Jatropha oil quality related to use in diesel engines and refining methods.

Technical Note

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1 Introduction

This note is intended for technicians and project managers starting up projects with Jatropha production, pressing and applying the PPO (pure plant oil, straight vegetable oil) in diesel engines.
Especially for the 3 pilot projects started by FACT in Mali, Mozambique and Honduras (MMH). Essential information that is complementary to this note can be found in section 4 and 5 of the FACT Jatropha Handbook [4].

It is important that long term running of diesel engines on PPO, for example jatropha oil, is sustainable, i.e. the engines might have some more maintenance than usual, but they should not brake down. The operation should become as reliable as operation on diesel fuel.
There are two major parameters that determine proper operation on PPO, the quality of the PPO and the type and state of the diesel engine.

In case newly fabricated engines, modified already for running on PPO are introduced, like the Marine Deutz diesels in Mali,no surprises are expected, supposed that fuel quality is sufficient.
In the case of Mozambique however, where existing running diesel engines (from flour mills etc) are going to be modified, it is less clear how the interaction between the properties of the PPO and the existing engines will work out.

Unfortunately, literature on long term running tests done in the eighties with PPO does not give enough clarification on the quality of the PPO and the conditions and operating mode of the engine, e.g. is the PPO preheated or not?

The question that arises for the 3 pilot projects of FACT is twofold:

- What are the requirements on the quality of Jatropha oil
- What are the required modifications to various engine types, that could be applied in the projects.

To mention two extremes:

Unmodified Lister type of diesels used in the 80's that broke down after more than 500 hrs of use, running on fossil diesel blended with more than 20% crude vegetable oil [1], compared to the other positive extreme of a modern VW car, running for over 8 years on rapeseed oil only, in Denmark (Niels Ansø)[2].

This note is focussing on fuel quality. For more information about engine failure and suggestions for modifications the reader is referred to a study by D. Fürstenwerth ***"Potentials of Coconut Oil Fuel as a diesel substitute in Pacific island countries"*** For downloading of the full report link to: http://www.sopac.org/tiki/tiki-index.php?page=Coconut+Oil+Fuel+Research+RMI [13]

1.1 Literature survey from the 80's

Since the 1980's running tests have been done with unmodified diesels running on Jatropha oil. Short term tests, with duration in the order of 36 hrs, did not give any problem at all, all engines did run perfectly.
After running around 400 to 500 hrs however, several engines broke down, due to clogged material in the diesels. The way how the tests were done, however, and what the exact quality of the oils was, is unknown. [1]
The main conclusion that can be drawn from this work is that operation of unmodified diesel engines on PPO of unknown quality is destined to fail.

1.2 Recent experiences

A more recent article however from prof. **Michael Allen** (2002) [3] describes long-term tests with a Kubota diesel on palm oil. The only engine modification was a dual tank system, and the diesel was started and shut down on fossil diesel.
On refined palm oil the engine ran perfectly for over 2000 hours. Refining included degumming with phosphoric acid, and removal of fatty acids.
Using crude palm oil however, the engine broke down after 300 hrs and the second time after 550 hours. Investigations showed that the inlet port and piston head were badly eroded, the piston rings were worn and the lubrication oil had polymerised. All of these phenomena can be traced down to insufficient fuel quality (too high content of phosphorus, free fatty acids and particles).

Ger Groeneveld, Groeneveld PPO (NL) 21 June 2007

"I can only add my own experience with a Lister ST3 engine. It has now run about 200 hours on filtered WVO, mainly a mixture of palm oil, sunflower oil and rapeseed. I did not have any fuel related problems running on this type of oils. Lots of mechanical problems were mainly due to some "stupid" mechanical design issues related to this type of engine and its considerable age (35 years): broken fuel pump fork, broken fuel lines (so the engine was lubricated by an overdoses of fuel). Most stationary engines are built to be used to run for a long period of time. Wear and tear will occur by frequent starting and stopping.

My (unmodified) TD Ford engine has done a almost 96000 km running on WVO with some fuel related hitches (mainly blocked fuel filters due to too low outside temperatures below 10°C): that is about a 2000 hours. "

Mauricio Gnecco, Aprotec, Colombia
"On my experience I found too much carbon on the indirect injection prechamber using pure and very well filtered Moriche palm oil (Mauritia Flexuosa).
People in charge of a Lister 10 HP, 600 rpm engine told me that initially the engine grew in inefficiency, then became very hot and finally stopped when the head seal was burned. I received the engine in my workshop and found too much carbon on the indirect injection prechamber throat. This occurred in more or less 800 hr, running 4 to 5 hours per day. The time information is not reliable because this engine was operating in a farm in middle of the llanos."

