JATROPHA HANDBOOK

2D EDITION

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CHAPTER 5 (OF 6)

Applications of Jatropha products

5 Applications of Jatropha products

5.1 Introduction

Jatropha has many potential applications. However, until now only a few have been realised on a reasonable and large scale. Jatropha is primarily cultivated for its oil. However, this oil is not the only usable product from the plant. During the process of extracting the oil, many useful by-products are created, as well. Here, first the oil applications are discussed, followed by the applications for the by-products.

5.2 Applications of oil

Jathropa oil can be used in several ways. The pure (untreated) oil can be used as fuel or for soap production. Jathropa oil can also serve as a resource for the production of biodiesel.
First the applications of the raw oil are discussed, followed by the oil refining to biodiesel.

5.2.1 Lamps and cooking stoves

Author: Peter Beerens

For lamps and stoves, the conventional fuels in most rural areas are fuel wood, charcoal and petroleum. By introducing alternatives like plant oils such as jatropha oil for cooking and lighting, the use of conventional fuels could be strongly reduced. Potential users of the jatropha oil are those people who currently buy their fuel (charcoal, kerosene) in areas where there is no free alternative (fuel wood) available.

5.2.1.1 Lamps

The difficulty when using jatropha oil for lighting is its high viscosity. Most kerosene lamps use wicks. The suction of the Jatropha oil is sufficient in the beginning, but as the oil level diminishes and the oil has to travel longer distances through the wick, the lamps dim. A second problem is the formation of cokes on the wick's surface, which is a second cause for the lamp to dim. Lastly the ignition temperature of jatropha oil (240° C) is much higher than for petroleum (84° C). This makes it more difficult to ignite the fuel.

To overcome the problem with a fixed wick a floating wick can be used. An example of a lamp using this principle is the 'Binga lamp' developed by the binga trees project in Zimbabwe. As the oil level drops, the wick sinks together with it keeping the distance between the flame and the oil constant. An impression of the binga lamp is given below.

Coking of the wick is caused by the higher evaporation temperature of jatropha oil. Petroleum normally evaporates from the wick while the flame burns. The flame burns at a small distance from the wick's surface thereby leaving the wick intact. As the jatropha oil does not evaporate as quickly, it burns on the wick's surface causing the formation of carbon deposits on the wick. After 8 hours the visible part of the wick is completely carbonized and has to be replaced [1].

Figure 1 - An ordinary petroleum lamp (r) modified to run on jatropha oil (l). [2]

Figure 2 - Binga lamp s developed in the 'Binga Trees' project Zimbabwe. [3]

5.2.1.2 Cooking stoves

Designs of stoves using the jatropha seed are based on three different methods. The first uses the solid jatropha seed kernels as fuel as with the UB-16, see Figure 3. The second method uses the jatropha oil in modified kerosene stoves with a wick. The third method utilizes the jatropha oil, vaporized and sprayed under pressure into a specially designed stove, like the 'Protos' (Figure 5). The main drawback of jatropha oil in cooking stoves is its high viscosity, which often leads to clogging of the fuel pipe or burners. Several stoves that have been adapted to or specifically designed for jatropha oil are shown below. Although it is documented that jatropha stoves have very low emission levels compared to wood stoves, it is not known yet if the smoke of jatropha fuel is harmful because of its toxic ingredients. This is an important aspect and further research is highly recommended.


(3)


(4)


(5)

Figure 3 - UB-16 stove that is claimed to be directly fired with (de-hulled) jatropha seeds.[4]

Figure 4 - The Wheel brand stove, a typical example of an adapted kerosene stove.

Figure 5 - Protos plant oil stove developed by BSH Bosch and Siemens Hausgeräte GmbH.

The 'PROTOS' plant oil stove was developed in 2004. This unusual stove can be fuelled by unrefined and refined vegetable oils such as coconut oil, sunflower oil, rapeseed oil, jatropha oil, castor oil, cottonseed oil and peanut oil. Except for the burner, this stove can be produced locally thereby creating employment. Over 500 ''Protos'' stoves have been tested in the Philippines, India, Indonesia, South Africa and Tanzania.

5.2.2 Direct fuel for cars and driving engines for shaft power or electricity generation – PPO

Author: Niels Ansø

5.2.2.1 Introduction

By nature, PPO generally has excellent properties as fuel in diesel engines, so-called compression ignition engines. Generally any warm diesel engine will run on heated PPO. Nevertheless, for generations diesel engines have been designed and optimized for diesel fuel. Since some fuel properties of PPO differ from diesel fuel, different conditions must be followed, and changes (conversions and modifications) must be made to the engines in order to handle some of these different properties. The necessary changes to the engine are typically named conversion or modification.

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

- The PPO fuel quality should meet criteria specified in PPO fuel quality standards. Such standards already exist in Germany for rapeseed PPO, DIN V 51 605. Similar standards should be made for other kinds of PPO.
- The diesel engine should be selected as suitable for PPO conversion, and it should be well maintained and in a well adjusted 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 will secure efficient combustion of the PPO, minimizing the emissions and fuel consumption, and guarantee a normal, long lifetime of the engine. Under these conditions, the performance and fuel consumption when running on PPO will be comparable to that of diesel. On the other hand, if the PPO is combusted inefficiently, problems can be expected sooner or later. Typically, this is because of deposits or other ways of accumulating unburned fuel in the engine. Or it could be the PPO damages the injection system because of aggressive properties leading to corrosion.

All measures, both on the engine side and on the fuel side, are simple and easy to understand. A good, practical approach is important, and most important is not to underestimate the value of each measure for fulfilling the criteria.

In the following chapter we try to cover the key topics relevant for running diesel engines on PPO in developing countries. This includes requirements pf the PPO fuel, selecting engines suitable for operation on PPO, and what has to be changed on these engines in order to operate safely with PPO. However, this is only a guideline. The main source for this chapter is based on Niels Ansø´s own practical experiences with Dajolka [6] (and at Folkecenter), made during more than 10 years, driving all own cars on 100% PPO, and conducting many practical activities including conversion of several hundreds of engines, mainly passenger cars and vans, but also diesel engines in other applications. Any attempt to follow the advice given in this chapter is however at one's own risk.

5.2.2.2 PPO fuel properties

On the fuel side it is essential to care about the quality of the PPO. This starts by selecting the right kind of crop/oilseed, cultivating and harvesting, transport, handling and storing the oilseeds and pressing, filtering, handling and storing the PPO. (See chapter 4)

The PPO fuel quality standard specifies two groups of parameters

- Characteristic properties: occurring naturally and are generally unchanged by production, handling and storing the oilseeds and PPO. These are less important as long as the kind of crop/oilseed is known.

- Variable properties: influenced by harvest, transport, handling and storing seeds, and production, handling and storing the PPO. These are very important for the stability of the PPO during storing, for prevention of damage to injection systems, and for efficient combustion of the PPO.

All parameters are important, but some are more critical than others. The bold marked variables in the table below, which are invisible, but which can damage an engine fast if limits are exceeded considerably. It makes sense to analyse the PPO for the four variable parameters on a regular basis.

