filter, extra filter) |
| | Q1b | What is purpose of the stop valve SH1? | The stop valve opens or closes for the extra fuel filter, which is connected parallel to the main fuel filter. The stop valve should be opened if the main filter is blocked and need to be changed. The opening/closing the valve can also help to identify if the main fuel filter is blocked. The extra filter is the original fuel filter, and the new fuel filter with electrical heating is the main filter. |
| | Q1c | Why is the fuel heated? | The fuel is heated to lower the viscosity, so the fuel can easily pass the fuel filter, and to melt eventually solid fat components, which can be present in vegetable oil, and which can block the fuel filter. The lower viscosity is also necessary for the injection pump to work normal. |
| | Q1d | What is installed on the main filter? | On the main filter is installed an electrical heater, which will heat the fuel the first 3 minutes after cold starting the engine. The purpose is to lower viscosity to ensure that the engine get enough fuel. The component could be taken out for tropical climate. |
| Cooling system | Q2a | Explain how the heat exchanger is connected to the cooling system of the engine? | The heat exchanger is connected to the cooling system at the coolant circulation pump. The hot coolant is taken out just before the thermostat, then pass the heat exchanger, and is returned un to the suction side of the coolant circulation pump. |
| | Q2b | What is the purpose of the thermostat in the engines cooling system? | The purpose of the thermostat is to keep heat inside the engine until it reached operating temperature, typically at 80-90℃, and then keep the temperature at this level by opening the thermostat, letting coolant circulate though the radiator to get cooled down.<br>Remarks: People often believe that it is better for the engine to be as cool as possible, and sometimes even the thermostat is removed to get it cooled down. But that is in general bad for the engine and will increase fuel consumption and shorten down the engine life time. And when operating on PPO it can even be dangerous for the engine, while cold temperature will lead to inefficient combustion, with increased level of emissions and generation deposits of unburned fuel in the engine. |
| | Q2c | Why is there a stop valve in the connection to the heat exchanger? | The stop valve is installed just in case the engine will be operated for a long time on diesel fuel – in that case the fuel heating is not a problem, but also not necessary. |
| Wiring system | Q3a | What is the purpose of the glow plug relay? | The glow plug relay controls operation of the glow plugs by energizing them with power. |
| | Q3b | From where does the glow plug relay get power? | The power is taken from the battery positive pole. On the specific solution it is connected to the battery positive pole found on the start motor. |
| | Q3c | What is the purpose of the fuses? | The purpose of the fuses is to protect wires and component in the electrical system against higher current than they are designed for. |
| | Q3d | What is the purpose of the 15 amps small fuse? | The 15 Amp (blue) fuse protects the electrical fuel heater and the wires. |
| | Q3e | From where does the glow plug relay get the control signals? | The glow relay are controlled by 2 signals – 1) "Ignition" signal(no.15) is taken from the Deep-Sea control panel, which will initiate the pre-heating before cranking and starting the engine. The relay will energize the glow plugs for 20 seconds. 2) the other signal is taking from the starting signal (no. 50), which is an indication that the engine is being started. This will initiate the after-heating, which means that the glow plugs are kept energized in 3 minutes after cold |