2 Norms for Jatropha oil quality for use in diesel engines.

Next to a good condition of the engine (running hours since last overhaul, etc.) and the quality of its conversion to PPO, the fuel quality is essential. Petro products like gasoline and diesel oil are produced to a standard and so should PPO.

Norms:

In Europe, where mainly rapeseed oil is produced and used, standards for PPO quality have been developed. Acceptable levels for rapeseed PPO in Europe are mentioned in the RK2000 standard (see below and fig 10, page 32 of the FACT Jatropha Handbook [4]).

It is important to notice the distinction that is made between the characteristic (fixed) properties and variable properties. Characteristic properties are relatively constant for a given kind of oilseed. The values given here hold for rapeseed oil but are a good direction for jatropha oil, too. More investigation is necessary to find out what PPO quality can be reasonably attained with jatropha in representative rural conditions.

Variable properties are strongly influenced by processing and seasons, e.g. climatic and geographic influences during growth of the seeds, the storage of the seeds, pressing conditions and further processing of the oil. Regardless of what numerical value can be achieved exactly, it is always good to strive for a low total contamination, low acid value, high oxidation stability and low contents of phosphorus, ash and water. The values given in the quality standard below can be regarded as guidelines. More research is necessary to determine what quality can be obtained with jatropha PPO. See chapter 3-4 of this note.

LTV-Work-Session on Decentral Vegetable Oil Production, Weihenstephan

Quality Standard for Rapeseed Oil as a Fuel (RK-Qualitätsstandard)

05/2000

in Cooperation with:

Properties / Contents	Unit	Limiting Value		Testing Method
		min.	max.	
charcteristic properties for Rapeseed Oil				
Density (15 °C)	kg/m³	900	930	DIN EN ISO 3675 DIN EN ISO 12185
Flash Point by P.-M.	°C	220		DIN EN 22719
Calorific Value	kJ/kg	35000		DIN 51900-3
Kinematic Viscosity (40 °C)	mm²/s		38	DIN EN ISO 3104
Low Temperature Behaviour				Rotational Viscometer (testing conditions will be developed)
Cetane Number				Testing method will be reviewed
Carbon Residue	Mass-%		0.40	DIN EN ISO 10370
Iodine Number	g/100 g	100	120	DIN 53241-1
Sulphur Content	mg/kg		20	ASTM D5453-93
variable properties				
Contamination	mg/kg		25	DIN EN 12662
Acid Value	mg KOH/g		2.0	DIN EN ISO 660
Oxidation Stability (110 °C)	h	5.0		ISO 6886
Phosphorus Content	mg/kg		15	ASTM D3231-99
Ash Content	Mass-%		0.01	DIN EN ISO 6245
Water Content	Mass-%		0.075	pr EN ISO 12937

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According to findings of various experiments [9,10,11], the composition of Jatropha Curcas PPO is as follows:

Properties of Jatropha from various sources

Parameter	Unit	Gubitz, 1998 [9],	P.Beerens 2007 [10]			Rietzler & Brandt 2007 [11]		
Origin of seeds	country	Nicaragua	Tanzania			Laos	Vietnam	India
Seeds treated with pesticides for transport		?	No			No	yes	yes

Characteristic properties

Parameter	Unit	Gubitz,	P.Beerens			Rietzler & Brandt		
Density at 15 °C	[g/cm]	0.920						
Viscosity at 30 °C	[cSt]	52						
Flash point	[°C]	240						
Cetane number	-	-						
Conradson carbon residue	[% m/m]	-						

Variable properties

Parameter	Unit	Gubitz, 1998 [9],	P.Beerens 2007			Rietzler & Brandt 2007		
Neutralization number (Acid value)	[mg KOH/g]	0.92	3.47	3.10	25.77	2.7	19.1	5.7
Sulphated ash	[% m/m]	-						
Water in the pressed oil	[% m/m]	0.07	-	-	-	-	-	-
Water in the seeds	[% m/m]	-	2.14	6.7	13.3	8.8	6.6	6.3
Phosphorus	[mg/kg]	290	16.2	23.2	2.4	4.8[a]/15.9[b]	164/180	56/150
Processing oil temperature	Degr. C		97	85	52	44.5/95	55/97	56/99

Note:
Rietzler & Brandt measure the contents after both cold pressing and hot pressing;

a) = Cold pressing
b) = Hot pressing".