Table 5.1: DIN V 51 605 – Quality standard for rapeseed oil as engine fuel, showing 1): The characteristic properties and the variable properties.

Parameter	Limit	Unit
Characteristic properties		
Density at 15 °C	900 - 930	kg/m³
Flashpoint Pensky-Martens	min. 220	°C
Kinematic viscosity at 40 °C	max. 36,0	mm²/s
Calorific value (lower; incl. H2O-Correction)	min. 36.000	kJ/kg
Cetane number	min. 39	-
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		
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)

5.2.2.3 Other properties

Another difference is the energy content, which is about 4%-5% less per volume for PPO, compared to fossil diesel. The lower energy content is partly compensated by more efficient combustion caused by the natural content of oxygen in the molecule structure of PPO.

Table 5.2: difference in constant characteristic properties of PPO (from rapeseed) and diesel

		PPO	Diesel
Density	kg/m^3	920	830
Energy content per weight	MJ/kg	min 36,0 (typically 37,0)	42,3
Energy content per volume	MJ/l	33,1	35,1
Oxygen content	%	11-12	0
Flame point	°C	220	60-70

Viscosity

Considering the hydraulic and mechanical systems in a diesel engine, the main difference in properties between PPO and diesel is, that the viscosity of PPO is many times higher than for diesel at ambient temperature. This makes it more difficult for the PPO to flow from the fuel tank to the engine and to atomize the cold PPO in the injectors. The high viscosity together with a much higher flash point makes it more challenging to start a cold engine on PPO and get satisfactory efficient combustion until the engine is hot.

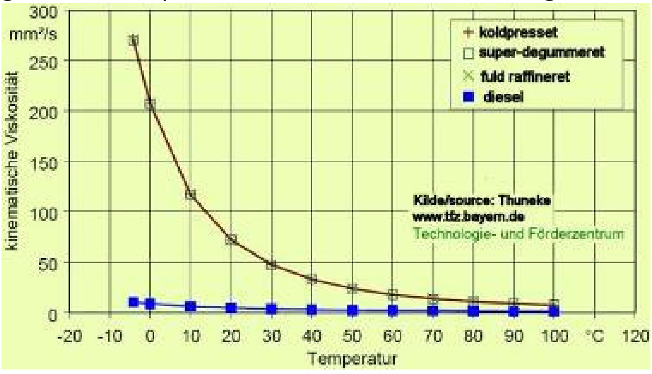

Figure 5.1 Viscosity

The figure shows the kinematic viscosity of rapeseed oil and diesel as a function of the temperature. The blue line show viscosity of diesel, and the red line - actually 3 lines on top of each other, shows the viscosity of rapeseed oil, respectively cold pressed, super degummed and fully refined. At 0°C the PPO is 20-30 times more viscous than diesel, but at 60-70°C the viscosity is near to diesel, the curve becomes flat and the difference disappears.

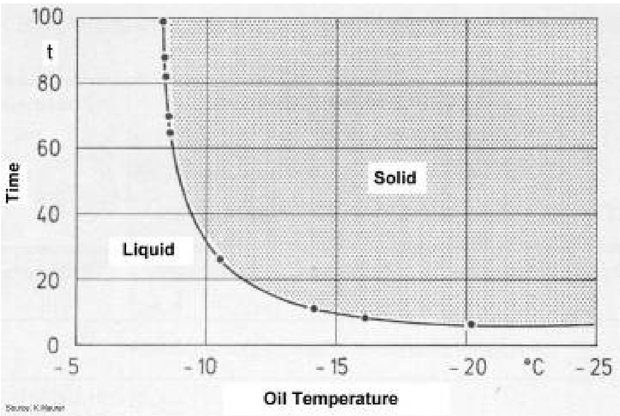

Figure 5. 2 solid/liquid phase shift

PPO can solidify at low temperatures. It's a reversible process and is both a function of temperature and the time. The figure shows the solid/liquid phase properties of rapeseed oil.

It must be emphasized that for jatropha PPO, these numbers will be different since, compared to rapeseed oil, it has a different fatty acid composition with a higher share of saturated fatty acids. Hence its viscosity curve (fig. 5.1) will be different and solidification point will be at higher temperature.

5.2.2.4 Engine conversion/ Engine types

To enable the engine to run safely on PPO the engine must be converted to handle the different fuel properties of PPO compared with diesel. For example, it's necessary to heat the PPO in order to decrease the viscosity, and to modify injectors and glow plugs to enable the engine to start on PPO.
Because of the large variety of engines combined with different manufactories and configuration of injection system, this chapter can only serve as a guide to the most basic things relevant for conversion. Only engines with mechanical controlled injection systems will be discussed, since engines with electronically controlled injections are still not common in developing countries, and because the conversion requires more specialized technology, tools and mechanics trained in these systems.

As mentioned before, 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.

5.2.2.4.1 Identification of the engine

Diesel engines exist in many different types and sizes. Most of them can be converted to PPO in one or the other way. It's important to first identify and choose a suitable engine, and then decide how it should be converted. The main question is whether the engine has direct or indirect injection, and how the engine cooling system is designed. The cooling system is important because it controls the engine operating temperature, and the expended heat from the engine is used to heat the PPO.

Generally all diesel engines with InDirect Injection(IDI) are very suitable for conversion to PPO.
Engines with Direct Injection (DI) can also be converted, but they are more sensitive to the load pattern and fuel quality, so they require more attention and are typically converted with a duel-tank (2-tank) system.

It is normally not recommended to convert engines equipped with distributor injection pumps manufactured by Lucas/CAV/Delphi, Stanadyne or Roto-Diesel. This is because there is a high risk of damaging the pump, typically when the pump and PPO are cold. Other engines can have other problems, making them less suitable for conversion, e.g. DI engines with a bore/stroke ratio > 1.

Therefore, before deciding to convert an engine, it is important to identify the engine, the type and manufacturer of the injection system, and the typical load pattern for the engine. Based on these factors, it's possible to determine if conversion of that engine is feasible.

Initially it is important to determine if the engine has direct or indirect injection, identify which type of preheating system is available (if any), the kind of injection pump and lift pump, and to identify the kind of cooling system. It can often be helpful to make a drawing of the fuel system, showing all components and fuel lines.

For exact identification of the engine it is important to get the following information: Manufacturer, engine code, year of manufacture, number of cylinders, displacement (cm^3), and power(hp/kW). From the engine code it is usually possible to get all technical data for the engine, but for some engines it's also necessary to physically identify the manufacturer of the fuel injection pump, because some models can be equipped with different brands.

Status of the engine

It's essential that the engine is adjusted correctly and is in a well-maintained condition. If the engine is smoking or in other ways is not performing well on diesel, the problems should be identified and corrected before the conversion. If the injectors are worn or the glow plugs burned out, these could be changed in connection with the conversion. The cooling system, including the thermostat, should work well so the engine will reach normal operating temperature as fast as possible – otherwise, if the thermostat is defect, the engine might work at a too low temperature for efficient PPO combustion. If no thermostat is installed, e.g. on air-cooled engines, the engine might cool too much because the cooling system is designed for the worst case. The engine, therefore, may have problems to reach an acceptable temperature, especially at low loads. It might disqualify the engine as suitable for PPO operation. At the very least, the engine should be measured to increase the operating temperature in a safe way.

