Screw-pressing of Jatropha seeds for fuelling purposes in less developed countries

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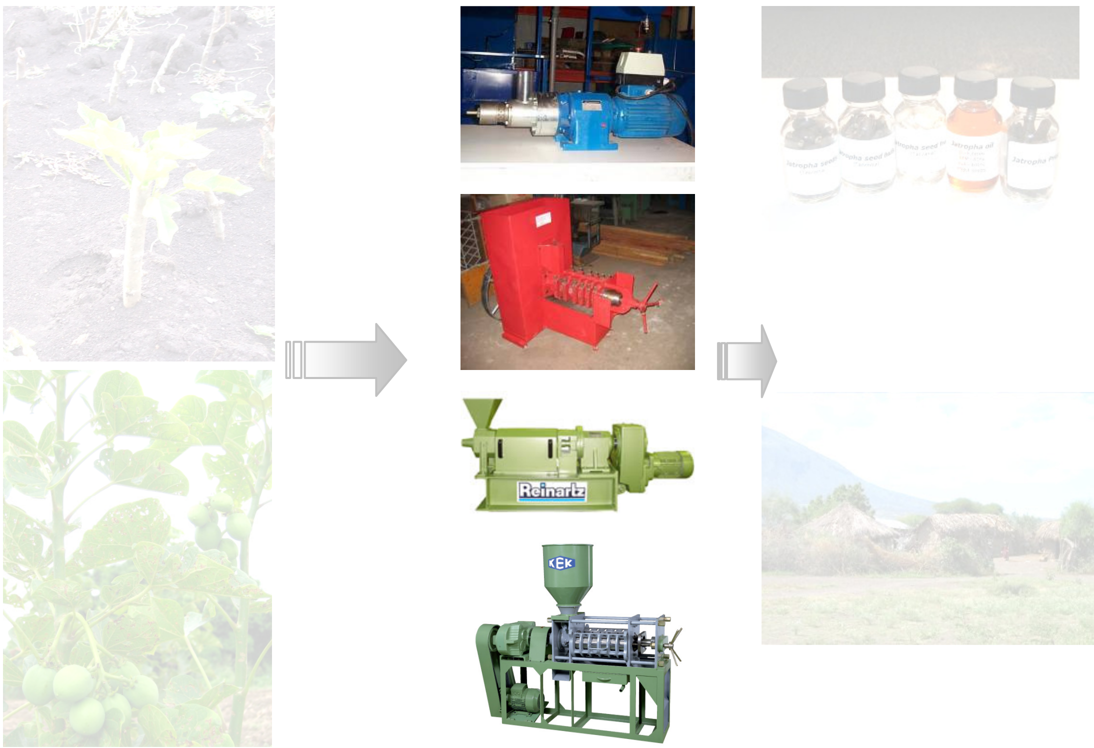

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Peter Beerens,
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Summary

People living in the poorest regions in the world, e.g. large parts of the African, Asian and Latin American continents, often lack access to energy sources in general. One approach to provide these people with energy to increase living standards is to enable them to produce energy from local resources. A promising local renewable energy source for people living in tropical regions is Jatropha Curcas L; a plant that grows oil yielding seeds that contain 31-38% oil.

The seeds need to be processed in order to obtain the useful end product oil. Mechanical screw pressing is the most popular method in the world to separate oil from vegetable oilseeds on small to medium scale. Therefore the impact of several variables on oil recovery, oil quality and energy costs for screw pressing is reviewed in this report. The main question to be answered in this report is:

- How can oil recovery, energy input and cost of Jatropha seed expression in screw presses be optimized while retaining a quality that complies with international fuel standards?

Additional consideration of the practical application of screw presses for the production of Jatropha oil in Tanzania led to answers to the following two additional questions.

- What is the optimal setup for the production of Jatropha oil in Tanzania?
- In what way can rural areas in which their use is anticipated benefit from Jatropha cultivation?

Two distinct low capacity screw presses were used; one located in the Netherland and the other one in Tanzania. Comparing the results of test on both presses reveals which of the two types is best suited to extract oil from Jatropha seeds. The following variables were in advance considered of main interest:

- Size of the restriction at the end of the press chamber
- Rotational speed of the screw press shaft
- Moisture content of the seeds
- Hull content of the seeds

The most important conclusions that can be drawn from this study are as follows:
Moisture content has the strongest effect on oil recovery. Restriction size and rotational speed of the screw are other influential parameters. The highest oil recovery measured were 89% and 91% for the BT50 and Sayari press respectively. These values resulted after one hour cooking in water of 70°C. Oil recovery values for untreated seeds under standard circumstances were 79% and 87%. Important to note is that the Sayari expeller requires dual passing of the material compared to single passing for the BT50. Additional Jatropha press tests were conducted at two industrial German press producers in order to put the other results into perspective. The tests conducted during this research showed close resemblance to industrial practice. Taking into consideration all the test results optimal oil recovery is expected at a moisture content of 2-4% after cooking at 70°C, 100% hull content and the smallest restriction size and lowest speed possible for a certain press type.

Based on purely financial results from the 'cost benefit analysis' large scale centralized processing is preferred over decentralized pressing. For similar production scale centralization allows an 'internal rate of return' of 61% compared to 30-40% in case of decentralization. However, reviewing both financial and non-financial aspects shifts preference to decentralized pressing for Tanzania and similar countries.

Jatropha has significant added value for rural communities in Tanzania. For a village of 9000 inhabitants Jatropha cultivation has an added value between $12,750 and $54,500 depending on seed yield, which is equivalent to approximately 100 annual minimum wages. Oil processing on village scale without the intervention of commercial firms seems preferable over mere seed selling if coupled to electricity generation and maize milling. 100 acres of Jatropha could easily provide an additional $1,500 per annum, which is equivalent to 19 monthly salaries to be divided between the initiators.

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1 Introduction

This chapter provides some background information important for this research. Furthermore the research problem and goals are stated. Working method and research limitations are also shortly elaborated on. Finally the structure of this report is shortly described.

1.1 Occasion

1.1.1 Background

People living in the poorest regions in the world, e.g. large parts of the African, Asian and Latin American continents, often lack access to energy sources in general. For cooking they often depend on gathered fuel wood and in case a connection to the electricity grid is present it is often unreliable. One approach to provide these people with energy to increase living standards is to enable them to produce energy from local resources. By means of such an approach the reliance on help from foreign countries is limited, which could lead to long term improvement of well-being. A promising local renewable energy source for people living in tropical regions is Jatropha Curcas L; a plant that grows oil yielding seeds. What distinguishes Jatropa from many other bio fuel crops are the benefits it can offer to relatively small rural areas in Less Developed Countries. Some examples are use for fencing, decreased deforestation for firewood collection and reduction of soil erosion. Once the oil is removed from the seeds, either mechanically or chemically, the oil and its by-products can serve various purposes some of which are: liquid fuel, gas, electricity, fertilizer and soap (Openshaw, 2000, 1-19).

Mechanical screw pressing is the most popular method in the world to separate oil from vegetable oilseeds on small to medium scale. Reasons for its popularity in for example India are that the machines require low initial and operation investments, can easily be operated, maintained and adopted by semi-skilled personnel (Bargale and Singh, 2000, 130-134). Furthermore it is possible to manufacture screw presses locally creating additional local employment. Both the oil and the de-oiled press cake obtained using screw presses are free of solvents and other chemicals as opposed to the more efficient solvent extraction method.

Research on mechanical screw presses for pressing oilseeds dates back to 1951 when V.D. Anderson Company patented the first expeller. Ever since considerable efforts have been made to gain better understanding of the processes inside a screw press and improve the oil extraction efficiency (Bargale and Singh, 2000, 130-134;Vadke and Sosulski, 1988, 1169-1176;Ward, 1976, 261-264;Zheng and others, 2003, 1039-1045;Zheng and others, 2005, 193-202). The earlier research was aimed at optimizing process variables like pressure, temperature and rotational speed of the press worm. In addition changes in moisture content and physical, thermal and hydrothermal pre-treatment of the seeds were considered in later research. The effect of research outcomes was that oil recovery rates increased from 50% to 80% for various oilseeds (Bargale and Singh, 2000, 130-134). Based on previous research various pre-treatments and process variables are considered for the present study, taking into consideration the possible application in rural Africa.

1.1.2 Problem

Although wild varieties of Jatropha exist in many regions attempts to cultivate the plant are limited. Cultivation experiments have been carried out in the previous decade and actual plantations have emerged in Africa, India and Latin America over the last few years. To name a few countries: Belize, Nicaragua, Ghana, Tanzania, Zambia, Mali and Mozambique (Hartlieb Euler and David Gorriz, 2004;Henning, 2007). There is however a lot of uncertainty on the best way to process the seeds into oil, taking into account the backward circumstances in less developed countries.

One of the disadvantages of screw pressing is the low oil recovery when processing untreated seeds. Even after multiple passes 5% to 10% of the oil remains in the press cake after pressing (Shahidi, 2005). Previous studies showed that oil recovery rates can be raised from 73% to 80% of the initial oil content for rapeseed and peanut and from 60% to 65% for cotton seeds by improvement of the press settings and proper the economic viability of local oil production by screw pressing and should therefore also be examined for Jatropha.

1.2 Goals

1.2.1 Research question

The most interesting application for the Jatropha oil is to use it as a fuel. This way the oil can be used for mobility (vehicles), electricity (generator), lighting and cooking. Once the intended use of the product is known, the production process can be chosen and analysed. The three most important aspects to consider when analysing expeller operation are the amount of oil removed, the amount of energy required to achieve this and the quality of the oil with respect to the intended application. Therefore these are also the aspects touched upon in the main research question:

- How can oil recovery, energy input and cost of Jatropha seed expression in screw presses be optimized while retaining a quality that complies with international fuel standards?

In this question oil recovery is defined as the amount of oil removed from the seeds compared to the amount that was initially present in the seeds.

There are three possible approaches to improve the properties mentioned in the research question namely pre-treatment of seeds before pressing, changes in press operation and changes in press design. However this research is extended beyond the determination of the optimal condition under which Jatropha seeds should be processed. The success of a new technology or production process is inseparably linked with the way it is introduced. It might therefore be worth the effort to go in search of an appropriate implementation approach for each specific project. For this research the north-eastern region of Tanzania was selected as a case study. In and around the cities of Arusha and Moshi attempts are made to set up a complete system to grow, process and use Jatropha to its full potential. Diligent Energy Systems is a Dutch company operating in the field of bio fuel production in less developed countries and active in Tanzania and Colombia. In 2003 Diligent started to contact local farmers and create networks for the collection of Jatropha seeds. By the end of 2006 their supply of seeds became sufficient to go on to the next step, which is processing the seeds into high quality oil. The problems Diligent encountered in determining the best suited processing method for Jatropha seeds in Tanzania gave occasion to this research. A moment of reflection reveals that this challenge not only requires a technical solution, but also demands investigation of local circumstances. Numerous examples exist of innovations that where technically sound, but still failed dramatically (Douthwaite, 2002). Therefore a second and third question are included to identify and avoid some of the pitfalls correlated with the introduction of innovations in less developed countries:

- What is the optimal setup for the production of Jatropha oil in Tanzania?

- In what way can rural areas in which their use is anticipated benefit from Jatropha cultivation?

1.2.2 Working Method

Two distinct low capacity screw presses were used; one located in the Netherland and the other one in Tanzania. Comparing the results of test on both presses reveals which of the two types is best suited to extract oil from Jatropha seeds. Both screw press settings and properties of the Jatropha seeds are varied to get a better understanding of the expression process and to find the optimal process conditions. The extent to which oil is separated from solid material is determined by analysing and comparing the oil content of both input (seeds) and output material (press cake). Based on literature the most important variables influencing the process will be (Bargale and Singh, 2000, 130-134;Eggers, Broeck, and Stein, 2006, 494-499;Vadke and Sosulski, 1988, 1169-1176;Zheng and others, 2003, 1039-1045):

- Size of the restriction at the end of the press chamber
- Rotational speed of the screw press shaft
- Moisture content of the seeds
- Hull content of the seeds

Because Jatropha oil is intended to be used in diesel engines it is important to compare the quality of the oil according to international standard for pure plant oils (PPO) and biodiesel. As this involves many different and time consuming chemical analyses, testing all fuel quality parameters is outside the scope of this graduation project. Indispensable tests on for example acidity and phosphorous content were contracted out to external research institutes.