3 Potential problems

It is important to know which effects the various components in the fuel have with regard to wear and breakdown of engines. Below the most important items are discussed, following Elsbett [12]. For a more extensive elaboration see [13].

3.1 Phosphor content

From comparison of the typical jatropha composition with the RK standard it can be seen that the **Phosphor content** can be a problem. Phosphorus is present in the oil in the form of phospholipids that have pressed out of the plant's cell walls. These substances are slimy and may lead to obstruction of the fuel system (plugging of filters). Furthermore the phosphorus may cause severe damage in the form of abrasive scaling in the combustion chambers.

According to current insights the level of phosphorus in PPO can be kept low by pressing the seeds smoothly at reduced temperature. Both elevated temperature and solvent extraction have a negative impact on the phosphorus content. Much more research must be done on pressing of jatropha to be sure about its PPO quality. For rapeseed pressing temperatures below 60℃ give a good quality of oil. Awaiting further research this value seems safe as a guideline for jatropha pressing.

3.2 Acid value[1]

The Acid value or neutralisation number expresses the amount of free fatty acids in the oil and it's influenced (positively) by refining of the oil and (negatively) by aging. It must be kept as low as possible because these acids may attack metal components in the injection system and because they may harm the engine oil, endangering the engine's lubrication. Following the RK standard a safe limit for the Acid Value is 2. This must be taken very seriously because the potential damage is very costly. (Potential damage is failure of the injection equipment, or the entire engine).
Aging of the PPO can be slowed down by storing the seeds and the PPO dark, cold and in closed cans (excluding air exchange).

3.3 Viscosity

The viscosity of the PPO is more or less constant for a given kind of oil, but may increase with aging of the PPO. It has an enormous influence on the atomisation of the fuel upon injection, possibly causing incomplete combustion with excess noise, smell and emissions and (in the longer run) engine damage. Some kinds of injection equipment may take permanent damage from running with too high fuel viscosity.

3.4 Particles (contamination)

Particles of too large size can have an abrasive effect on the injectors and the combustion chamber walls and can plug filters etc. A plugged filter is annoying, but not dangerous. The filter is a safety measure preventing contamination of the fuel system. First pressing trials [10,11] show that crude unfiltered Jatropha oil contains much more sediment than rapeseed oil (about 30% against 5%). Removal of sediment by filtering or by centrifugation is of immanent importance.
A good mesh size of the filter cloth is 5 micron.

3.5 Water

Water is naturally present in the oil in small amounts. Its amount should be kept as low as possible, because it can cause cavitation, erosion and corrosion in the injection system. Furthermore a boundary between water and oil in the tank (possible above some 0.1 %) may provoke the development of bacteria and fungi that block the fuel filter (as does water itself). In colder climates a last risk is obstruction of the fuel system because the water freezes.

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[1] The relation between Acid Value in[mg KOH/g] and content of FFA [%,m/m] is : Acid Value/2 = FFA in volume percentage of the oil.

4 Diesel engines

Diesel engines are available in a wide range. "The diesel engine" should be distinguished in a number of diesel types each of which may require different modifications:
Type 1: the old fashioned engines with prechamber or swirl-chamber, like "Lister type" and older automotive engines
Type 2: Direct Ignition type DI (Hatz, truck engines and modern automotive engines)
Type 3: Marine engines with preheating systems built in to run on crude oil (Deutz)

The diesel engines of type I are the most suitable for running on PPO with only little modification.
Should it be possible to choose between different types of engines, the prechamber or swirl chamber engines, with water cooling, proves the least risks and needs the least adaptations to work efficiently and reliably with PPO.
Indications from literature and experiences from users on internet are that blending PPO with diesel at a ratio lower than 20% might be safe on the long run for engines of all types, but this statement is not backed by sufficient long term testing. Furthermore the engine condition and its usage profile are essential and cannot be generalized.

For modern DI car engines modifications like other injector nozzles, changing the injection timing, etc are required to make good operation possible without troubles and with low emissions as well.