| | | | |
|---|---|---|---|
| | | | starting. In case the engine is already warm >65℃ when started, a thermo switch will disconnect the start signal to the glow relay, and it will only energize the glow plugs during 20 seconds from ignition. |
| Glow system | Q4a | What is the purpose of the glow plugs? | The glow plugs are energies before starting the engine to pre-heat the combustion chamber before starting. And in many application glow plugs are kept energized for some minutes after starting for optimizing the combustion. When started a cold engine on PPO, both pre-heating and after heating is obligatory to insure good starting and optimize the combustion of the cold engine. |
| | Q4b | How to check if the glow plugs are working? | There are several ways to get indication if the glow plugs are working.<br>1) Measure the resistance though the glow plug with a multimeter. A healthy glow plug typically has a resistance of 1,0 Ω, but if the glow plug is "burned out", the resistance typically increase to several kΩ. The resistance is measured between the battery negative pole(chasis) and the electrical connecter at the end of the glow plug. If several glow plug are supplied with power paralleled with a bridge, the bridge has to be disconnected first, in order to measure directly on one glow plug only.<br>2) Measure the currents consumed by the glow plugs when energies. A healthy glow plug typically consumes 15A just when energized, and then the current with drop to about 7,5A as the glow plug heats up.<br>3) Energize the glow plug and observe if the outer 5-10mm of the glow tip get very hot and glowing orange. Normally the glow plug should be taken out of the engine to observe this. |
| | Q4c | How was the glow plugs controlled on the original system before the conversion? | The Perkins engine was born with glow plugs, but the genset control system did not include any glow plug control system, probably because the genset from the manufactory was intended to work on diesel in hot climate, and there for pre-heating was not necessary. |
| Injection system | Q5a | Why was the injectors changed? | The mew injector nozzles are necessary for starting the engine directly on PPO(1-tank system) and burn the PPO efficiently to minimize emissions and deposits inside the engine from unburned fuel. The injector nozzles are specially selected to this engine, and one of the typical properties is that it makes a small pilot injection before the main fuel quantity is injected. |
| | Q5b | What was changed with the pressure? | The pressure has been increase from the original 125bars to 145 bars in order to have better atomizing of the PPO. |
| | Q5c | How was the pressure changed? | The injector opening pressure is adjusted by changing thickness of the Shims, which looks like washers, and are situated between the upper injector holder part and the spring. Larger thickness of the Shims makes higher force from the spring and therefor higher opening pressure. |
| Power system | Q6a | How many wires come out from the generator? | There are 3 phases and 1 neutral, totally 4 wires |
| | Q6b | What is the voltage between the wires? | There are 400 V between the phases, and 230 V between each phase the neutral. |
| | Q6c | How many wires and which voltage is used to run a drill machine? | A typical hand held drill machine is a single phase 230V motor, which needs 2 wires from the genset – 1 phase and 1 neutral. |
| | Q6d | How many wires and which voltage is used to run the maize mill? | The maize mill typically use a 3 phase 400V motor, which needs 3 phases from the genset, for triangle connection. For star connection the neutral is also needed, totally 4 wires. Special motor starter switches which are used to limit the starting current consumed by the motor, typically use start connection to spin the motor up, and the switch to triangle connection. |

### 5.4.2 Evaluation of the participants

The performance and answer from each participant was evaluated during the examination, and the result is shown in the following table.

Explanation of notes: ↗ Good or very good, → acceptable, ↘ below average.

| | | Team name and participant no. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Preparation team | | Heat exchanger team | | Fuel system team | | Injector team | | Electrical team | | remarks |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Category | Questions | | | | | | | | | | | |
| Fuel syst. | Q1a | ↘ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | → | → | |
| | Q1b | ↘ | ↘ | → | → | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | |
| | Q1c | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | |
| | Q1d | ↗ | ↘ | ↗ | ↗ | ↗ | ↗ | ↘ | ↘ | ↘ | ↗ | |
| Cool. syst. | Q2a | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | |
| | Q2b | ↗ | ↗ | ↘ | ↘ | → | → | ↗ | ↗ | ↘ | ↘ | |
| | Q2c | ↘ | ↘ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↘ | ↘ | |
| Wiring syst. | Q3a | ↘ | ↘ | ↗ | ↗ | ↗ | ↗ | → | → | → | → | |
| | Q3b | → | → | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | |
| | Q3c | ↗ | ↗ | ↘ | ↘ | ↘ | ↘ | ↗ | ↗ | ↗ | ↗ | |
| | Q3d | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↘ | ↘ | → | → | |
| | Q3e | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | ↘ | → | → | |
| Glow syst. | Q4a | ↗ | ↘ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↘ | ↗ | |
| | Q4b | ÷ | ÷ | ↗ | ↗ | ↗ | ↗ | ↘ | ↘ | ↘ | → | |
| | Q4c | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | |
| Injec. syst. | Q5a | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | |
| | Q5b | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | |
| | Q5c | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | ↗ | |
| Power system | Q6a | ↗ | ↗ | ↘ | ↘ | ↗ | ↗ | ↗ | ↗ | → | ↗ | |
| | Q6b | → | → | → | → | ↗ | ↗ | ↗ | ↗ | → | ↗ | |
| | Q6c | → | → | ↘ | ↘ | ↗ | ↗ | ↗ | ↗ | ↘ | ↗ | |
| | Q6d | ↗ | ↗ | ↘ | ↘ | ↗ | ↗ | ↗ | ↗ | ↘ | ↗ | |

All participants passed the examination, and our general impression was the level was good.

The examination also gave us some useful feedback, because there were some issues regarding the fuel system and the wiring system which none of the participants had understood. So we got the chance to explain these things once more, and for the next time remember to explain these topics better or in a different way.