5.2.2.4.2 Differences between DI and IDI engines

Figure 5.5: the photo 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)

Figure 5.6: the photo shows a cross section of a DI combustion chamber. A) multi-hole Injector, B) glow plug, D) cylinder head, E) piston, F) cylinder wall. (photo: Robert Bosch GmbH)

Figure 5.5 and 5.6 show the cross section area of en IDI and DI engine, respectively. The IDI engine is better for PPO combustion because the fuel is injected into a relatively small and hot pre-chamber, where the combustion starts, before it continues into the cylinder. On a DI engine the fuel is injected directly into the cylinder, which is relatively large and cold compared to the pre-chamber. On both figures an active hot glow plug is shown, which is important for the cold start and to improve the combustion of the cold engine. The glow plug will switch off after starting, but remains activated for a few minutes.

In DI engines, especially, there's a higher risk that unburned PPO will reach the colder cylinder wall, which can lead to deposits on the piston and piston rings, and cause increased flow of PPO along the cylinder wall down to the crankcase, which will dilute the lube oil. Due to its high boiling point, PPO in the lube oil will not evaporate again as with diesel and gasoline, so the concentration will always increase. Initially dilution of the lube oil is not a problem. After time, with concentrations more than 10% PPO in the lube oil, the thermal load of the mixture can cause polymerization, which leads to a sudden and dramatic increase of the viscosity of the lube oil, causing damages or total destruction of the engine. The phenomenon is connected both to the type and quality of the lube oil and the PPO [8].

Figure 5.7

The photo shows a lube oil sample from a DI engine where polymerization had happened. To illustrate how viscous the oil is, a small amount was poured out on a piece of A4 paper, which was then lifted to vertical position. The photo shows the situation after 26 seconds – the oil flowing very slowly. With such viscous oil there is naturally a high risk for damaging the engine due to insufficient lubrication and cooling. The operator might get a warning from the oil pressure warning lamp when starting the engine, because oil pressure builds up slower than normal, but the best is to avoid this situation by frequently checking the level and consistency of the lube oil and taking appropriate action.

5.2.2.5 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.
As mentioned before, 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 the most challenging part, which is the cold start and operation of the engine from being started until it has reached normal operating temperature.

- 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.

5.2.2.5.1 Realizing and operating 1-tank systems

IDI engines can easily be converted with a single tank (1-tank) system, enabling them to start promptly directly on PPO. The first condition for realizing a 1-tank system is that a glow plug must be present in the combustion chamber (see figure 5.5), and it is necessary to install special glow plugs and injectors, and to adjust the injection timing and injection pressure. Realizing a 1-tank system requires special focus on the injectors, glow plugs and the adjustment of the engine. Using an engine converted with a 1-tank system is very similar as using the original engine with 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.

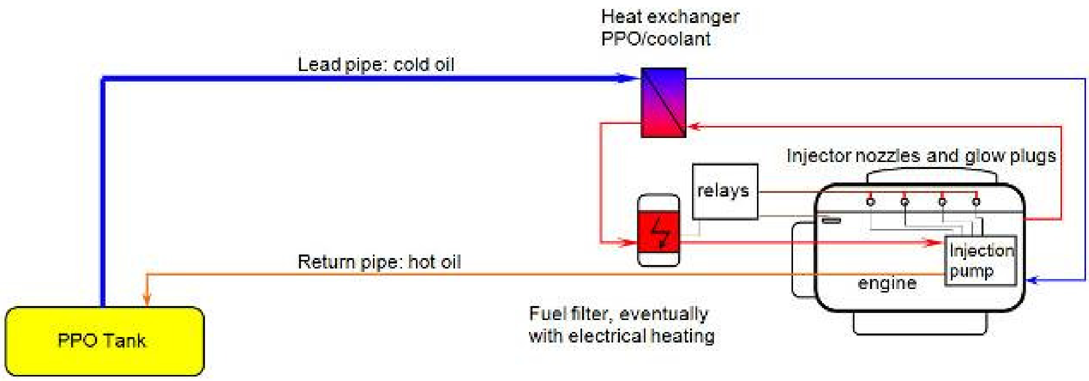

Figure 5.3 Typical configuration of 1-tank system, including larger fuel pipes, heat exchanger, electrical fuel heater, injectors, glow plugs relays etc.

5.2.2.5.2 Realizing and operating 2-tank systems

Some DI engines can also be converted with a 1-tank system, but it is much more challenging to get prompt start and clean combustion of a cold engine, so DI engines are typically converted by a 2-tank system, which can relatively simple. A typical conversion for a car is demonstrated in figure 5.4. For more basic engines, as used in Africa for example (figure 5.11), with no battery for electric starting, preheating and electrical controlled fuel switching, the conversion system typically consist of the following: 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 decreasing the volume in 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.

Realizing and operating a 2-tank system is usually relatively simple. The engine starts on diesel as usual, and is switched to heat PPO when the engine has reached operating temperature – either manually by the operator or automatically via a control system, e.g. using a thermostatic switch in combination with 3-way solenoid valves. Before stopping the engine for cooling, 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. For DI engines it is best to switch to diesel if 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. The extra tank for diesel takes up space, typically inside the cabin if it's a passenger car or a van, where increases the risk of spilling when filling up (except if installed with extern filling system).

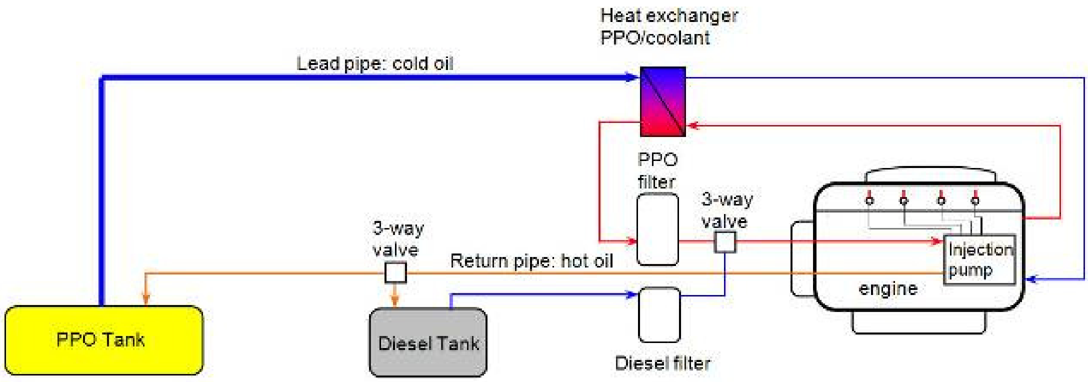

Figure 5.4 Typical configuration of 2-tank system on engines with lift pump integrated in the injection pump. It includes larger fuel pipes, heat exchanger, extra fuel tank and fuel filter for diesel, 3-way valves for switching between PPO and diesel, etc.