Various strategies can be followed in engine conversion, dependent on the type of engine, its condition, its usage profile, personal preferences and last but not least financial considerations. It is impossible to give a short advice that is valid for every situation.

5 Refining: measures to improve oil quality for use in diesel engines

Next question is which methods exist to reduce the unwanted components in the PPO to an acceptable level, both small scale, simple, low cost methods, which can be applied in the low industrialised countries, like Mozambique and Mali, as well as large scale, more industrialised methods which might be appropriate to Honduras.

5.1 Small scale, simple, low cost methods to bring components within acceptable level: KISS (keep it simple)

Component	Process	Method
Phosphor	Mechanical pressing;	Make sure the oil is pressed at temperatures below 60 degrees Celsius. No refining might be necessary.
Particles/ contamination	Removal	1 sedimentation (time & volume consuming) See [4] 2 Filtering with cloth See [4]
FFA	Neutralisation	Not recommended on small scale. To prevent increasing of FFA over time, it is better to store the oil dry, cool and in closed cans.
Water	Heating	First: test with the "crackle test" a) whether water is present. Passing the "crackle test" is required, but

		not sufficient. Too much water may still be present. Then: heating the oil to 120℃ will reduce water content by boiling the water out.

a) "Crackle test" is heating a small sample of oil up to 100℃ and notice cracking (spitting) sound. Theoretically, refining processes to reduce the FFA (free fatty acids) and phosphorus content are available (see below). However, these are industrial processes and their execution in unprotected circumstances without fully educated personnel is not recommended because of considerable safety risks for man and machine.

For the realisation of an oil pressing and treatment plant, a number of issues need to be taken into account, such as:

- the availability of input materials for the refining;
- the processing equipment to be obtained with availability of spare parts on the long term;
- technical capacity of local people to operate, maintain and repair it.

Similar issues should be considered for modification of the engines.
Only when care is taken to work out the best technical and economical options, a sustainable operation can be achieved

5.2 larger scale, more industrialised methods to bring components within acceptable level .

Component	Type of engine	Process	Method
Phosphor		degumming	1 with water 2 with acids
Particles/ contamination		Removal	Centrifugation, filtering
Fatty Acids		Refining	Neutralisation

Degumming is a treatment to eliminate phospholipids by thermal treatment with water and other degumming agents such as phosphoric acid, citric acid, or acid mixtures. Drying under vacuum may be required to remove water sufficiently.

Neutralisation is a treatment to remove free fatty acids by adding caustic soda solution, NaOH/KOH. The free fatty acids in the oil will bind to the lye and form soap in the water phase, that can be separated from the PPO.

4 Conclusions and recommendations

- There are a number of PPO characteristics that have influence on the sustainable diesel engine operation, to mention: Phosphor content, Free fatty acids content, viscosity, water and particles (contamination).
- Phosphor leads to problematic deposits in the engine
- FFA, represented by the acid number, can cause corrosion and lubrication oil problems, and finally complete engine breakdowns.
- By maintaining the maximum levels as set in the European Norm: RK2000, the quality of the Jatropha PPO will probably be sufficient to guarantee a trouble free running of the engines as far as PPO quality is concerned (supposed the engines have been adapted according to the needs of the type of engine)
- There is no uniform composition of Jatropha from various countries nor over different years or from different presses. The reasons why there are great differences, especially in the phosphor contents, are not clear yet and need to be investigated.
- The temperature during pressing influences the phosphor contents of the pressed oil. For rapeseed pressing temperatures above 60℃ cause the amount of phosphor to increase to unacceptable high levels. Awaiting further research this value seems safe as a guideline.
- Sedimentation in crude Jatropha PPO is high, requiring proper filtering. Research on pressing may lead to better values of crude oil.
- As overall conclusion: The PPO quality issue should be taken very seriously, and it is necessary to understand how to control the process which starts from harvesting the seeds, and maybe even before that. (stated by Niels Ansø)

Recommendations:

- To guarantee sufficient PPO quality, start with the first pressing and treatment plant with the methods of table 5.1.
- Apply simple field tests if possible, like the crackle test, check if the oil is clear instead of hazy, no clouds and no precipitation on the bottom, if possible, try a titration to estimate the acid value, etc.
- Samples of the first produced PPO need to be sent to laboratories to be tested on the critical parameters, for instance by sending them to qualified laboratories like ASG Analytic Germany http://www.asg-analytik.de/)