# 6 Other technical issues

## 6.1 Maintenance of gensets and engines

When operated on PPO, the engines should generally be maintained in the same way as when running on diesel.

Glow-plugs:

The glow plugs are used for longer time when starting on PPO, so therefor it should be expected shorter lifetime than when used for diesel start. Actually the glow plugs in these engines were not connected when delivered – probably because the manufactory considered that using the glow plugs are not necessary in tropical climate.

Injectors:
The injector usually will have the same lifetime as if operated on diesel. But with PPO operations there are some risk that the PPO could have high acid value which will shorten the life of the injectors. Therefor PPO quality issue should have necessary attention. The injector Nozzles are special for PPO, and the opening pressure is increased compared to diesel operation.

Lube-oil:
On this kind of engine the lube oil change interval can generally be kept on the same level as for diesel operation, but in case the engine runs long time idling or on low load, its advisable to shorten the oil change interval to the half, which mean the lube oil should be changed every 250hours.

The problem with low load operation on PPO is that unburned PPO can reach and contaminate the lube oil. Initially it is not a problem, but by time and the high lube oil temperature, the PPO can polymerize, and can suddenly change its liquid properties and turn into semi solid pudding. It's a general challenge for Direct Injection engine, and less a problem for Indirect Injection Engines, like the Perkins used in this project.

We recommend to take samples of the lube oil when it is changed after250 hours operation on PPO, and send a 100ml sample to a laboratory to analyzed for PPO content in the lube oil. The test costs 45 EURO´s and can be done in Germany.

# 7 Follow-up

The most important issue to follow up on, is to make sure that the gensets are operated with a good quality PPO, and to check that the engines starts and operate good on PPO. It is important to check the lube oil level frequently, and important to change the lube oil after max. 250h of operation in PPO.

# 8 Conclusion

All technical tasks were completed within the planned time schedule.

The training workshop had been planned very well by ADPP, and 10 motivated participants passed the examination at the last day.

The 8 Perkins gensets are very suitable for conversion to PPO, and the conversion system installed is a very professional and well tested system, which can work for many years without special requirements.

# 9 Appendix

## 9.1 Daily checklist for operation of genset

| Date 2014 | Time | genset hours | Check before start | | | | Added fuel | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | lube oil level (daily) | water level (daily) | battery acid level (weekly) | fuel level (daily) | Diesel liter | PPO liter | |
| 1/1 | 8:20 | 125 | ÷ | OK | OK | OK | 0 | 15 | 0,5 liter oil added |
| | | | | | | | | | |
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Suggestion for a checklist to use for operation and maintenance of the gensets.

## 9.2 Work plan for the conversion.

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.
   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 genset control system, DSE7120
   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.)