During a visit to Tanzania the test results gathered at Eindhoven University of Technology were compared to a different type of screw press operating at Diligent’s workshop in Arusha, Tanzania. The main goal of the visit was to identify local circumstances and technological means to design a plan for local expression of Jatropha oil. At the moment of writing there is little activity involved in organized pressing of the seeds. Field studies were conducted from Jan-Mar 2007 consisting of visits to farmers who grow Jatropha, a local producer of screw presses, running Jatropha presses, involved Non government Organisations (NGOs), universities actively researching Jatropha and other interesting opportunities that presented itself. The collected data was used to perform a ‘Cost Benefit Analysis’ (CBA) on optimal Jatropha processing scale in Tanzania.

1.2.3 Research limitations

In this report the impact of several process variables on oil recovery, oil quality and energy costs are reviewed. The results are obtained by practical tests on two different standard types of screw presses; namely cylinder-whole press and strainer press. The practical research is restricted to variation of pre-treatments and press operation. Changes in screw design in order to improve oil yield were not included in this study. In addition costs and maintenance required for operation are estimated.

The only method of oil extraction examined in the report is mechanical extraction. Solvent extraction can achieve a reduction in the oil content of the press cake to less than 1% (Shahidi, 2005). In spite of its higher oil yields solvent extraction has some drawbacks especially for small scale applications. Solvent extraction facilities are typically constructed to process several thousands of tons of seed per day and cost in the order of tens of million dollars (Shahidi, 2005). In addition the commercially used solvent hexane can become highly explosive when mixed with air. Pre-treatments for size reduction and cell rupturing are also required prior to solvent extraction adding extra costs. For the purpose of pressing oilseeds on a small scale in less developed countries screw presses seem to be the better option despite their lower yield. As current methods of solvent extraction are not applicable in the region of interest they are not treated in further detail in this study.

Further treatment of the oil that comes out of the press might be required before it can be used to properly run a diesel engine. Although these steps are touched upon in the report no tests were carried out on the effect of different treatments of the oil on the performance or emission of a diesel engine.

The examination of socio-technological aspect in addition to the technical aspects is considered an added value to this report. Presumably the performed CBA will be less thorough than would be the case for a graduation project fully dedicated to this subject.

1.3 Report structure

The Jatropha plant and the applications of the oil and its by-products are elaborated on in more detail in chapter 2. In chapter 3 the working principles of different types of screw presses are explained. In this third chapter the variables affecting the pressing process are also discussed. Chapter 4 focuses on the research method of the experiments that were carried out on the screw press and the chemical analyses used to analyse the press cake. The research results are explained and discussed in chapter 5. Chapter 6 provides an overview of the findings in Tanzania. Based on the identification of local circumstances and a Cost Benefit Analyses (CBA), ideas on how to setup Jatropha pressing in Tanzania is discussed. Finally conclusions and recommendations are given in chapter 7.

2 Jatropha and its applications

This chapter serves as both an introduction to Jatropha for the layman and a detailed description of characteristics of Jatropha seeds and oil related to screw pressing. Paragraph 2.1 is a general description of the Jatropha tree. In paragraph 2.2 some interesting seed properties with regards to screw pressing are mentioned. The third paragraph deals with the various applications for Jatropha products and specifically Pure Plant Oil and biodiesel.

2.1 Plant description

When people use the term Jatropha, usually they refer to the species Jatropha Curcas L., which is one of the 170 known species of this plant (2006;Paramathma and others, 2006). The species Jatropha Curcas, of particular interest for this study, will for simplicities sake from now on be referred to as Jatropha. Jatropha is a wild plant; in other words it has not been cultivated through variety research. The plant belongs to the family Euphorbiaceae and is indigenous to Latin America (Akintayo, 2004, 307-310) and naturalized throughout tropical and subtropical parts of Asia and Africa where it is mostly used for hedging (Augustus, Jayabalan, and Seiler, 2002, 161-164). Both plant and seeds are toxic to humans and animals due to the presence of phorbol esters (Haas and Mittelbach, 2000, 111-118). Seeds from the Jatropha tree are known by many different names, the most common of which is “physic nut”. In Tanzania it is known as “Mbono” or “Makaen” and in the Netherlands as “purgeernoot”. Jatopha is a bush or small tree that is able to survive on marginal lands and can get up to 6 or 8 meters high. Its leaves have length and width of 6 to 15 cm and are shaped as is visible in Figure 2-1. This perennial

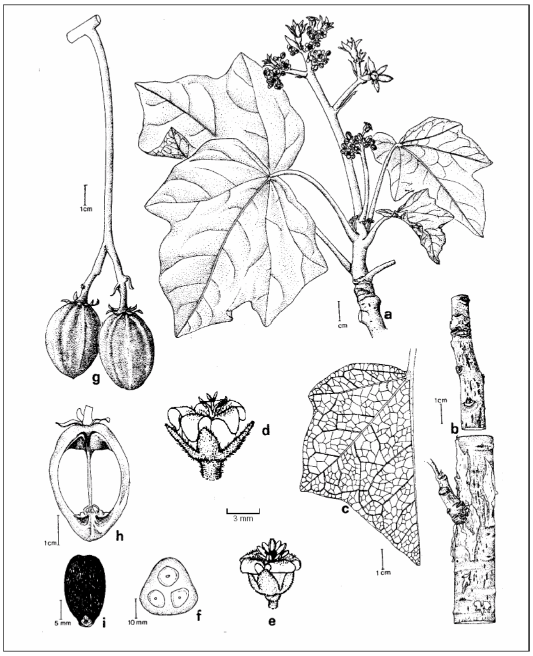

Figure 2-1 Left: Representation of the Jatropha plant (a,b,c,d), fruits (g,h) and seeds (i) Right: close-up of Jatropha fruits near Arusha, Tanzania (Heller, 1996).

bush can live up to 50 years and starts to grow fruits from the 2nd or 3rd year. Under favourable conditions it can grow to a thick bushy fence of approximately one meter high in 6-9 months (Augustus, Jayabalan, and Seiler, 2002, 161-164). Jatropha will grow under a wide range of rainfall regimes from 200-1500mm. Ideal would be 600mm in moderate climates and 1200mm in hot climates (Biswas, Kaushik, and Srikanth, 2006). Being drought tolerant the plant still sheds its leafs during dry periods, which means that it cannot grow fruits (Openshaw, 2000, 1-19). In addition to water a plant needs nutrients. In case of Jatropha deficiency of these nutrients leads to increased failure of seed development as was encountered during my field studies in Tanzania in February 2007. The plants yield varies strongly and although it survives on marginal land, yields will be significantly lower than for fertile lands. Claims on yields range from 0.4 to 12 ton/hectare/year (Openshaw, 2000, 1-19). The number of trees per hectare has been reported to vary from 1100-3300, which equals 445-1335 per acre (Openshaw, 2000, 1-19). The seed yield of Jatropha has been estimated to range from 0.75-2 kg/year per plant after three to four years (Biswas, Kaushik, and Srikanth, 2006). In contrast to the overoptimistic claims of 12 tons/hectare (4.8 tons/acre) calculation using the above values predict yield between 0.8-6.6 tons/hectare (0.33-2.7 tons/acre). This seems a reasonable when compared to claims in the comparative studies by Benge (Benge, 2006).

2.2 Seed properties

Much research has been conducted on the composition and properties of Jatropha seeds by others ((Openshaw, 2000, 1-19), (Heller, 1996), (Henning, 2004) and (Sirisomboom, 7 A.D.)). These studies also provide insight in the possibilities of using Jatropha oil for fuel purposes. Knowledge of the physical and mechanical properties of Jatropha is required for adequate design of machines for de-hulling, drying and pressing of the seeds. Restrictions on how to store the seeds are linked to these properties. Mechanical properties such as rupture force and energy required for rupturing fruit, nut and kernel provide insights on how to adapt the pressing process to Jatropha seeds.

Table 2-1 Physical and mechanical properties of Jatropha (Sirisomboom, 7 A.D.). Note that the data concerns fresh seeds and that under normal conditions the density is less than that of water.

Physical properties	**Nut**	**Kernel**
Length [mm]	21.02 ± 1.03	15.45 ± 0.54
Equatorial width perpendicular to length [mm]	9.58 ± 0.28	7.42 ± 0.33
Breadth perpendicular to length and width [mm]	11.97 ± 0.30	10.25 ± 0.36
Solid density [kg/m^3]	1040	1020
Bulk density [kg/m^3]	450	420
Mechanical properties	**Nut**	**Kernel**
Rupture force [N]	146.63 ± 14.82	67.72 ± 19.03
Hardness [N/mm]	69.98 ± 6.22	38.52 ± 5.59
Energy used for rupture [Nmm]	124.44 ± 19.95	51.61 ± 26.84

Jatropha fruits are slightly elliptical in shape with length approximately 35 mm and contain 3 seeds on average (Sirisomboom, 7 A.D.). The fruits and seeds are shown in Figure 2-1. The size of the seeds varies between 11-30 mm (average 21mm) in length and 7-12 mm (average 11mm) in width (2006;Sirisomboom, 7 A.D.). More detailed information on the physical and mechanical properties of Jatropha seeds is given in Table 2-1. Hardness values in Table 2-1 indicate that Jatropha seeds are relatively soft compared to for example rapeseed (>52.6 N/mm) (Faborode and Favier, 1996, 335-345) and sunflower (35.3-65.3 depending on seed orientation) (Gupta and Das, 2000, 1-8). The seeds weigh about 1 ton/m^3. The oil content of the seeds varies with origin and growing conditions and is between 30-40 wt.%, which makes it a high oil content seed. Variations of oil content with origin are shown in Table 2-2. For Tanzanian varieties this is approximately 38%. The influence of seed quality on oil content could not be checked as the samples were provided by various parties.

Table 2-2 Oil content of seeds of different origin determined by soxhlet extraction

Origin	Oil content
Brasil	30.9%
Tanzania	37.8%
Ethiopia	38.8%
India	36.8%
Gambia	32.7%
Nigeria	33.7%

2.3 Jatropha applications

Jatropha can be utilized for various purposes of which application as transport fuel is probably the most interesting one from both an economical and ecological point of view. Nevertheless the other uses are worth mentioning as they provide insight in the total value chain of Jatropha products. In rural Africa Jatropha is mostly used as a natural fence to prevent cattle from feeding on crops for medicinal purposes and more recently for soap making by local women groups. The bark and leaves contain dye and latex with medicinal properties for the pharmaceutical industry (Augustus, Jayabalan, and Seiler, 2002, 161-164). As mentioned earlier one drawback of Jatropha is that there are hardly any yields during the first two or three years. One option to overcome this problem is intercropping of Jatropha with other crops like for example maize. In Madagascar Jatropha is, for the same reason, used to support vanilla plants (Benge, 2006). If planted wisely the plant can be used to prevent soil erosion or even reclaim exhausted land. When managed properly it has potential as a commercial crop for the production of Pure Plant Oil or biodiesel. The press cake formed during oil production also has a wide variety of applications depending on local circumstances. As it still contains most of the nutrients it can be used to fertilize land. Other options are the production of briquettes for industrial steam boilers or charcoal for household stoves. A GTZ (Gesellshaft für Technische Zusammenarbeit) project with plant oil stoves in Tanzania indicates that the oil might also have some potential as fuel for cooking stoves. Possibilities for biogas production from Jatropha press cake have also been studied (2006;Aderibigbe and others, 1997, 223-243).