6 Literature on testing of engines running on Jatropha PPO or Bio-diesel

1 **Titel:Using unmodified vegetable oils as diesel fuel extender, a literature review**
Author: Sam Jones & Charles Pederson**,** Publication and date: University of Idaho, USA, 2002 Key words: Literature Research, vegetable oil as diesel fuel Summary: In early 80's varies short term tests with diesels running on any combination of diesel with vegetable oil, like rapeseed, sunflower, cotton oil, etc proved to be no problem. Long term tests with vegetable oils of more than 20% volume mixed in fossil diesel, almost invariable led to engine damage or maintenance problems. (with unmodified diesel engines).

http://journeytoforever.org/biofuel_library/idahovegoilslitreview.pdf

2 **Titel: Short note regarding PPO as engine fuel.** Author: Niels Ansø, Publication & Date: FACT publication 2006 Key words: Implementation (see www.fact-fuels.org)

3 Titel**: Straighter-than-straight vegetable oils as diesel fuels,** Author: Michael Allen. Publication and date: website: message to the Biofuels-biz mailing list, 8 Oct. 2002 Link: http://journeytoforever.org/biodiesel_SVO-Allen.html

4 Titel: **Jatropha Handbook, Chapter 4 & 5** Author: Thijs Adriaans Publication & date: Jatropha handbook, FACT, March 2006 (see www.fact-fuels.org)

5 **Titel: Local and Innovative Biodiesel",** Author: M. Wörgetter, et al. Publication & date: ALTENER, final report No 4.1030/C/02-022, 2006 Summary: 7 varieties of vegetable oil from different sources, including Jatropha, have been synthesized into biodiesel and have been tested in a small engine for endurance test of 256 hrs. After each test the wear parts have been taken out and measured and validated. (the piston, cylinder and nozzle). Also measurements on emissions were carried out. Not much difference in wear was found between the biodiesels and fossil diesel. Jatropha biodiesel came out well. Link: http://www.blt.bmlfuw.gv.at/vero/veroeff/0964_LIB_Forschungsbericht47.pdf (1,5 MB).

6 **Titel: Parametric studies for improvement of a Jatropha oil-fuelled compression ignition engine** .Author: J. Narajana Reddy et al. IIT , Madras, India, Publication: Elseviers 2005Summary: An extensive parametric research project on a 1 cylinder DI engine on Jatropha PPO was done. The effects of timing of injection (earlier timing), flow (mount of fuel injected per time unit), pressure at nozzle opening and extra swirl at intake. The following units are measured: efficiency, pressure over the cylinder and emissions. Link: http://www.sciencedirect.com/science/article/B6V4S-4HNSG34-1/2/b57fac866a81dc0ca4a41d59f0b96e80

7 **Titel: Jatropha Oil in compression ignition engines. Effects on the engine, environment and Tanzania as supplying country** Author: E.L.M. Rabé Publication & Date: Eindhoven University of Technology, Thesis work 2004?? Key words: (tree structure website): Research, jatropha bio diesel, (see www.fact-fuels.org)

8 **Titel: Degumming, etc**, IULPAC, AOCS Workshop, Alpha Laval http://www.aocs.org/archives/analysis/pdfs/logan_andrew.pdf

9 **Exploitation of the tropical oil seed plant Jatropha Curcas L.** Gubitz, G.9 et al, Elsevier 1998.

10 **Screw-pressing of Jatropha seeds for fuelling purposes in less developed countries**, Peter Beerens, Thesis work TUe, August 2007 (to be published on FACT website)

11 **Using Jatropha Curcas for generating Energy-A study of the properties during processing,** J. Rietzler, TU Ansbach, Germany & H. Brandt, PPM Pilot Pflanzenoltechnologie Magdeburg e.V. Germany June 2007, see FACT website. (see www.fact-fuels.org)

12 **Günter Elsbett, Die Normung von Pflanzenölen als Kraftstoff (2005)**

13 **D. Fürstenwerth "Potentials of Coconut Oil Fuel as a diesel substitute in Pacific island countries"** For downloading of the full report link to: http://www.sopac.org/tiki/tiki-index.php?page=Coconut+Oil+Fuel+Research+RMI