## 9.3 Technical documentation

### 9.3.1 Wiring diagram

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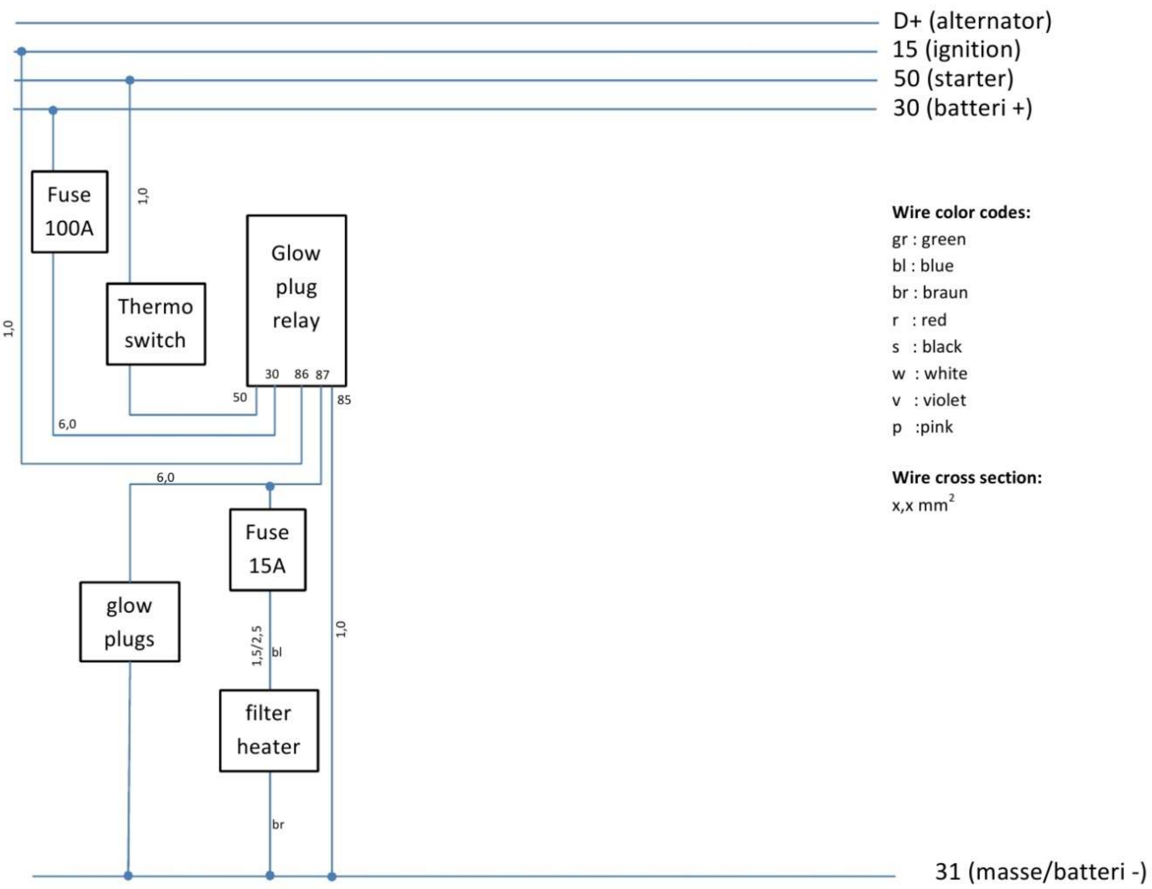
DK-9330 Dronninglund
Danmark
niels@dajolka.dk , www.dajolka.dk
Tlf:+45 9885 4220 , Mob:+45 4014 8020
CVR nr. 20448636

NA 20/5 2013

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

Gensets, GB



## 9.3.2 Fuel line diagram

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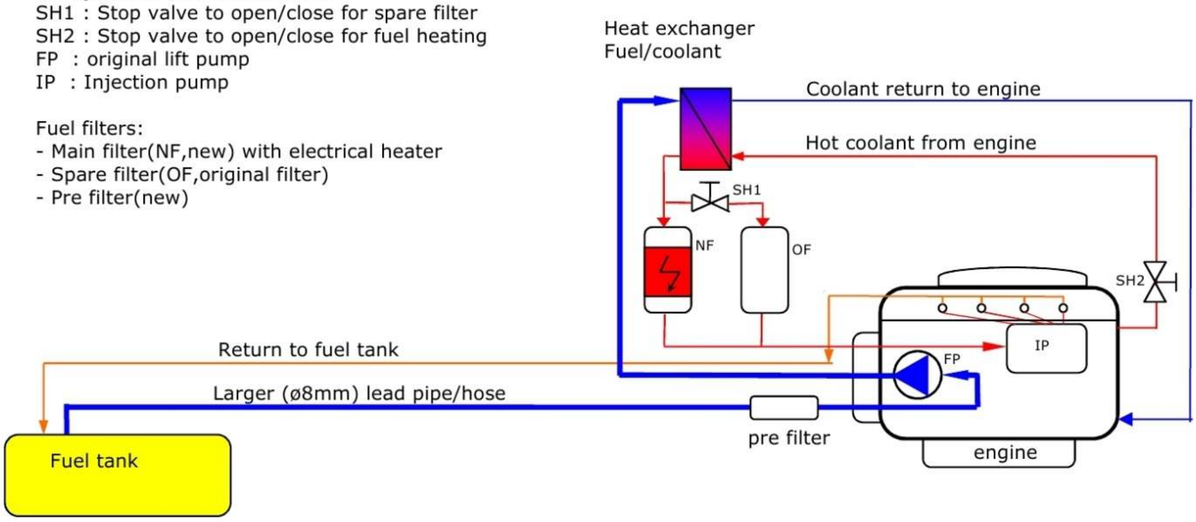
NA 20/5 2013

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

**Components/abbreviations:**
SH1 : Stop valve to open/close for spare filter
SH2 : Stop valve to open/close for fuel heating
FP : original lift pump
IP : Injection pump

Fuel filters:
- Main filter(NF,new) with electrical heater
- Spare filter(OF,original filter)
- Pre filter(new)




## 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:**

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Dalmosevej 2
9330 Dronninglund

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

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