2.3.1 Fuel

In spite of all other options fuel is considered the most promising application for the Jatropha seeds. The potential work that a fuel can do is determined by its energy content. In
Table 2-3 the calorific values of solid and liquid Jatropha fuels are compared to those of conventional fuels. More detailed information on seed and oil properties is provided in Appendix A. An interesting value when judging a fuel is the energy value. The numbers in Table 2-3 suggest that, judging on energy value, liquid fuel is the highest-grade product to be obtained from Jatropha seeds. In addition press cake seems a valuable by-product. One should think of using the press cake for the production of for example briquettes, charcoal or biogas (Vyas and Singh, 2007, 512-517). Jatropha press cake has an energy content between that of coal and wood. Jatropha oil shows lower energy content than conventional fuels. This indicates higher fuel consumption per kilometre. When converting to the more interesting quantity MJ/litre the values for Jatropha and diesel change to 34.77 MJ/litre and 37.72 MJ/litre respectively, reducing the difference in energy content to 8%. Most Jatropha related activities as well as this report are centred on liquid fuel. Therefore PPO and biodiesel from Jatropha are discussed in more detail in paragraph 2.3.1.1 and 2.3.1.2.

Table 2-3 Calorific value of Jatropha oil and seeds compared to conventional fuels (Augustus, Jayabalan, and Seiler, 2002, 161-164).

Parameter	Calorific value (MJ/kg)
Jatropha seeds	20.1 ± 0.08
Jatropha press cake	18-25.1**
General purpose coal (5–10% water) *	32–42
Wood (15% water) *	16
Jatropha oil	37.8 ± 0.08
Biomass and fossil fuels	
Fuel oil (mexico)	43.158
Crude oil	44.091
Gasoline	47.127
Diesel *	46

* http://www.kayelaby.npl.co.uk

** depending on residual oil content in the press cake

2.3.1.1 PPO

Vegetable oil that has not been treated apart from filtering is often referred to as Pure Plant oil (PPO) or Straight Vegetable Oil (SVO). Jatropha oil is just one of a wide variety of PPOs. The main reason to use PPO instead of converting it to biodiesel is the costs involved in the transesterification process. Compared to conventional diesel the use of PPO in a diesel engine reduces the emission of sulphur oxides, carbon monoxides, poly aromatic hydrocarbons, smoke, particle matter and noise (Agarwal and Agarwal, 2007, 2314-2323). The main disadvantage of PPO on the other hand is its high viscosity that leads to unsuitable pumping and fuel spray characteristics. The high viscosity of Jatropha oil is a result of the presence of the saturated and unsaturated acids identified in Table 2-4. The acids consist of relatively long carbon chains (C14:0-C20:0) when compared to conventional diesel (C12:0-C15:0) (Knothe and Steidley, 2005, 1059-1065). The acid composition in Table 2-4 also hints an acidic nature of Jatropha oil, which is harmful to rubber engine components. Poor atomization, low volatility and insufficient fuel-air mixing can lead to combustion chamber deposits, gum formation and unburned fuel in the lubrication oil (Agarwal and Agarwal, 2007, 2314-2323).

Table 2-4 Jatropha oil fatty acid composition (Akintayo, 2004, 307-310;Augustus, Jayabalan, and Seiler, 2002, 161-164;Kandpal and Madan, 1995, 159-160;Mohibbe Azam, Waris, and Nahar, 2005, 293-302))

Saturated acid		Augustus,2002	Akintayo, 2003	Kandpal & Madan, 1994
Palmatic acid	(16:0)	14.1%	19.5% ± 0.8	12.8%
Stearic acid	(18:0)	6.7%	6.8% ± 0.6	7.3%
Unsaturated acid				
Oleic acid	(18:1)	47.0%	41.3% ± 1.5	44.8%
Linoleic acid	(18:2)	31.6%	31.4% ± 1.2	34.0%

In Table 2-5 a comparison between Jatropha and conventional diesel is made. The enormous difference in viscosity is striking. The high saponification together with a low unsaponifiable mass shown in Appendix A indicates that Jatropha oil is a normal triglyceride. Although much higher than the viscosity of normal diesel or biodiesel, standards of which are between 1.6 and 6 cST, the viscosity of Jatropha (34-36cST) is average compared to other plant oils such as soybean (31cST), cottonseed (36cST) and sunflower (43cST) (Knothe and Steidley, 2005, 1059-1065). Its viscosity being comparable to other plant oils makes Jatropha a potential material for fuel production, although measures to reduce it seem necessary (Akintayo, 2004, 307-310). German PPO norms are included in Appendix B to show the other specifications to comply with.

Table 2-5 Some fuel properties of Jatropha oil and mineral diesel compared (Agarwal and Agarwal, 2007, 2314-2323).

Parameter	Fuel	
	Mineral diesel	Jatropha oil
Density (kg/m^3)	840 ± 1.732	917 ± 1
Kinematic viscosity at 40°C (cST)	2.44 ± 0.27	35.98 ± 1.3
Flash point (°C)	71 ± 3	229 ± 4
Fire point (°C)	103 ± 3	274 ± 3
Calorific value (MJ/kg)	45.343	39.071
Carbon (wt%)	80.33	76.11
Hydrogen (wt%)	12.36	10.52
Nitrogen (wt%)	1.76	0
Oxygen (wt%)	1.19	11.06
Sulfer (wt%)	0.25	0

2.3.1.2 Biodiesel

Biodiesel is a fuel type that has already been proven suitable for use in diesel engines. Biodiesel consists of fatty acid methyl esters (FAMEs) of seed oil and fats and is produced through transesterification. The reaction equation for biodiesel production is shown in Figure 2-2. The triglyceride esters of oil are changed into methanol monoesters (methyl esters), each with single fatty acid chains causing the lower viscosity of biodiesel. FAMEs are environmentally safe, non-toxic and biodegradable making them a suitable transport fuel (Mohibbe Azam, Waris, and Nahar, 2005, 293-302). The biggest advantage of biodiesel over PPO is its lower viscosity (Knothe and Steidley, 2005, 1059-1065).

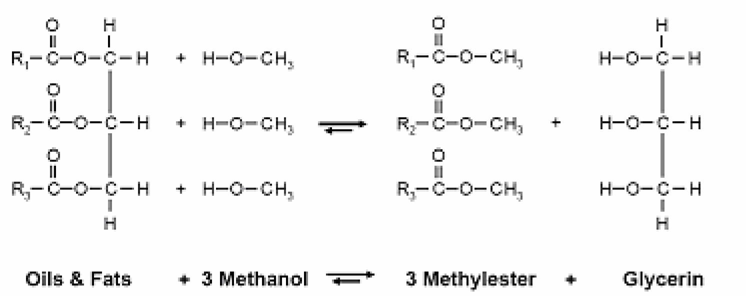

Figure 2-2 Reaction equation of transesterification (www.biofuel.be)

One of the important values for selection of FAMEs for biodiesel is the cetane number (CN). This is the ability of a fuel to ignite quickly after injection. Higher values indicate better ignition quality. Some of the most widely used biodiesel standards from the USA (ASTM D 6751), Germany (DIN 51606) and European Organization (EN 14214) set CN at 47, 49 and 51 respectively (Mohibbe Azam, Waris, and Nahar, 2005, 293-302). The CN for Jatropha biodiesel is on the high end being 52.31 (Mohibbe Azam, Waris, and Nahar, 2005, 293-302).

Another important criterion for biodiesel quality is the iodine value (IV), which indicates the degree of unsaturation (amount of double bonds). Some level of unsaturated fatty acid components is necessary to prevent FAMEs from solidification. However at too high IV unsaturated molecules start to react with atmospheric oxygen and convert to peroxide which might lead to the polymerization of biodiesel into plastic-like material. High temperatures occurring in internal combustion engines tend to accelerate this process. To comply with all standards the IV should be less than 115 (Mohibbe Azam, Waris, and

Nahar, 2005, 293-302). With an IV of 93.0 (Mohibbe Azam, Waris, and Nahar, 2005, 293-302) Jatropha biodiesel is well within range.

Research by Mohibbe Amam et al, 2005 points out Jatropha biodiesel to be among the twenty-six best suited FAME mixtures (from a 75 species comparison) judging CN, IV and other variables like linolenic acid value, boiling point and carbon chain length. The latter causing higher viscosity with increased chain length (Krisnangkura, Yimsuwan, and Pairintra, 2006, 107-113).

3 The screw press

Chapter 3 is intended to give the reader more information about the screw pressing process. Therefore paragraph 3.1 first explains the working principles of oil expelling in a screw press. The two main screw press designs are treated in paragraph 3.2. Finally paragraph 3.3 goes into more detail on the parameters affecting the screw pressing process.

3.1 Working principles

Mechanical pressing and solvent extraction are the most commonly used methods for commercial oil extraction. Screw pressing is used for oil recovery up to 90-95%, while solvent extraction is capable of extracting 99% (Shahidi, 2005). In spite of its slightly lower yield, screw pressing is the most popular oil extraction method as the process is simple, continues, flexible and safe (Zheng and others, 2005, 193-202) (Singh and Bargale, 2000, 75-82). Screw presses exist with raw seed capacities ranging from 10 kg /hr up to tens of tons/hr. The operation principle of a screw press is rather simple to visualize although very difficult to model judging from attempts by Shirato (1971), Vadke (1988) and Wang (2004). Therefore most improvements made to screw presses over the last decades are based on manufacturer's experiences and intuition rather than on the basis of physical principles (Vadke and Sosulski, 1988, 1169-1176); (Singh and Bargale, 2000, 75-82). During the pressing process oil seeds are fed in a hopper and then transported and crushed by a rotating screw in the direction of a restriction (sometimes referred to as die or nozzle). As the feeding section of a screw press is loosely filled with seed material the first step of the compression process consists of rolling, breaking and the displacement and removal of air from intermaterial voids. As soon as the voids diminish the seeds start to resist the applied force through mutual contact (Faborode and Favier, 1996, 335-345). The continuous transport of material causes pressure to increase to a level needed to overcome the restriction. This pressure causes the oil to be expressed from the seeds. The end pressures in a screw press can vary from 40 to 350 bar (4-35 MPA) depending on the type of press and input material.

Material conveyance through the press barrel is a result of the friction forces between material, screw and barrel. This force balance is represented in simplified version in Figure 3-1. If F_p (induced by the screw) and F_{r4} (friction between material and barrel) are larger than the sum of the other friction and pressure forces the material will be properly transported. When the friction forces between screw and seed material increase beyond F_{r4} slip will occur and transport will reduce or even stop.

The oil is situated at different locations inside the cell, together with other constituents like proteins, globoids and nucleus represented in Figure 3-2. All these elements are contained within cell walls, which need to be ruptured to free the oil. A combined force of friction and pressure in the barrel causes the cell walls to rupture and oil to flow out of the liquid solid mixture inside the barrel. The separated oil is discharged through holes provided along the press barrel. The compressed solid material or press cake is simultaneously discharged through the restriction at the end of the barrel. The various screw press components have been described in detail by Ward (1976), Singh & Bargale (2000) and Shukla (1990).