Mixing PPO to the diesel tank can be avoided by delaying the return valve, so that the return fuel will continue running 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 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 over the supply and return lines can be up to 5 times as much as the actual consumption.

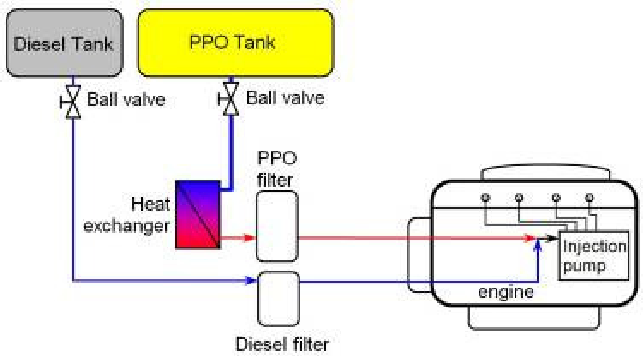

Figure 5.5: Simple 2-tank system for engines without electric system and fuel lift pump. The switching between diesel and PPO is done manually by 2 valves. The heat source for the heat exchanger depends on the options available for the specific engine, e.g. coolant, lube oil, hot air or exhaust.

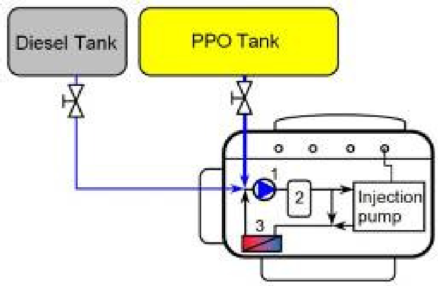

Figure 5.6: Another variant of a simple 2-tank system for engines without electric system, but with original fuel lift pump (1). This system was installed on the irrigation pump shown on figure 5.11. The original fuel filter (2) and a heat exchanger (3) was installed within a loop of the return fuel from the injection pump. By looping the fuel the fuel heating could be realised by a fuel hose turned 1 time round the cylinder of the air cooled engine. With only 1 fuel filter in the loop, the purging time between diesel and PPO is longer, but it is not important for an engine running permanently for many hours.

5.2.2.5.3 Running on PPO-Diesel mixtures

PPO and diesel mix very easily, and the diesel reduces the viscosity and flash point of the mixture. If a mixture is left in a tank for a long time without movement, the concentration of PPO can increase in the lower layers due to the higher density, but in a frequently used vehicle and with circulation of the fuel (return flow to fuel tank), it is normally not a problem. In cold seasons, mixing 10-15% diesel into the PPO can improve the cold start of the engine, but it is normally not necessary with a good 1-tank conversion.

It may seem attractive to run diesel engines on mixtures without conversion, and for some IDI engines it seems to work for a long time with concentrations up to 50% PPO. But for DI engines it's much more risky, and the concentration which will work is much lower, e.g. max 20-30%. The main risk is that the engine over time will be contaminated with deposits of unburned PPO. Initially it might seem the engine works fine, but when deposits increase, it can suddenly lead to more serious, irreversible problems. Therefore we can generally not recommend running on mixtures without a real conversion.

5.2.2.6 Important technical issues

5.2.2.6.1 Glow system

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

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

5.2.2.6.2 Injectors

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

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

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

5.2.2.6.3 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.

5.2.2.6.4 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.

5.2.2.6.5 Materials

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

Figure 5.8 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.

5.2.2.6.6 Lift pump

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

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

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

5.2.2.6.7 Fuel heating

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

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

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

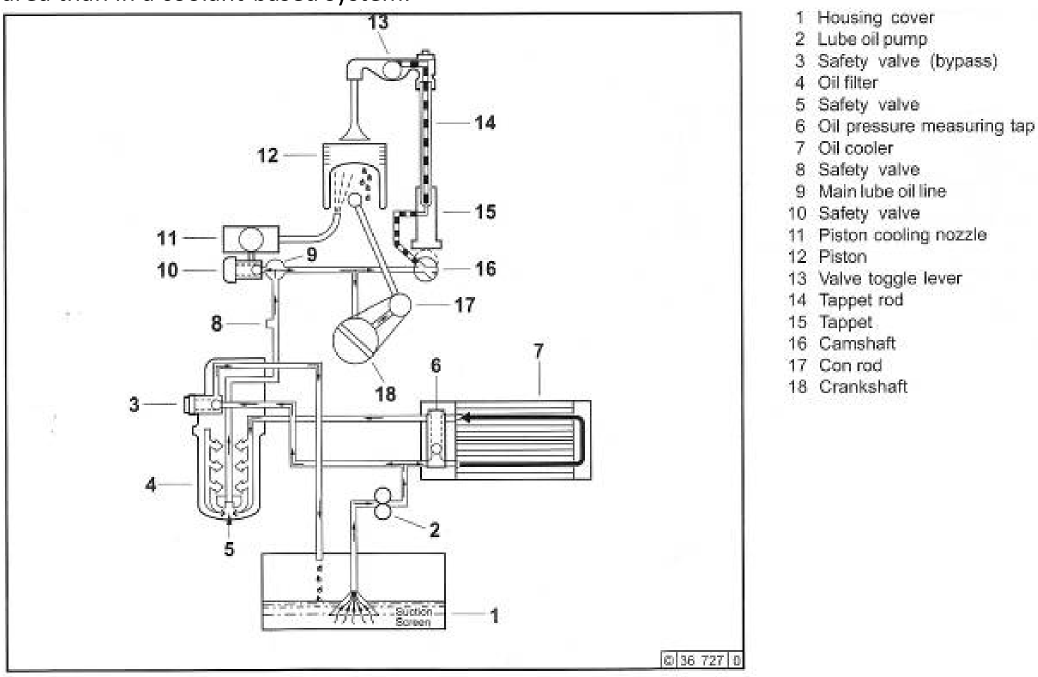

Figure 5.9 The figure shows the lube oil circuit on an air cooled Deutz 910 L03 engine (Source: Deutz AG)

If the engine has an external oil cooler, e.g. like a Deutz 910 (see figure 5.9), 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.

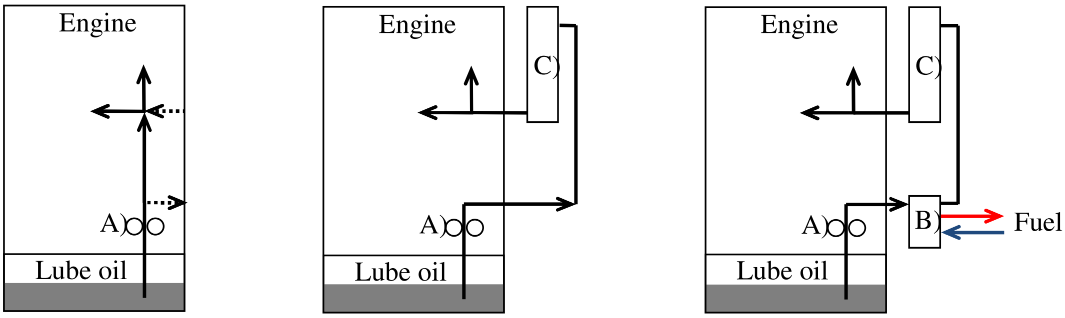

Figure 5.10. Three variants of a simplified lube oil circuit of an air-cooled engine. Left: the engine is prepared for connection of external oil cooler, oil filter or cabin heater (C). Centre: External oil cooler is installed. Right: a heat exchanger (B) has been connected to the lube oil pipe between 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.