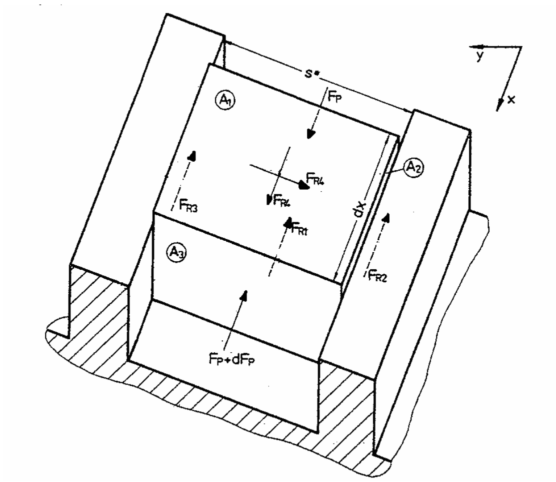

Figure 3-1 Forces acting on a press cake element situated between two worm shafts. The x-direction indicates movement towards the restriction. (Eggers, Broeck, and Stein, 2006, 494-499)

Expression of liquid solid mixtures generally consists of two steps: filtration and consolidation. Whenever free flowing particles are present the process is called filtration. From the point where all solids combine into a solid bed it is called consolidation (Willems, 2007). The extent to which consolidation occurs is mainly determined by the geometry of the extruder channel and outlet and material properties. Filtration is expected not to be present inside a screw press (Venter and others, 2006, 350-358) and therefore consolidation is the main process of interest here. Further distinction can be made between primary consolidation comprising rearrangement of the solid bed and liquid removal, and secondary consolidation consisting of material deformation and further liquid removal (Willems, 2007).

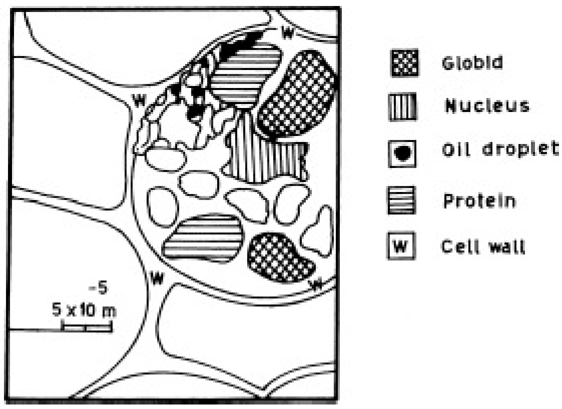

Figure 3-2 Cell composition of oilseeds, in this case rapeseed (Singh and Bargale, 1990, 106-110).

Modelling attempts

Extrusion of polymers, which closely resembles oil expelling, is more easily understood because of a continuous material flow in and out of the press chamber. All that comes in at the entrance comes out at a single exit, which makes drawing up mass and energy balances relatively easy. Oil expelling is more complicated as a radial oil flow leaves the press barrel at the oil outlet, thus creating a second outflow of material as is illustrated in Figure 3-3 (Vadke, Sosulski, and Shook, 1988, 1610-1616). This oil flow is difficult to model and therefore theoretical models have not yet been used to improve expeller design. In the 1970's and 1980's the flow of liquid from a solid-liquid mixture has been studied based on Terzaghi's (1943) consolidation theory. Mrema and McNulty (1985) used consolidation theory to predict oil flow from rapeseed and cashew nuts in a piston ram-press. Furthermore Körmendy (1974) and Shirato (1971) developed mathematical models for the mechanical separation of liquid from clay-water substances. In the late 1970's Shirato et al extended their analysis towards continuous expression in screw presses. Their model for the prediction of the amount of water separated from the clay-water mixture still required prior knowledge on axial flow rate of the mixture and the pressure profile along the worm. This restriction makes the Shirato model unsuited for design purposes as these variables are not known in advance. Vadke et al (1988) produced a more complete model to predict the throughput and the reduction in liquid content in a liquid-solid mixture in a press of unrestricted geometry. Unrestricted geometry implies that the size of the cylinder and worm can be varied freely in the model. The most recent attempt to model screw pressing of oilseeds was undertaken by Willems (2007) and based on the Vadke model including consolidation theory.

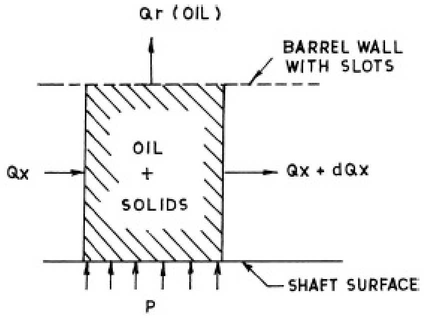

Figure 3-3 Material flow in a section of a worm channel during oil expelling (Vadke, Sosulski, and Shook, 1988, 1610-1616).

Towards the press cake outlet the radial pressure on the mixture inside the barrel increases due to volumetric compression. The compression is induced by the worm shaft as it forces more and more material inside the same volume. According to Ward (1976), who conducted early research on screw presses the pressure distribution along the shaft would look like Figure 3-4. Work by others shows that the distribution might be shaped differently as presented in Figure 3-5 (Eggers, Broeck, and Stein, 2006, 494-499). Recent studies by Willems (2007) suggest that the calculated profile measured by Eggers is more sensible than the one by Ward. Increased radial pressure increases the outflow of oil from the cells (Singh & Bargale, 2000). Results by Eggers and Ward were both intended for the 'strainer press' type that will be further explained in the following paragraph.

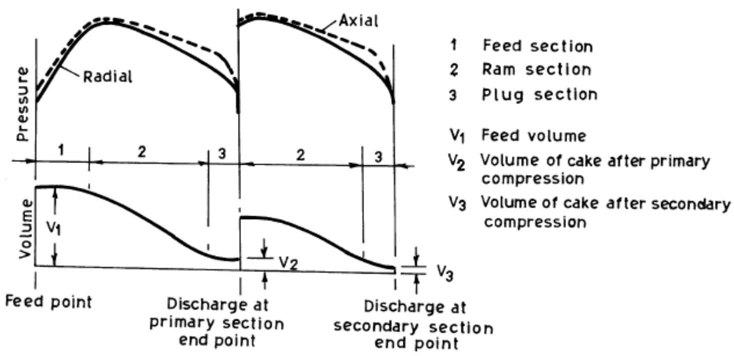

Figure 3-4 Pressure variation based on theory of Ward for strainer press (1976)

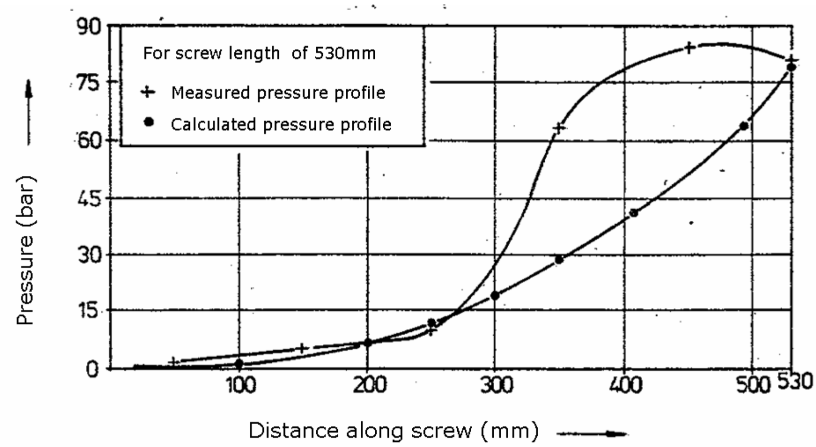

Figure 3-5 Pressure distribution along the screw for strainer press (Eggers, Broeck, and Stein, 2006, 494-499)

3.2 The two main screw press designs

Screw presses can be subdivided into two main types, namely the 'strainer press' and the 'cylinder-hole press'. They mainly differ in screw geometry, oil outlet and press cake restriction.

3.2.1 Strainer press

For this first type the screw rotates in a cage lined with hardened steel bars, resembling a strainer. Spacers placed between the steel bars permit oil outlet as the pressure on the feed material increases. The gaps between the bars form an adjustable oil outlet. This adjustability allows the pressure to be optimized for different input materials. Figure 3-6 shows a schematic of the 'strainer press'. The figure shows the increasing diameter of the screw in order to increase pressure in the direction of the choke. Instead of increasing the screw diameter inserting cones on a constant diameter screw is a frequently applied alternative. The screw design causes the volume displacement at the feed end to be considerably larger than at the discharge end. The resulting pressure increase forces the oil through the strainer (Khan and Hanna, 1983, 495-503). For flexibility often different screw types are available or subsections can be replaced. The cake is pressed out of the adjustable choke in the form of flat and often fractured flakes. The choke gap can be adjusted to influence pressure and the shape and oil content of the press cake. For smaller machines, a hand wheel on the opposite end of the screw is typically used to adjust the choke (Khan and Hanna, 1983, 495-503). 'Strainer presses' are available with capacities ranging between 15 and 2000 kg/hour (Ferchau, 2000).

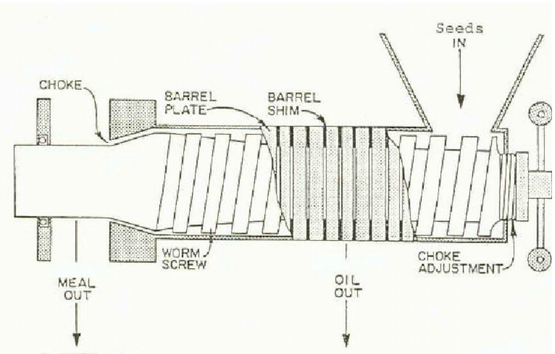

Figure 3-6 Strainer press (Ferchau, 2000).

3.2.2 Cylinder-hole press

With the second press type the oil is pushed out through holes drilled in the cylinder tube. The profile of this 'hole cylinder press' is shown in Figure 3-7. Increasing pressure forces the press cake through a circular nozzle at the end of the cylinder. In order to avoid blocking of the press, the area around the nozzle (press head) is usually preheated before operation which decreases the viscosity of the paste inside the press. When pressing rapeseed the temperature of the oil should not increase above 40°C, because increasing temperature leads to higher phosphor content in the extruded oil. High phosphor content is an undesirable fuel property as it can cause deposits and clogging in engines. To prevent the oil from reaching 40°C the temperature near the die, which is the location where maximum temperature occurs, should at maximum be in the range of 60 to 80°C. If on the other hand the cake outlet temperature is too low the solid content in the oil becomes unacceptable (Ferchau, 2000).

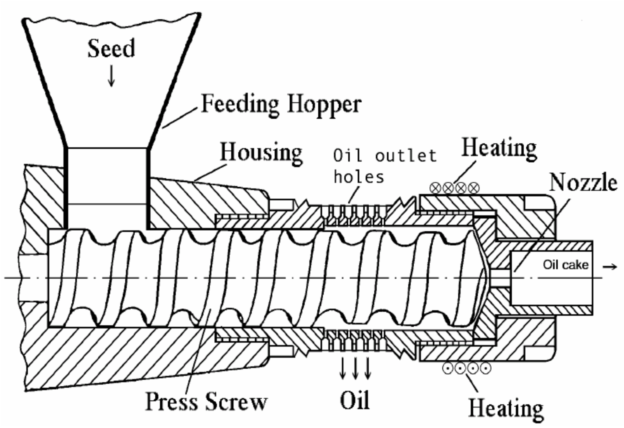

Figure 3-7 Hole cylinder press (Ferchau, 2000).

The pressure level in the screw press is influenced by nozzle diameter, screw design and seed conditions. Pressure increases with decreasing nozzle size. This effect would suggest a small nozzle, in order to extract as much oil as possible. Decreasing the nozzle also has some negative affects. First of all the seed throughput decreases for smaller nozzle diameters. Second, due to increased resistance the temperature inside the screw press increases. This could cause the temperature of the oil to exceed threshold values or lead to faster machine wear. Thirdly the solid content in the separated oil is higher at higher pressure caused by reducing the restriction size (Ferchau, 2000). Finally the chance of blockage increases with decreasing nozzle size. Comparable adaptations are possible for the strainer based screw press. As a rule of thumb the minimal oil content of the press cake when using screw presses should be about 5-6% (Hui, 1996). In case of rapeseed a rotation speed of 20 to 50 rpm is normally used because energy use is low in that case.

3.2.3 Different designs

In addition to conventional expeller design several variations have emerged over time. One of these variations is a 'twin-screw extruder' which is claimed to achieve very high yields on de-hulled seeds compared to traditional single-screw presses (Dufaure and others, 1999, 1073-1080). Further advantages are flaking and boiling pre-treatments would be redundant for 'twin-screw extruders'. As no literature on the performance of 'twin-screw extruders' with Jatropha seeds was found they are mentioned here only for the sake of completeness and will not be treated in any more detail in this report. Another variation is solvent injection in an extruder. Claims by Foidl indicate that 0.3% residual oil content can be achieved when injecting isopropanol under 300 bar pressure (Foidl, 2007). Foidl also expects 1.5% residual oil content to be possible when using CO_2 as a solvent (Foidl, 2007). Unfortunately no official results to underpin the claims by Foidl were obtained.

3.3 Parameters affecting the screw pressing process for oilseeds

A number of variables need to be taken into account to optimize oil production using screw presses. For quality preservation temperature is an important parameter. The friction inside the barrel generates heat which is passed on to the oil. For oil recovery and energy consumption pressure is more interesting to monitor. A short explanation of the variables considered in this study is written down below. For more detail on oilseed processing volume 5 of 'Bailey's industrial oil & fat products' should be consulted.

3.3.1 Independent variables

RPM
Higher screw speed means more throughput and higher residual oil content in the press cake since less time is available for the oil to drain from the solids. At higher speed the viscosity thus remains lower resulting in less pressure build-up. This again causes the residual oil content to be relatively high (Willems, 2007).

Restriction size
When the restriction size is reduced the pressure required to overcome the restriction increases. A resulting decrease in oil content causes increased viscosity of the paste and further pressure rise.

Hull content
Hull content is expected to affect both oil recovery and energy requirement. By removing a part of the hard hull material less energy is needed for breaking and compressing (Zheng and others, 2005, 193-202). As Jatropha hull contains no oil reduced amounts of hull may lead to decreased absorption of oil, thereby increasing oil recovery.

Moisture content
An optimal moisture level for oil expression is expected to exist. In case of rapeseed it is a moisture level close to 7% (Bargale and Singh, 2000, 130-134). For flaxseed the optimal moisture content is expected to be around 6% (Zheng and others, 2005, 193-202). The optimal value for Jatropha is expected to be in the same order of magnitude

Cooking
Cooking causes increased cell wall rupturing thereby facilitating the outflow of oil. The oil point pressure decreases while pressure build-up increases due to increased viscosity in turn drastically increasing oil recovery.

3.3.2 Dependent variables

Variables treated in this paragraph change as a result of the independent variables treated previously.

Oil recovery
This is the most important dependent variable considering the goal of this report. The effect of the independent variables on oil recovery can be explained by looking at the dependent variables described below.

Temperature
The friction inside the barrel generates heat which is passed on to the oil. Above certain levels the amount of phosphor and changes in acid value have a negative effect on engine performance.

Pressure
When speaking of pressure radial pressure is meant in this report. Pressure is expected to change due to changes in all independent variables. Pressure is expected to be a proper measure for oil recovery. In general higher pressure will mean more oil is recovered.

Throughput
The amount of material transported through the press per unit of time is affected by the independent variables. Throughput can be used to explain oil recovery and is an important variable for commercial processing. Low throughputs often imply high oil recovery.

Energy requirement
Energy requirement is probably related to the pressure inside the press head. The viscosity of the material to be pressed and the rotational speed will also determine the amount of energy needed.

Oil point pressure
The oil point is defined as the stage which occurs just before oil flows out of compressed solid particles (Sukumaran and Singh, 1989, 77-84). The oil-point is theoretically coupled to the kernel density of an oilseed (Faborode and Favier, 1996, 335-345). As this stage will always occur before oil is separated from its surrounding solids Sukumaran & Singh (1989) identified it as an important material property when studying mechanical oil expression. The material to be pressed consists of oil bearing solids. For the oil to be freed from the solids it has to come to the surface of the seeds and fill interparticle voids (Sukumaran and Singh, 1989, 77-84). Oil recovery is assumed to depend on the pressure exerted on the material in excess of the pressure that is required to reach the oil point. Sukuraman & Singh found that the cell walls were still in tact at the oil-point confirming that rupturing of cell walls is not a precondition for oil expression. The oil can leave the cell through plasmodesmata (pores) in the cell wall (Faborode and Favier, 1996, 335-345). For rapeseed the oil point pressure was found to be 57-97 bar depending on moisture content and rate of deformation.

The oil point pressure is affected by the rate of deformation in mm/min (which can be translated to screw speed in case of an expeller) and the moisture content. Press tests by Sukuraman & Singh (1989) using a loading piston indicate that pressure corresponding to the oil point increases with increased moisture content and with increased rate of deformation. The most significant effect can be attributed to moisture. Should the same principles hold for an expeller it is to be expected that the oil point pressure of the material inside will increase for higher moisture level and screw speed. Size reduction and heating can be applied to increase compressibility of the seed material and thus lower the oil-point pressure (Faborode and Favier, 1996, 335-345).

4 Materials and method

This chapter describes all experimental methods conducted at both Eindhoven University of Technology and Diligent Tanzania LTD. In paragraph 4.1 the experiments conducted at the university are described. Paragraph 4.2 elaborates on tests done at Diligent Tanzania LTD.

4.1 Experiments at Eindhoven University of Technology

4.1.1 Materials

Seeds of Jatropha Curcas L were obtained from Diligent Energy Systems (Eindhoven, The Netherlands). The origin of the seeds is the northern region of Tanzania around Arusha. Two different batches were supplied; one harvested in July 2005 and the other one in July 2004. The oil content of the seeds, determined by soxhlet extraction with petroleum ether, was found to be 37.8 wt.% (dry basis). Further details on the soxhlet extraction are given in paragraph 4.1.4. Standard Silica crystals were available at the faculty of Chemical Engineering. Petroleum ether (boiling range 40-60°C) was bought from (Fluka Riedel de Haën, Buchs, Switzerland).

4.1.2 Experimental setup

A Danish screw press (BT Bio Presse Type 50, BT biopresser aps, Dybvad, Denmark) was made available by Diligent Energy Systems and FACT Foundation (Eindhoven, The Netherlands) to extrude the oil from the seeds in one pass. Figure 4-1 shows the BT 50 test setup. This small capacity press was designed for smaller seeds like rapeseed and sunflower but proved to run properly on the bigger Jatropha seeds. The capacity of the press for Jatropha is approximately 12kg/h. The screw is powered by a 1.1 kW electric motor. Screw RPM is directly regulated between 0-70 RPM by a variable speed drive(Altivar 31, Schneider Electric SA, Rueil-Malmaison, France). The variable speed drive is also used for readings on power consumption of the electric motor. The restriction size at the press cake outlet can be varied by placing different sized nozzles. Detailed specifications of the press geometry are tabulated in Appendix C. During press tests only a single screw geometry, which was not optimized for Jatropha, was used. Pressures during testing reached up to 300 bars at temperatures of over 140 $^\circ$C.

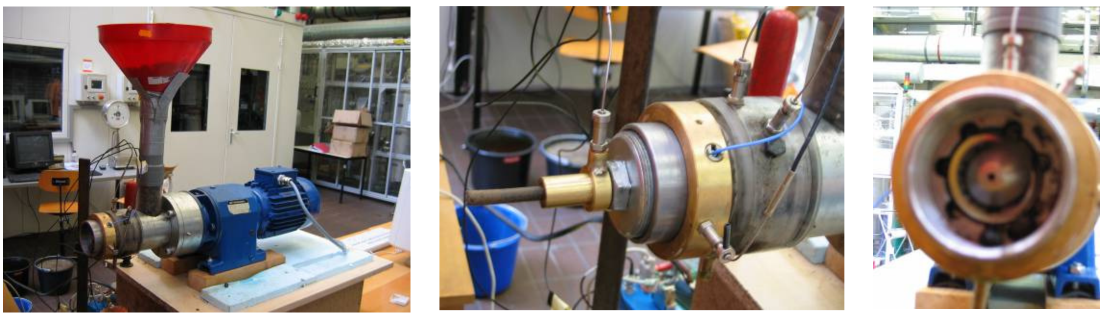

Figure 4-1 Left: BT50 test setup at Eindhoven University of Technology. Middle: situation of thermocouples and pressure sensor (blue wire). Right: front view inside the press head.

The seeds underwent different pre-treatments in order to evaluate the effect on amongst others oil yields and oil quality. Hull content was varied between 60 and 100% using the custom built de-huller shown in Figure 4-2. Separation of hull and kernel had to occur manually. The prepared samples each weighing about 2 kg were either sealed for storage or instantly fed into the screw press. Determination of the moisture content is done by oven drying (Heraeus BR 6000, Hanau, Germany) just before the seeds are fed to the screw press in order to minimize errors.

Figure 4-2 Hand powered de-huller designed together with Gerard van Hout from the workshop at Mechanical engineering.

4.1.3 Experimental procedure

The description of a typical experiment is used to explain the experimental procedure. To prevent jamming the press head is heated to 70-80˚C using a hot air pistol. While continuing heating small amounts of seeds are fed into the hopper. A sample size of 2kg was chosen as this allows stable measurements and simplifies the calculation of throughput. Crude oil is collected at the oil outlet and press cake exit on the left (see Figure 4.1 middle) in the shape of small pellets. Temperature is measured at 4 positions along the press cage (type J Thermal Insulated thermocouple, Themocoax, Netherlands). The first is located at the press cake exit, the second at the point where maximum temperature is expected and the third & fourth at different positions along the oil outlet as indicated in Figure 4-3. The radial pressure is measured (6152AAA Mold Cavity Pressure Sensor, Kistler Instruments AG, Switzerland) at the point of maximum expected pressure, which coincides with the point of maximum temperature. The sensor signal is amplified into a signal in the range of 0-10V by a charge amplifier (5073 Industrial Charge Amplifier Manufacturing, Kistler Instruments AG, Switzerland). All data was digitally recorded using a PCMCIA card (NI4350, National Instruments, United States) and 'Virtual Bench Logger'. In addition the time required for a batch to pass through the press was measured. It was difficult to determine the instant at which the pressing finished, therefore the time measurement was started when the pressure showed a steep increase after seeds were fed and stopped once pressure drastically declined while the press was almost empty. Power consumption was recorded using one of the Altivar 31 voltage output signals. The output signal ranged from 0-10V where 10V indicates twice the nominal power of the 1.1kW electric motor (Altivar 31 user manual). A graph in appendix D shows maximum power measurement while the press is jammed.

Jatropha seeds with increased different moisture content were obtained by equilibrating the seeds for one week in a sealed environment with a fixed amount of water inside plastic bag. A similar method was used in other studies on mechanical expression of oil seeds (Vadke and Sosulski, 1988, 1169-1176;Zheng and others, 2005, 193-202). To decrease the moisture content below the natural value of around 7% a similar method was used with silica crystals. The silica was oven dried overnight at 103˚C. All moisture contents were determined according to DGF standard method B-I 4 (DGF-Einheitsmethoden, 2002).

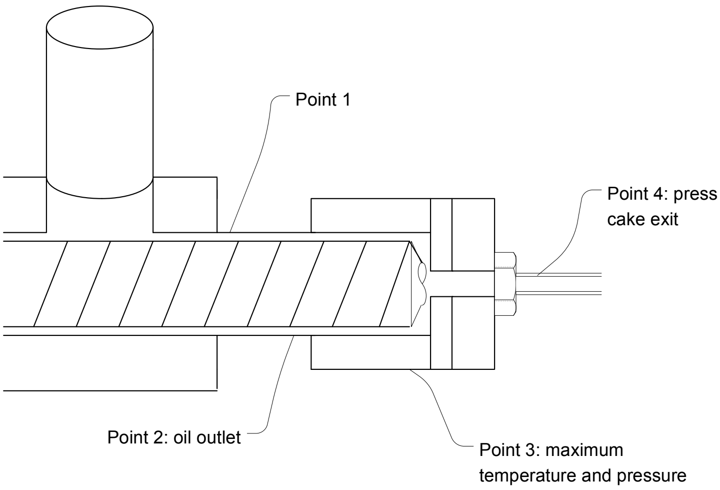

Figure 4-3 Location of measurement devices

After pressing a sample of the press cake was analyzed on oil content with Soxhlet extraction according to DGF standards (DGF-Einheitsmethoden, 2002). After leaving the oil to settle for a week relative amount of foots in the crude oil could be determined.