5.2.2.7 Service and maintenance

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

Fuel filter

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

Lube oil and filter

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

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

Injectors

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

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.

5.2.2.8 External components attached to the engine

The engine can be equipped with different external components, which are relevant for the operation on PPO. Typical equipment like turbo chargers and catalytic converters is attached to the exhaust gas system. The relevance to PPO operation is both for the function of the components, and for the health and lifetime of the engine.

Exhaust Gas Recirculation

Many modern engines are equipped with an EGR system (Exhaust Gas Recirculation), which leads a part of the exhaust gas back to the intake manifold under medium load, in order to reduce the emission of NO_X. During idling and full load the valve should remain closed. The EGR control valve has a tendency to get stuck by deposits after years of operation. Sometimes the valve will hang permanently in open position, and allow exhaust gas to pass even at idling, which will make the problem with deposit worse, and at full load, will make the engine smoke due to lack of oxygen. Therefore, it is important to observe if the EGR valve is working properly, and if not, get it fixed and clean the valve and intake manifold from deposits.

Turbo
There is usually no special problem to run a *turbo* engine on PPO. Nevertheless a turbo charger can be a weak point if the engine is running with bad and incomplete combustion, especially if the lube oil gets thick due to polymerization.

Catalytic converter
A flue gas catalyst (catalytic converter) works fine with PPO exhaust, and helps to reduce the smell of unburned PPO. High amounts of ash building components in the fuel (P,S, Ca, Mg) may inhibit the function of the catalyst. Generally the application of PPO in engines with particle filters is still not recommended because of this last reason, that particle filters are very sensitive towards ash, and because of special challenges for the regeneration process.

5.2.2.9 Emissions

With good conversion of a healthy engine and good quality PPO meeting the fuel quality limits, the emissions from the engine will be on the same level as with good quality diesel, or better. Of course, the CO_2 reduction by using biofuels as substitute for fossil fuel is the most important advantage, but the emission of CO, HC and PM can also be reduced. Sulphur (S) related emissions (SO_2 and PM) are reduced due to the naturally very low content of S in PPO. NO_X emission is not connected directly to the nature of the fuel, but is generated because of the natural excess of combustion air (with O_2) in a hot diesel engine, so finally the NO_X emission can increase or decrease a little. If the engine is adjusted for earlier injection, the combustion temperature and the NO_X emission can increase, but on the other hand PM emission and fuel consumption will decrease, due to more efficient combustion. The natural content of oxygen (O_2) in PPO improves the combustion efficiency and reduces the amount of black smoke, so typically a PPO engine emits no black smoke. It is normal that a DI engine smokes after idling and after cold start, but otherwise a PPO engine should not emit visible smoke. If it does, it can be a sign of incomplete combustion, and the probable causes of the problem should be investigated. Until solved, it's better to run the engine on diesel.

5.2.2.10 Examples of converted engines

Figure 5.11 Irrigation pump with Lombardini 15 LD 440, (1 cyl 442ccm, 10,5hp) air cooled DI engine with manual start. Converted with a simple 2-tank system, Honduras October 2008 (Gota Verde Project).

Materials used: 2 m Ø8mm rubber hose, 2 ¼" ball valves, fittings and hose clamps. Total costs of materials about 20 EURO.

The fuel heating was realized by looping the return fuel and leading it one time around the hot cylinder and back to the lift pump. After each single pass in the loop, the fuel heats a little, and after few minutes operating the engine, the fuel temperature reached about 60°C.

Figure 5.12 Toyota Hilux 2,8D (3L). IDI engine. Converted by an ELSBETT 1-tank system, Honduras October 2008 (Gota Verde Project).

Material used: ELSBETT 1-tank kit for this specific engine, including warranty and all materials needed for the conversion. Price 790EURO. It is estimated that the price for a similar conversion kit made locally would cost about 300 EURO, excluding profit and allocations for development, testing, documentation, warranty etc.

A remark on prices: Prices vary a lot depending on the exact engines to be converted, the quality of the conversion system, user wishes, and how and where the components for the conversion are purchased.

5.2.3. Feedstock for soap production

Author: Titus Galema

In various countries in Africa, soap is made in villages and sometimes on a small industrial scale, as in Tanzania (Reinhard Henning, Jatropha curcas L. in Africa, Bagani). The process of soap-making is relatively easy, and requires only some caustic soda and water as ingredients. If desired, colorant and perfumes could be added to make the soap more attractive for domestic use. The soap is often made in simple moulds (e.g from plastic bottles) and after hardening, it is cut into handsome pieces. The soap can then be sold at a good price, which makes soap-making a profitable small-scale business. The soap is mainly used for washing hands and since medicinal properties are attributed to the jatropha soap, the soap can be sold at a good price in Tanzania (R Henning).

In general, soap-making involves dissolving caustic soda in water (ca 150 g of caustic soda in 0,35 liter of water) and then mixing the oil (1 liter) with the solvent and letting it harden overnight. Adding less

water gives a harder soap, adding more water requires addition of flour or starch to get a consistency that is solid enough.   Two methods to produce soap are given in the ANNEX to Chapter 5.
Care should be taken when handling caustic soda; Sodium hydroxide (NaOH) or potassium hydroxide (KOH), since both are aggressive substances[1] .

5.2.4. Feedstock for biodiesel production

Author: Thijs Adriaans

Instead of adapting the engine to run on PPO, the oil can also be chemically treated to produce biodiesel. Properties of biodiesel are very similar to those of fossil diesel, and hence it can be used in any diesel engine without adaptations. Clean, well-produced and refined biodiesel is at least as good an engine fuel as regular fossil diesel. It gives better ignition and combustion and emits fewer harmful components like smoke and sulphur. The disadvantages are its slightly lower energy content, leading to an increase in fuel consumption of about 2-10%, and the fact that it may work as a solvent. Biodiesel tends to clean the fuel system, taking the dirt that has been gathered during previous diesel use, which may cause blocking of the fuel filter shortly after switching. Furthermore its solvent nature may affect the integrity of the fuel lines and gaskets in the fuel system, depending on their material.