4.1.4 Analysis

Oil content

Prior to determining the oil content of seed or press cake the sample was dried at 103˚C for 5 hours in a drying oven (Heraeus BR 6000, Hanau, Germany). The oil contents are compared on a dry basis for ease of comparison. After drying the sample was ground together with a small amount of petroleum ether for 20 seconds at 25Hz in a ball mill (MM301, Retsch GmbH & Co, Haan, Germany). Oil content was determined through overnight Soxhlet extraction with petroleum ether with the setup in Figure 4-4. The petroleum ether was heated to 100°C to ensure sufficient solvent flow rate. Standard cellulose extraction thimbles (603 Cellulose Extraktionshülsen, Schleicher & Schuell Microscience GmbH; Whatman group, Dassel, Germany) were used to prevent solid particles from entering the oil sample. After extraction the obtained oil sample was oven dried at (103 ± 2) °C for 5 hours to remove remaining solvent. The oil content, expressed in g/100g, was determined by comparing the weight of the extracted oil to the total weight of the sample prior to extraction.

Figure 4-4 Soxhlet extraction setup at Eindhoven University of Technology

Moisture content

A drying method according to DGF standards was used to determine the moisture content of the seeds before pressing. The drying method is similar to the one used before soxhlet extraction. Samples of approximately 5 grams were weighed and put in the oven (Heraeus BR 6000, Hanau, Germany) for 5 hours. After drying the weight was again determined.

Oil analysis

Analyses of some oil samples on phosphorous content and acid value was out contracted to consulting engineers (Ingenia, Eindhoven, The Netherlands). Analysis of the samples was done by ASG Analytik-Service Gesellschaft mbH (Neusäss, Germany) according to DIN methods. The samples consisted of crude Jatropha oil that had been subjected to different cleaning methods.

4.1.5 Accuracy and reproducibility of experimental results

Results obtained at Eindhoven University of Technology are more accurate than the ones from Tanzania, due to superior equipment. Press experiments were only conducted once due to time constraints. Repetition of measurements would have increased reliability and accuracy. Soxhlet extraction can be repeated at 1% accuracy according to DGF standards. More information on accuracy is written in paragraph 5.1.

4.2 Experiments at Diligent Tanzania LTD

As official descriptions of some tools were not available pictures and additional information have been included in Appendix E.

4.2.1 Materials

Seeds from Jatropha Curcas L were obtained from Diligent Tanzania (Arusha, Tanzania). All the seeds used for this research originated from the same village Engaruka located 180km North West of Arusha in order to create homogeneous samples. The oil content of the seeds, determined by soxhlet extraction with petroleum ether and hexane, were found to be 38 wt.% and 39 wt.% successively (dry basis). The moisture content of stored seeds during the testing period was determined to be 6.7 wt.%.

4.2.2 Experimental setup

Oil expelling tests were performed using a Sayari expeller (Vyahumu Trust, Morogoro, Tanzania). Although the original design of this strainer press, known under the name Sundhara, originates from India it was adapted to Tanzanian standards by engineers from GTZ in the early 90's. The Sayari press, depicted in Figure 4-5, is now a locally produced screw press that was initially designed to process sunflower seeds although suitability to press Jatropha is mentioned in the 'Operator's instruction manual'. Production is subcontracted to three workshops located close to the Vyahumu office, one of which is Intermech (More information on the workshop and Sayari expeller, including pictures showing the assembly of the Vyahumu press is shown in Appendix F). The capacity of the Sayari for sunflower is around 140kg/hr (Peter Chisawillo, Director Intermech) and the minimum processing capacity is 70kg/hr (Operator's instruction manual). According to Vyahumu and Intermech (Lehada C.Shila, 2007;Peter Chisawillo, 2007) the capacity for Jatropha should be about 70-80 kg/hr. Tests at Diligent Tanzania LTD showed similar results. The press is powered by a 5.5 kW asynchronous generator (MA 132 SA 4, Marelli Motori, Italy) rotating at 1500 RPM. A simple transmission made of sprockets and chains reduces the rotational speed of the press worm to 55 RPM. The four cones mounted on the screw (see Figure 4-5 right side) enable pressure to build up by gradually reducing the clearance between screw and press cage. Pressures inside the press can reach values up to 150 bars at temperatures of around 110°C. High pressure and friction inside the press cause significant heating of the press during operation.

Figure 4-5. Left: Sayari press at Diligent Tanzania premises, with (1) feeder, (2) oil outlet, (3) press cake outlet. Right: Worm inside Sayari screw press showing 3 cones with diameters 90, 94 and 98mm (4) from right to left. The fourth cone, located at the press cake outlet, is adjustable by a hand operated turning wheel on the far left.

4.2.3 Experimental procedure

The description of a typical experiment is used to explain the experimental procedure. Before starting the measurement the press required preheating to 60-70°C during approximately 20 minutes of normal operation using seeds, press cake or a mixture of the two. After preheating seeds or press cake were inserted in the feeder (1) on the right side of the press shown in Figure 4-5. The normal seed batch size for measurement was 10-20kg because it takes some time for the process to stabilize. Crude oil was collected at the oil outlet (2) and press cake exits the machine at the adjustable cone (3). A thermocouple (type J Thermal Insulated thermocouple, Themocoax, Netherlands) located at the third cone (see Figure 4-5 (4)) measured temperature changes. The radial pressure was measured at the same cone (6152AAA Mold Cavity Pressure Sensor, Kistler Instruments AG, Switzerland). A charge amplifier (5073 Industrial Charge Amplifier Manufacturing, Kistler Instruments AG, Switzerland) transformed the sensor signal to a signal in the range of 0-10V. All data was digitally recorded using a PCMCIA card (NI4350, National Instruments, United States) and 'Virtual Bench Logger'. In addition the time required for a batch to pass through the press was measured. It was difficult to determine the instant at which the pressing finished, therefore the time measurement was started when the pressure showed a steep increase after seeds were fed and stopped once pressure drastically declined while the press was almost empty in order to generate comparable results.

After pressing a sample of the press cake was analyzed on oil content with Soxhlet extraction according to DGF standards (DGF-Einheitsmethoden, 2002). After leaving the oil to settle for a week relative amount of foots in the crude oil could be determined. The remaining press cake was fed back into the press and the whole process repeated for a second time.

Jatropha seeds with increased moisture content were obtained by equilibrating the seeds for one week in a sealed environment with a fixed amount of water inside a plastic container. Other studies on mechanical expression of oil seeds (Vadke and Sosuslski, 1988; Zheng, Wiesenborn et al 2004) reported to have used similar methods. Moisture content was reduced below the natural 6.7% by sun drying. As this method depends heavily on weather conditions the drying time was not constant. Resulting moisture contents were determined by oven drying.

4.2.4 Analysis

Oil content

Oil content was again determined through soxhlet extraction with hexane. The oil content, expressed in g/100g, was determined by comparing the weight of the extracted oil to the total weight of the sample prior to extraction. The method differed from DGF standards as some of the required equipment was not available in Arusha. The setup differed from DGF standard on the following aspects:

- A mortar and pestle were used to grind samples prior to extraction instead of the ball mill.
- Samples were wrapped in normal filter paper (Whatman qualitative filter paper 125mm, Cat No. 1001125) instead of extraction thimbles.
- Hexane was used as solvent instead of petroleum ether. However comparative tests for Jatropha with petroleum ether showed comparable results with hexane the values were 38% and 39% respectively.
- The electrical balance (440-33N, Gottl. Kern & Sohn GmbH, Balingen-Frommern, Germany) did not meet accuracy requirements; 0.01g instead of 0.001g.
- Samples of ± 10 grams were used instead of the prescribed ± 5 grams in order to reduce the effect of measurement errors.
- The samples were not dried before extraction. A correction was applied afterwards based on drying of representative samples.

These deviations from the standard method lessen the accuracy of the results. Due to the less accurate soxhlet setup in Tanzania samples were transported to the Netherlands for accurate extraction.

Moisture content

A drying method according to DGF standards was used to determine the moisture content of the seeds before pressing. Samples of approximately 5 grams were weighed and put in the oven (Nevica, designed for domestic use, see Appendix E for picture and drying profile) for 3 hours. Due to the simple oven design a drying profile had to be determined in order to keep the temperature in the acceptable range of 80-100°C.

Foots

The relative amount of foots in the crude oil were determined after one week of settling in plastic bottles (see Figure 4-6). Oil and foots levels were marked and refilling with known quantities of water resulted in an approximation of the actual volumes. A 1000ml graduated measuring cylinder with 5ml accuracy was used for the water refilling.

Figure 4-6 Oil samples left for settlement

4.2.5 Accuracy and reproducibility of experimental results

Repetition of each pressing experiment would allow proper judgment of accuracy. Due to limitations in both means and time repetition was seldom possible for the press tests executed in Tanzania. Results on oil yield, temperature are therefore meant to identify trends and are assumed to deviate up to ±2 and ±5%. For example oil content found to be 37% means that the actual value lies between 35-39%. Less accurate mounting of the pressure sensor in the Sayari expeller compared to the BT50 caused pressure values to deviate ±20% instead of 10% as will become clear from the results section 5.1. In addition to the less accurate mounting of the pressure sensor its position relative to the third cone changes up to 1cm when changing restriction size. To what extent this affects pressure measurements could not be determined. The accuracy for measuring oil and foots levels was estimated at ±50ml, due to inaccurate reading of the marked bottles. This comes down to deviation in the range of 5-15% depending on sample size.

5 Results and discussion

The objective of this chapter is to show the effect of various seed pre-treatments and press settings on the oil yield of mechanical expression of Jatropha seeds. Increased oil yield can be achieved either by increasing the amount of crude oil or by reducing the relative amount of foots in the oil. The variables included in this research are listed below in Table 5-1. An overview and explanation of the exact values for speed, moisture content etc is given in Appendix G.

Table 5-1 Overview of the tested variables for the two different presses

	BT50	Sayari
Press settings		
RPM	X	
Restriction	X	X
Seed pretreatments		
Moisture content	X	X
Dehulling	X	X
Torrefaction	X	
Heating in water	X	X
Crushing	X	X

The effect of a pre-treatment on the pressing process is best explained by the behaviour of pressure and temperature inside the press (Eggers, Broeck, and Stein, 2006, 494-499;Vadke and Sosulski, 1988, 1169-1176;Willems, 2007). The following paragraphs provide an overview of the most relevant test results and an explanation of what causes the observed differences. Finally the experimental results are used to optimize the pressing process.

The test settings for the two different press types that were used are as follows. For the BT 50 all tests with respect to seed pre-treatment were conducted at standard conditions which are 49 RPM, 100% hull and a restriction diameter 9mm. The standard settings for the Sayari expeller were 55 RPM, 100% hull and a restriction gap size of 1.8mm. These settings were selected as standard setting because they ensured smooth running of the presses. The restriction sizes of the two presses schematically indicated in Figure 5-1 refer to different geometries and can therefore not directly be compared.

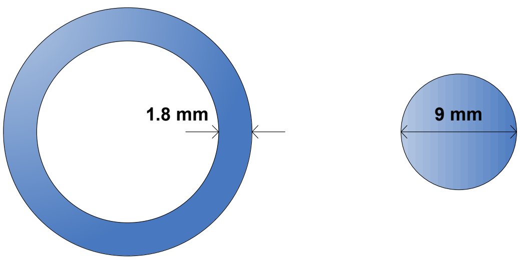

Figure 5-1 Schematic representation of the restriction shape of the Sayari expeller (left) and the BT50 (right). The white circle on the left side represents the adjustable cone of the Sayari expeller.