5.2.4.1. Some chemistry

The production of biodiesel is essentially a simple chemical process. The vegetable oil molecules (triglycerides) are cut to pieces and connected to alcohol (methanol or ethanol) molecules to form methyl or ethyl esters. As a by-product glycerin is formed. Schematically the reaction looks like this:

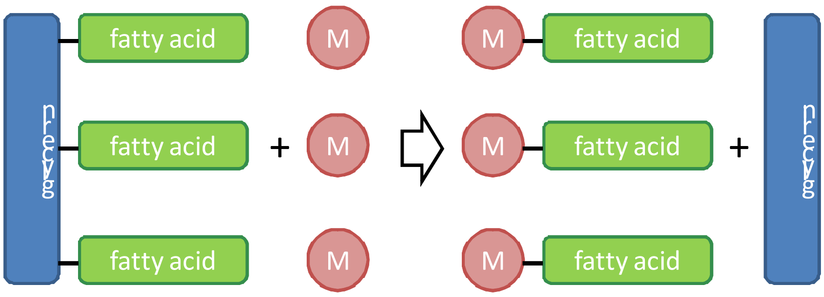

Figure 6 - Schematic representation of the biodiesel production process.

On the left is a PPO molecule (triglyceride). Three molecules of methanol (M) are added. The triglyceride molecule is broken into its three fatty acids and these fatty acids combine with the methanol to form methyl esters. Glycerin combined with the lye or potassium FFA (soap) remains as a side product. The biodiesel molecules are each a lot smaller than the triglyceride at the left, the main cause for its more favorable properties as a fuel. The required catalyst is not shown in the picture, as it appears unchanged on both sides. An excellent and more extensive description can be found on http://en.wikipedia.org/wiki/Biodiesel.

5.2.4.2. Type of alcohol

The type of alcohol used for the reaction is usually methanol, made from natural gas. Theoretically any alcohol could be used. The advantage of using ethanol is that it can easily be produced in a biologically, for example by fermentation. However, the use of ethanol has four disadvantages:

1. **Cost.** Buying ethanol of sufficient quality is more expensive than buying methanol.

[1] Annex Chapter 5: safety sheet Sodium hydroxide (NaOH) and potassium hydroxide (KOH)

2. **Processing**. The esterification process with ethanol is more complicated and less straightforward than with methanol. One of the problems is that the ethanol must be free of water (anhydrous), which is not easily accomplished in a non-industrial setting. The Journey to Forever website documents why ethyl ester production is such a hassle.
3. **Properties**. The properties of methyl esters are more favourable than those of ethyl esters. Especially the cold-related properties like CFPP and viscosity lag behind. Although these are not of such importance in tropical climates, it is advisable to convert the engine to SVO instead of going through the hassle of producing ethyl ester since its gain in properties is marginal.
4. **Energy.** For the reaction to proceed , the mixture should be heated to a temperature near the boiling point of the alcohol. The heavier the alcohol molecule (due to more carbon atoms) the higher the required energy input due to a higher boiling point.

For these reasons only the use of methanol is considered in this case.

5.2.4.3. Preparation of PPO feedstock

PPO can be produced from other resources, but clean, fresh vegetable oil is the easiest and most straightforward feedstock. However, there are three kinds of properties can cause trouble: composition, chemical impurities and physical impurities.

Physical impurities (particles, sediment) are most easily removed first. These can be sludge/presscake from the oil seeds in fresh oil, and sand/dirt. Though the oil can be filtered over cloth, the preferred option is to leave it alone for some weeks to sediment. Then the oil is decanted from the sludge. Both the sludge and the water are removed in this way. The water is clean enough to start making biodiesel if it remains clear upon shaking.

Chemical impurities need not pose problems. If the oil has been pressed fresh from oilseeds like jatropha or rapeseed according to the guidelines in chapter 4 of this book, the oil should be readily applicable as a feedstock. Unrefined sunflower oil should be dewaxed. If fresh oil has been standing longer under unfavourable conditions, it is wise to check the water content and eventually acidity (FFA, free fatty acids). See appendix for water content and acidity tests.

Finally the composition of the oil/fat is important. (For more information about the contents see tables in the appendix.) This primarily concerns the temperature below which the oil starts to get hazy or even to gel/solidify. Fresh oil from jatropha, soy, sunflower or rapeseed will stay clear and liquid down until temperatures around the freezing point (0°C) or much lower. Palm oil, coconut oil and animal fats usually solidify at about room temperature. This poses problems for their straight use in engines but also has consequences for the biodiesel produced. The biodiesel will exhibit the same behavior as the oil/fat but at lower temperatures. Biodiesel from the latter feedstocks usually only makes a suitable summer fuel, as the fuel may gel in winter conditions. Since this property cannot be changed without large efforts, care must be taken to choose a suitable feedstock. The same may hold for used cooking oil, depending on the oil that was used originally. Storing samples of the used oil in the fridge or freezer for at least several days may give some information about the temperature behavior. If the used oil is a mixture, it may solidify partly. If so, let this happen for about a week and then decant the liquid portion on top. This can be used after testing its behaviour in cold.

5.2.4.4. Biodiesel production recipe

Generally this recipe can be followed to produce biodiesel from fresh PPO and methanol in a base catalyzed environment. The recipe below is a very much summarized general guideline. Many tips and tricks and safety recommendations have been left out for the sake of compactness. It is good to read more about this before starting. If you would like to work with used cooking oil, ethanol or another catalyst instead, many Internet sites can help you adapt the recipe. Please note that the methanol and lye involved are quite dangerous chemicals. Be sure to know what you are doing, work in a well ventilated area and wear protective clothes and glasses!

Required materials

The following resources are required (all quantities are expressed per liter of PPO): 1 liter of PPO, the younger the better; at least 3.5 grams of lye (caustic soda; NaOH (> 95%)); at least 220 ml of methanol (> 99%). Eventually you could use KOH (> 85%) instead of NaOH; then use at least 5 grams.

Required actions

First dissolve the lye into the methanol. Shake or swirl until all the lye has dissolved. This may take 10 minutes. It is normal that temperature rises. This mixture is called sodium methoxide. Now make sure the PPO is in a vessel large enough (at least 150% of its volume), preferably with a valve at the bottom, and heat it to about 60°C, then stop heating. Then add the methoxide mixture and make sure it is mixed well for at least 10 minutes. Leave the vessel and let the different constituents separate by sedimentation. The glycerin will settle out at the bottom. After 8 to 24 hours the sedimentation is complete and the glycerine can be drained off. It is widely advised not to try to speed up the process by shorting the settling times! What remains is raw biodiesel. If water washing is considered difficult the biodiesel may be used straight, although its quality may be inferior because of impurities. In this case additional settling for at least a week is advised to get rid of the majority of soaps.

Magnesium silicate (bleaching earth)

Magnesium silicate is used for the purification process of the biodiesel. It provokes the impurities to settle and it permits them to be filtered out. Settled magnesium silicate should be handled as chemical waste.

5.2.4.5. Biodiesel refining

If the biodiesel produced is not clear, water-washing and/or bubble-washing will remove most of these impurities. Bubble-washing requires less water but needs compressed air and more time.

Water-washing can be applied one or more times. The first time it's best to add a small amount of acetic acid (vinegar) before adding the water. The acetic acid brings the pH of the solution closer to neutral because it neutralizes and drops out any lye suspended in the biodiesel. Add the biodiesel on top of a layer of water and stir gently. Let settle for at least a day and separate the layers by either draining the water from the bottom or pouring the biodiesel out gently.