All tests in the BT50 press were single pass, meaning that only seeds were pressed and the press cake was not fed back for a second run. Most tests in the Sayari expeller were dual pass tests. Because of the higher residual oil content of the press cake from the Sayari expeller a second press run was worthwhile. Single pass and dual pass are indicated in the figures with Sayari results.

5.1 Data processing

This paragraph briefly explains the coming about of the graphical representations in the following paragraph. The main points concerned here are data selection and error margin determination

Oil recovery

The oil recovery graphs were obtained by comparing the residual oil content in the press cake to the initial oil content in the seeds using the following formula (see Appendix H for derivation):

$$Y = 1 - \left[\frac{\left(\frac{Ws}{1-Ws} \right)}{\left(\frac{Wo}{1-Wo} \right)} \right]$$

with Y= oil yield or oil recovery (%oil/oil)
Wo= Oil content in original seed (g/100g)
Ws= Oil content in press cake sample (g/100g)

The oil recovery is expressed as the recovered fraction of the initial amount of oil. So knowing that the Jatropha seed contains 37wt.% oil and assuming an imaginary recovery rate is 80% this means that from 100kg seeds 29.6kg of oil are recovered. Taking into account the density of 0.92kg/l (Akintayo, 2004, 307-310;Pramanik, 2003, 239-248;Ruud van Eck, 2006) this means 32.2 litre.

The error bars indicate a ± 2% fixed error, which means that a value of for example 37% is between 35-39%. The accuracy of the soxhlet extraction is stated as 1% (DGF-Einheitsmethoden, 2002). The other 1% is attributed to variations in the oil content in the press cake when it leaves the machine.

Throughput

Throughput was determined by dividing the batch weight by the time required for pressing the batch. Starting time was identified by a sudden increase in pressure. Time recording is slightly inaccurate as it is hard to determine at what moment the last material exits the press. Timing errors are assumed to be within 30 seconds leading to 5% inaccuracy for large batches (BT50 tests with 2kg batches and Sayari tests with 20kg batches) and 10% inaccuracy for small batches (BT50 tests with 1kg batches and Sayari tests with 10kg batches).

Pressure

The graphs indicating pressure dependence were compiled using average pressure values. Only pressure values after a sudden rise, indicating pressure build up inside the press, were included. Due to the rotating screw the pressure occurring in the press head is very turbulent. In spite of the Kistler 6152AAA pressure sensor being 1% accurate a 10% error is used to take the fluctuations into account. Graphs showing the initial measurement output are shown in Appendix I to support this choice.

Temperature

The temperatures as indicated in figures similar to Figure 5-2 b represent the average value at the same axial location as the pressures. Thermocouple calibration in a thermostatic bath showed an accuracy of 2.5% in the temperature range of 90-100°C and less than 1% for lower temperature (see Appendix D). The available recording equipment lead to the selection of thermocouples that were suboptimal for the temperature range and therefore the variation in temperature is assumed to be 5%.

Energy input
The graphs for energy input were computed from averaged power output readings of the Altivar 31 variable speed drive converted into kJ/kg and kJ/l values. As the accuracy was not given by the producer a 5% error was assumed for both graphs. Unfortunately the energy input could not be measured during the experiments carried out on the Sayari expeller in Tanzania. An approximation of the energy requirement for the BT50 made prior to testing is shown in Appendix J.

5.2 Influence of RPM

BT50
The graph in Figure 5-2 a shows a reduction in oil recovery for increased rotational speed. This effect is largely explained by the increasing throughput indicated in the same figure. Increased throughput means reduced residence time and thus less chance for the oil to flow from between the solid material. The higher residual oil content in the material ensures that the viscosity of the paste remains relatively low and therefore pressure build-up is also lower at higher speed as can be seen in Figure 5-2 b. The lower pressure is a second cause for the oil recovery to be lower for higher speeds. A third cause for decrease in oil recovery with increasing screw speed can also be an increase in oil-point pressure as studies by Sukurman & Singh (1981). The rotational speed of the worm inside the screw press could be considered analogue to the rate of deformation under uni-axial compression. Under uni-axial compression the oil-point pressure increases with increasing rate of deformation (Sukumaran and Singh, 1989, 77-84). Only the pressure exerted in excess of the oil-point pressure is assumed to result in oil to be recovered from the compressed seeds. Applying the same assumption to screw pressing would predict lower oil yield at higher screw speed.

Combining throughput and oil recovery reveals that the oil production capacity varies from 4.2l/hr at 28RPM to 8.7l/hr at 70RPM. The increase in temperature for higher speed could be explained by increased friction heating or simply be due to the fact that the tests were executed successively from low to high speed and the press had not yet reached equilibrium temperature. Temperature differences can be considered insignificant for changes in rotational speed.

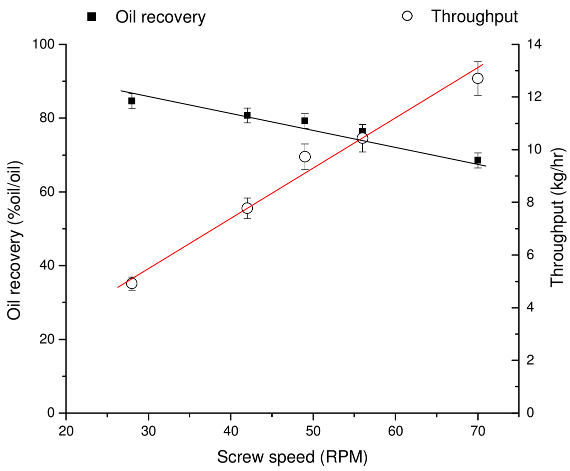

Figure 5-2 a Influence of screw speed on oil recovery and throughput for the BT50

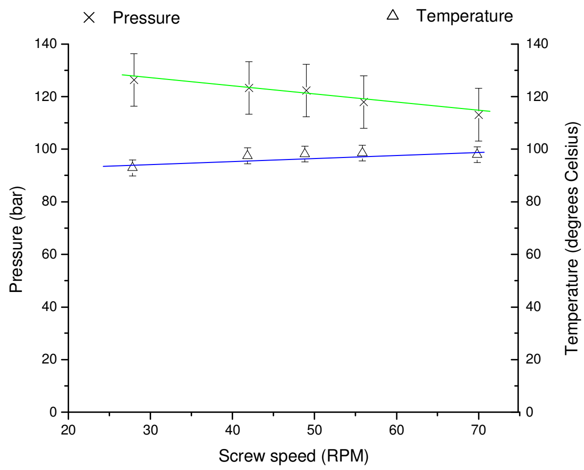

Figure 5-2 b Influence of screw speed on radial pressure and temperature for the BT50

The energy requirement to press the seeds is represented in Figure 5-2 c. Higher rotational speed requires more power and at the same time reduces processing time. The negative slope of the upper line indicating energy input per litre in Figure 5-2 c shows that the energy requirement is most strongly affected by the reduction in processing time.

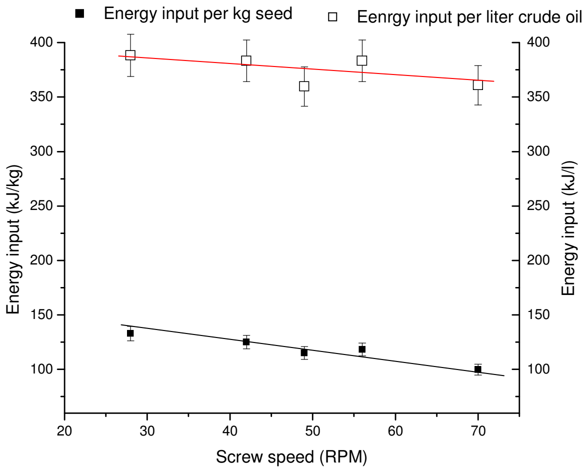

Figure 5-2 c Influence of screw speed on energy requirement for the BT50 expressed per kg and per litre crude oil

5.3 Influence of restriction size

BT50

Figure 5-3 a and Figure 5-3 b show the influence of the choke opening on pressure and residual oil content for the BT50 press. Decreasing the choke opening increases the resistance to flow at the end of the extruder. The pressure required to overcome this resistance significantly increases judging from Figure 5-3 b. It is difficult to draw conclusions on the effect on throughput as only two data points are available. Judging from the figures the higher oil recovery for smaller restriction can directly be attributed to increased pressure and friction.

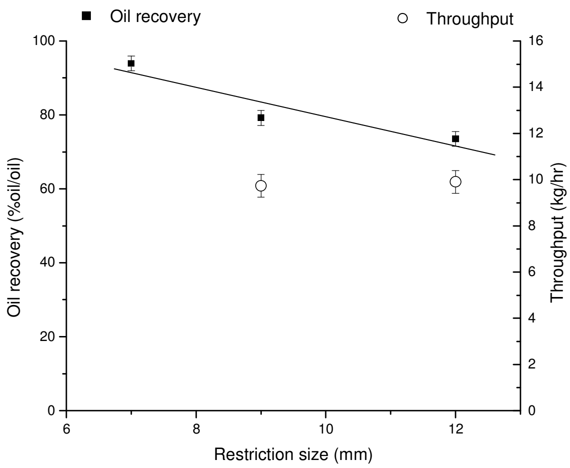

Figure 5-3 a Influence of restriction size on oil recovery and throughput for BT50 press

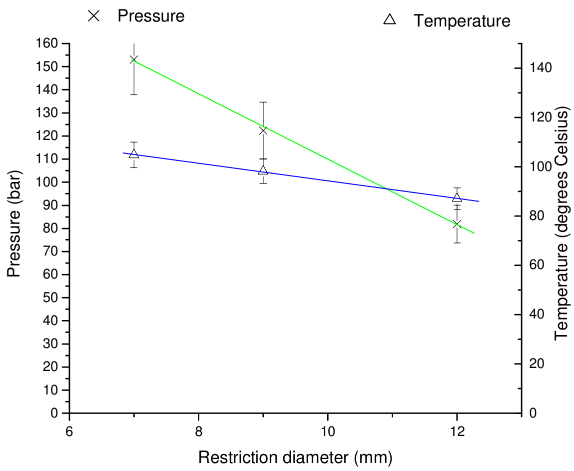

Figure 5-3 b Influence of restriction size on temperature and pressure for BT50 press

Because the throughput for 7mm was not measured it is also not possible to calculate the required energy input. The two data points in Figure 5-3 a incline to a slight decrease of throughput with reduced restriction size due to the balancing effect of increased resistance and better filling of the press chamber. Although limited data is available on the effect of restriction diameter on energy requirement for the BT50 Figure 5-3 c suggests a reversed dependence between restriction size and energy input.

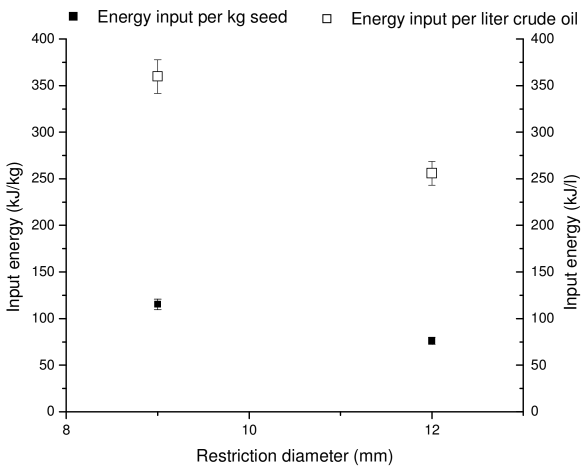

Figure 5-3 c Influence of restriction size on energy requirement for the BT50 expressed per kg and per litre crude oil

Sayari
As can be seen in Figure 5-4 a reducing restriction size clearly results in an increase in the amount of oil recovered from the seeds. The effect of restriction size was only observed for a single pass as this already shows how this variable affects oil yield. For a second pass the shape of the oil recovery graph is expected to be similar in shape although less steep. The expected reduction in steepness is due to being closer to the theoretic maximum oil recovery at smaller restriction sizes after the first pass. Obviously when decreasing the restriction size the mixture inside the press experiences more resistance when exiting the press cake outlet.