Bubble-washing works with air bubbles formed by compressed air passing through an air stone, for instance from an aquarium shop. Add about 30 milliliters of vinegar (acetic acid) per 100 liters of biodiesel and then about 50% water. Then drop in the air stone and switch on the air pump. The air bubbles rise through the biodiesel, carrying a film of water which washes the biodiesel as it passes through. At the surface, the bubble bursts, leaving a small drop of water which sinks back down through the biodiesel, washing again. If the mixture is still cloudy after a couple of hours, add a little more vinegar. Bubble-wash for 12 hours or longer (up to 24), then drain off the washing water, skim off any wax floating on top. Repeat the bubble wash two more times; keep the water from the 2nd and 3rd wash for washing the next batch. For severe soap formations, first heat the biodiesel/soap mixture to 50°C. Add enough vinegar to bring the pH to slightly below 7. Stir for half an hour, cool and continue with bubble-drying as usual.

5.2.4.6. Biodiesel by products

The main by-product of the biodiesel process is glycerine. Other by-products of the biodiesel reaction and purification process are water with soap residues, magnesium silicate with soap residues, recuperated methanol or ethanol and free fatty acids (FFA). In the following paragraphs a short description for the applicability of these by-products is given.

5.2.4.6.1. Glycerine

Glycerine is the simplest 3-fold alcohol and comes into existence when the vegetable oil molecules are split into fatty acids and glycerine during the biodiesel process. The fatty acids react with the methanol to biodiesel. Glycerine is a high viscosity liquid with a high density (1,26 kg/l) [11]. The name comes from the Greek word *glykys* meaning sweet. The amount of glycerine that is formed in the reaction depends on the FFA level of the oil used, but can vary between 10% and 30% of the amount of oil used. Biodiesel floats on glycerine since its density is lower. Separating the glycerine from the biodiesel can be easily done by draining off the bottom layer of a gravity drained decantation tank after a sedimentation time of eight hours after the biodiesel reaction. In a continuous process, separation is done by a centrifuge based on the density difference.

Glycerine can be used as resource for other products, including soap, organic manure, biogas, fuel, and recycled alcohol for the biodiesel process. (For details, see appendix.)

5.2.4.6.2. Water with soap residues

If the biodiesel is washed with water, it dissolves the formed soaps and residual methanol. If there would be no methanol residue present in the crude biodiesel, the wash water could be used directly as degreasant water for internal industrial purposes. In practice there will be methanol present, so this must be removed first. A way to do this is by heating an open drum with the washing water in a well- ventilated area (preferably outdoors) to about 50°C. Don't inhale the vapors! A better way is to recover the methanol for reuse by distilling or flashing it off.

5.2.4.6.3. The recuperated alcohol (methanol)

The recuperated alcohol can be used directly in the transesterification process again. Be sure no water is present in the recuperated alcohol. It is recommended to mix small volumes of recuperated methanol with fresh alcohol to ensure the quality.

5.2.4.6.4. Free Fatty Acids (FFA)

The residual FFA normally are mixed with the glycerine where they can be converted into soap (see paragraph on soap). They can also be neutralized and separated to be converted into biodiesel through an acid/base transesterification process. Large boilers can often handle biofuel with several percents of acid content, so the FFA could be mixed with (neutral) vegetable oil and fired for energy generation, though this is not a very common application in developing countries.

5.2.4.7. Concluding remarks

Making biodiesel is something that needs to be practiced. with different feedstock and circumstances. The observations and procedures may show large variations. With more experience, one will be able to judge the effects and streamline the processes. Use this section as a guideline and try to use literature, for instance the excellent Journey to Forever website, to gather more detail information.

5.3. Applications of other jatropha products

Author: Janske van Eijck

When the seeds are pressed to oil, about 20%-30% of oil is gained. The rest remains as presscake. Not only are all the minerals still inside this cake (PPO contains virtually no minerals) but due to the oil content the presscake still contains a considerable amount of energy. With its 20-25 MJ/kg it's about half as energy-rich as the oil that contains 40 MJ/kg – but the fact that there is two to four times more presscake, compensates for this. Theorectially, the best use of the presscake is for energy purposes first, and then as a fertilizer. Digestion to biogas for energy leaves the nutritional value intact, and use as a fertilizer implies that the calorific value is lost. Direct combustion of the presscake, by contrast, will leave the majority of the nutrients in the ashes, but the nitrogen will be lost with the flue gases. The process scheme below will clarify the process.

The following by-products can be distinguished: presscake, wooden stems and leaves.

5.3.1. Wooden stems and leaves

Jatropha leaves contains 4.7% nitrogen, 0.15% phosphorus, 3.77% potassium, 0.61% calcium, 0.49% magnesium and 0.25% sulphur. It also contains elements like zinc, boron, copper, manganese, boron and sodium. These elements, though found in small amounts, are good for growth, production and drought tolerance like potassium. When the plant sheds off its leaves, these minerals go back to the soil when the leaves decompose. The wood from jatropha has an energy content of 15.5 MJ per kilogram and nitrogen content of 3.3%, phosphorus 0.1%, potassium 2.9% and calcium 0.3% and other trace amount of nutrients which suggests that it can be used for firing in stoves but also useful in increasing soil nutrients after decomposition or as ash from combustion [9]. The stems contain a milky substance, which makes direct firing difficult, they have to be dried first

5.3.2. Presscake

5.3.2.1. Handling

The presscake storing conditions to avoid are the following:

- Do not store at high humid temperature. The presscake is prone to fungal attack.
- Store at or below 6 °C for optimal conditions, however this implies a cooling system which for most projects will be too expensive.
- The cake should be dried to obtain a low moisture content (5-7%) and stored in an airtight container or otherwise stored in a dry and cool place.
- Keep the presscake away from oxidizing agents and flammable materials [15].

5.3.2.2. Presscake as a biogas generation feedstock

Biogas production from organic matter, like animal manure and agricultural waste, is produced by small units on large scale for households in countries like China, Nepal and Vietnam. The usual size for households is a 6 to 12 m3 holder for which 4 to 10 cows would produce sufficient manure. Biogas is used for cooking and lighting. With a larger production it can also be used for running gas engines. Biogas, is a mix of methane (CH_4) and carbondioxide (CO_2) in a ratio of 60-40, with a net caloric value of approx 20 MJ/m3

Jatropha presscake can be mixed with manure from animals as cow dung or from people. Results from lab test on behalf of FACT proved that jatropha presscake alone, when started with fermentation bacteria to start the process, showed a fairly good production of biogas. Based on these tests a prediction for real life productions was made as follows: CH4 content of ca 50%-60% and CH4 yield ca 0.5-0.6 m3/kg. LHV between 18-22 MJ/kg. [16]

One case where it is produced on a larger scale is with Diligent Tanzania, see the Case below.
Water is the other input ingredient and after anaerobic fermentation in the digester two products are created, which are biogas and sludge. As with any biogas installation there is quite a big amount of water needed for the fermentation process. If, for example, toilets can be connected, there will be a steady water flow available. Once the biogas digester runs out of water, all bacteria die and starting up the system again can take up to a month. This means the biogas system has to be monitored. The bigger the system, the easier it will become to maintain. For a 60m3 size digester, for example, there is no problem if there would be no water for a day or two. For smaller systems the water flow should be more constant.

The sludge which is left after the presscake is fermented can be used as a fertilizer. It has a higher nutrient volume than the manure and in addition all pathogens have been killed during fermentation, which gives a very clean natural fertilizer.

There are different designs for a biogas digester, most frequently used are fixed dome, floating dome and plug flow digester (Kerkhof, 2007). The digester of the Kerkhof case is a fixed dome. There are no special requirements for a biogas system to be able to run on jatropha presscake. However, there is little experience with a system running on cake alone. Biogas cannot be stored. This means the end-user has to be close to the biogas digester. Depending on the size of the digester (and the pressure under which the biogas is transported, 0,2 bar) a maximum of one kilometer between the end-user and the digester is advised. Besides using the gas in a kitchen, a biogas generator could also be used. However for this a large digester is necessary. The digester discussed in the case (60 m3 digester with 12 m3/day of biogas) could drive a 2 kW engine for about 11 hours/day.

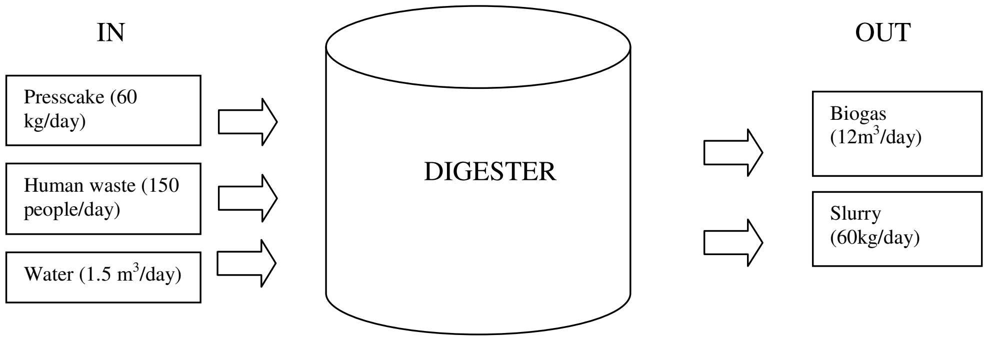

Figure 7: Process scheme biogas digester 60 m3 with combined feedstock based on the biogas digester of Diligent (Tanzania).

Case biogas installation at Diligent (Tanzania)
For a 60m^3 digester which is fed by a combination of toilets (8 toilets for about 150 people) and Jatropha seedcake (as is the case for the digester at Diligent Tanzania in Arusha) an amount of 60 kg of seedcake is required per day (and 1500 liters of water) to produce around 12 m^3 of gas per day (which is about 20% of the size of the digester). This amount of gas is enough to fuel three stoves in a kitchen which serves 250 people.

Figure 8 - Stove run by biogas at Diligent Tanzania ltd
Figure 9 - The 60 m3 digester at Diligent Tanzania ltd. (installed by Camartec,

5.3.2.3. Presscake as briquettes for fuel

Case biogas installation at Diligent (Tanzania)
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5.3.2.3.1 Presscake briquettes

Jatropha presscake has an energy content of around 25 MJ per kg. Although the ***press***cake already is a pressed product, its energy content per liter can be considerably increased by compacting the material to increase its density. This process of compacting the biomass material to increase density (biomass densification) is traditionally called briquetting. A low pressure briquetting machine operates in a similar way as a screw press, the ***pres**s**cake*** is in principle compressed again. The cohesion force between the presscake particles is small, so a binding material has to be added during the process of making briquettes. This enhances compaction for a low pressure compaction system. A suitable binding material can for example be starch. Also slightly burning the outer part of the briquette increases the strength of the briquette.
The disadvantage of these presscake briquettes (from fresh presscake) is that a lot of smoke is emitted when they are burned. The energy content however is very high.

(10)(11)(12)

Figure 10 – Example of presscake briguettes At Diligent Tanzania ltd

Figure 11 – Example of presscake briguettes At Diligent Tanzania ltd

Figure 12 – Electrical briguetting machine, produced by temdo Tanzania, at Diligent Tanzania ltd.

5.3.2.3.2. Charcoal briquettes

A second option is to turn the presscake into charcoal. This increases the energy content as the weight is reduced. In principle 'charcoaling' means burning the presscake without oxygen. The smoke emission from burning these charcoal briquettes is much lower than from the presscake briquettes and they burn more easily. The presscake can be turned into charcoal before or after pressing into briquettes. If presscake is turned into charcoal (dust) a similar process as with presscake briquettes can make charcoal briquettes. Again, a binder is necessary. In an oven or a traditional way of making charcoal (covering with soil) a presscake briquette can also completely be turned into charcoal. About 60% of the weight of a presscake briquette will remain when processed into a charcoal briquette.

(13) (14)

Figure 13 - charcoal production at TEMDO, Arusha Tanzania (pic JvE)

Figure 14 - charcoal briquettes at Diligent Tanzania ltd (pic JvE)

5.3.2.4. Presscake as a fertilizer

Jatropha presscake contains high amounts of nitrogen (3.8-6.4% by wt), phosphorus(0.9-2.8% by wt) and potassium (0.9-1.8% by wt). It also contains trace amounts of calcium, magnesium, sulphur, zinc, iron, copper, manganese and sodium. One ton of presscake contains approximately 51 kg of nitrogen,18 kg of phosphorus and 13 kg of potassium. It is equivalent to 153 kg of NPK industrial fertilizer having the composition ratio of 15:15:15, based on nitrogen content in presscake. [9] Presscake has to be composted before it can be used as fertilizer. This can be done by leaving the cake for some time (a few days) outside. Especially when presscake with a high oil content is put on the plants directly, it will negatively affect the plants, as it decreases the permeability of the soil.

5.3.2.5. Insecticide from oil and/or press cake

Jatropha oil has also proven to be an effective pesticide. In one study 1.4 liters of jatropha oil was mixed with 16 liters of water and sprayed on cotton and acted efficiently [10]. An organization in Tanzania promotes the following process for obtaining insecticide out of jatropha seeds: grind some jatropha seeds, soak them in water for 24 hours, filter the particles from this mixture, dilute the mixture in a 1:10 ratio with water.

5.3.3. What is *not* recommended

When jatropha presscake is pressed directly into briquettes, these briquettes produce a lot of smoke when burned. Use of these briquettes indoor without proper ventilation is not recommended. However if they are used in, for example, industrial boilers or in ovens with chimneys, the smoke will not be inhaled.
Unlike many other oilseeds, the jatropha presscake cannot be used as animal feed, as it is toxic due to the presence of several components (phorbol esters, curcins, trypsin inhibitors and others).

5.4. References

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Opmerking [J1]: Welke site

Opmerking [J2]: Naam

Opmerking [J3]: Recommended literature?? Of verwijzingen door de tekst.

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