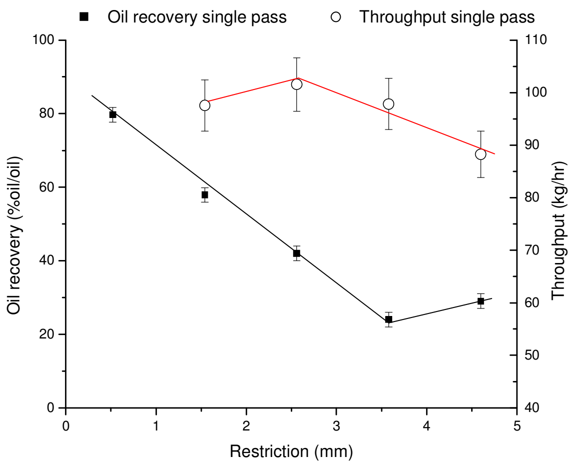

Figure 5-4 a Influence of restriction size on oil recovery and throughput for Sayari press

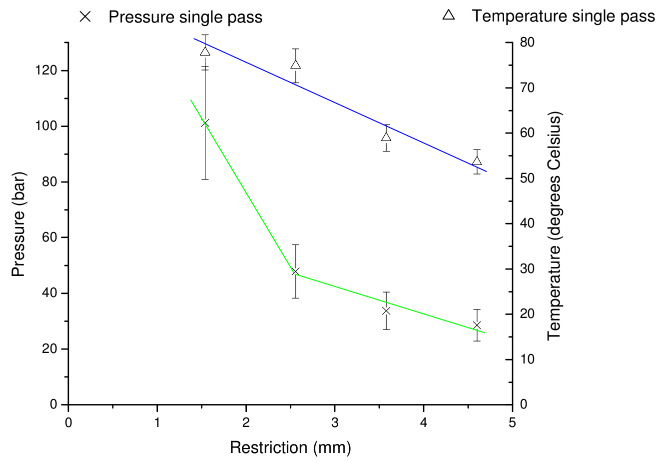

Figure 5-4 b Influence of restriction size on temperature and pressure for Sayari press

The supply of input material is assumed to stay more or less constant resulting in increased compression close to the press cake outlet as is indicated by the pressure development in Figure 5-4 b. The increase in throughput with decreasing restriction size can appear conflicting at first sight. It might be contributed to better filling of the voids inside the worm channel at higher pressure therefore enhancing the press's performance. The increase in temperature with decreasing restriction size is easily explained by increased resistance and pressure. Although oil recovery is highest at smaller restriction size there is an operational limit. The tightest setting of 0.6mm exceeded the operational limit of the Sayari press resulting in severe jamming. For this reason corresponding values for throughput, temperature and pressure are not indicated in Figure 5-4 a and Figure 5-4 b.

5.4 Influence of moisture content

BT50

The results of press tests for varying moisture content using the BT50 press are shown in Figure 5-5 a to Figure 5-5 c. Figure 5-5 a shows that with increasing moisture content the throughput decreases, although the decrease is less than with increasing screw speed. The effect of moisture content on oil recovery is on the other hand considerable. Only part of the decrease in oil recovery with increased moisture content can be attributed to the increase in throughput. When comparing Figure 5-5 a to Figure 5-2 a it is apparent that with increasing moisture content the increase in throughput is smaller and the decrease in oil recovery is bigger, which directly points out that changes in throughput caused by varying moisture content are an insufficient explanation for the occurring changes in oil recovery. The strong decrease in pressure visible in Figure 5-5 a hints another cause for the reduction in oil recovery. Higher moisture content might cause increased deformability and reduced rupture fore as suggested by Singh & Bargale (2000). In addition emulsification or plasticizing effects occurring in the pressed material at higher moisture levels reduce the viscosity and thereby decrease pressure build-up. This pressure drop seems an appropriate explanation for the rapid decline in oil recovery in Figure 5-5 a. The suggestion by Willems (Willems, 2007) that during expression water can only be removed by evaporation brings up another contribution to the cooling effect. The amount of water present in the seeds however seems insufficient to induce the temperature drop by more then 50%. A more plausible explanation is a cooling effect of the input material. Lower friction and pressure build-up due to the reduced viscosity reduce heat generation at higher moisture content. The cooling effect of the cold material entering the press might in this case counterbalance heat generation or even lead to faster cooling than is the case after normal experiments. Although oil recovery is optimal for a moisture content of 2.14% this might not be the optimal processing conditions as the oil temperature reaches high values that could lead to changes in the composition of the oil as is the case for rapeseed (Singh and Bargale, 2000, 75-82;Zheng and others, 2005, 193-202).

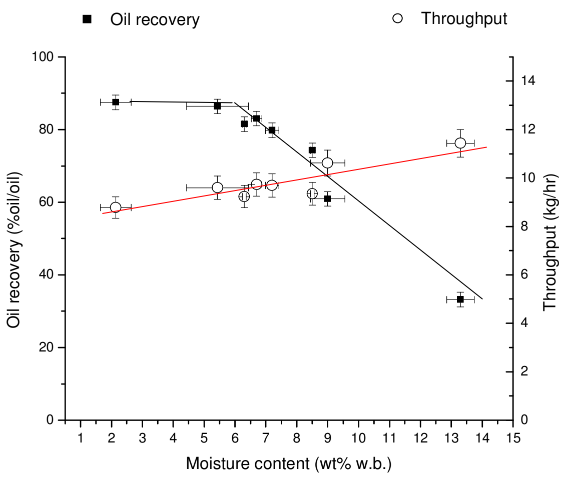

Figure 5-5 a Influence of moisture content on oil recovery and throughput for the BT50 press

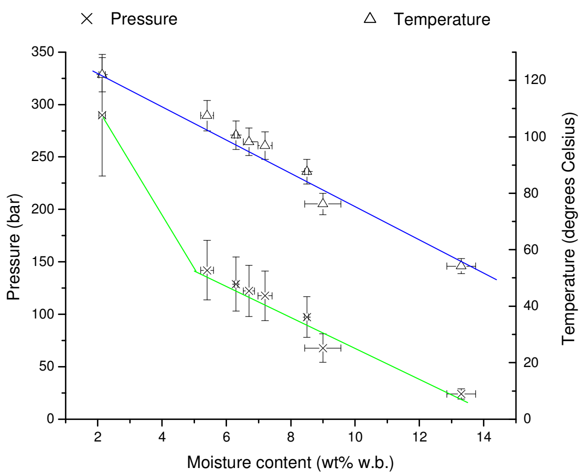

Figure 5-5 b Influence of moisture content on temperature and pressure for the BT50 press

Judging from Figure 5-5 c the energy requirement per kilogram of input material reduces for increasing moisture content. However at higher moisture content more seeds are required judging from Figure 5-5 a. More seeds per litre mean longer processing time per litre. This results in the decreased slope of the upper line in Figure 5-5 c at higher moisture levels. From a cost perspective it is not desirable to decrease the energy use by increasing the moisture level in the seeds as the costs of three times as much input material per litre are much higher than the savings of using three times less energy. This example directly shows that energy requirement is not expected to be a limiting factor.

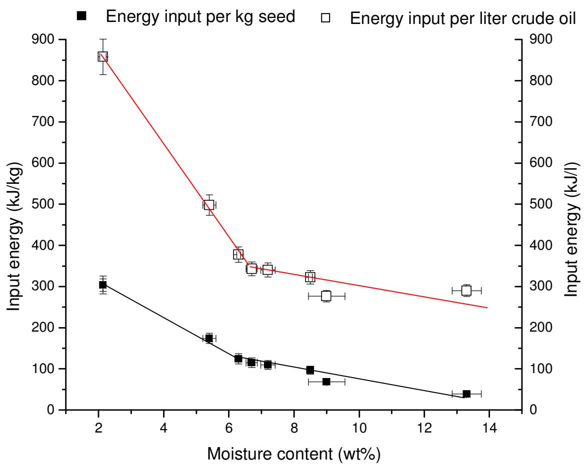

Figure 5-5 c Influence of moisture content on energy requirement for the BT50 expressed per kg and per litre crude oil

Sayari

The effect of moisture content was tested for dual passing in the Sayari expeller. Due to the design of the Sayari expeller it is much more difficult to execute steady test runs. In addition conditioning of the seed moisture level was less accurate due to less sophisticated instruments. The uneven distribution of data points in Figure 5-6 a is the result of this unsteady operation and imprecise conditioning. Oil recovery after dual passing shows a slight decrease for increasing moisture content. The effect of moisture is less than for the BT50. An explanation could lie in the multiple stage compression in the Sayari expeller. Although data on throughput seem inaccurate the increase in throughput with moisture level is plausible when compared tot the BT50 results in Figure 5-5 a. Temperatures and pressures are also less aligned compared to the previous figures. Test results from the Sayari expeller in Figure 5-6 b show a drastic decrease in pressure with moisture content, as was the case for the BT50, and to a lesser extend temperature. Judging from Figure 5-5 b and Figure 5-6 b for moisture levels between 6 and 9% the temperatures in the Sayari press are about 15% lower than for the BT50. The slopes of both temperature lines are comparable. In the same moisture range the pressure measured in the BT50 is approximately two times the value measured in the Sayari expeller. This shows that changes in pressure are an indicator for changes in temperature, but the absolute temperature value is largely determined by the combined effect of pressure, friction, material and design of cage and screw.

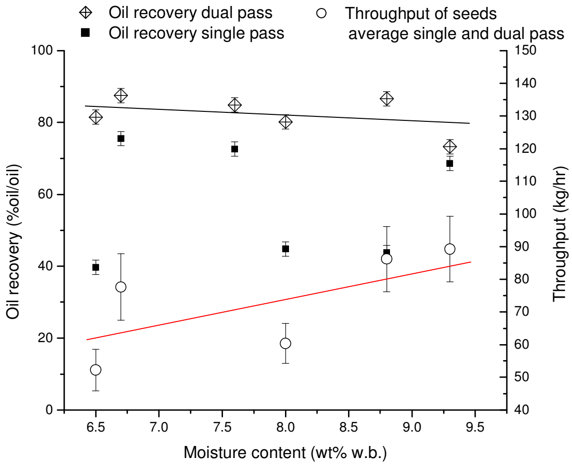

Figure 5-6 a Influence of moisture content on oil recovery and throughput for the Sayari press

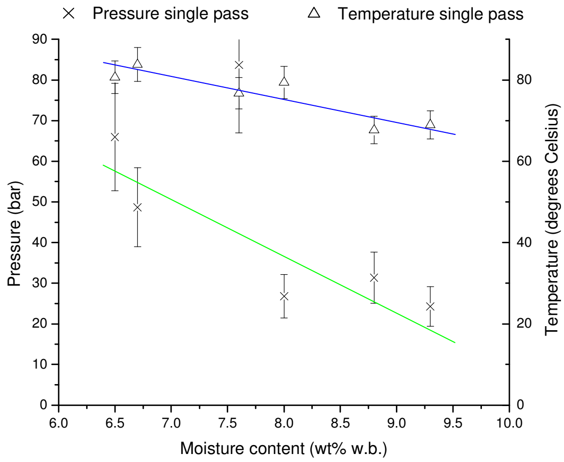

Figure 5-6 b Influence of moisture content on temperature and pressure for the Sayari press (single pass)

When comparing Figure 5-6 b and Figure 5-6 c one can see the difference between pressing seeds (single pass) and pressing press cake (dual pass). What stands out is that the temperature at dual pass is higher while the pressure is lower. The higher temperature is the result of repressing the press cake while it is still hot (about 60-80°C). Due to this unintended preheating of the press cake comparison between pressing seeds and press cake is difficult.

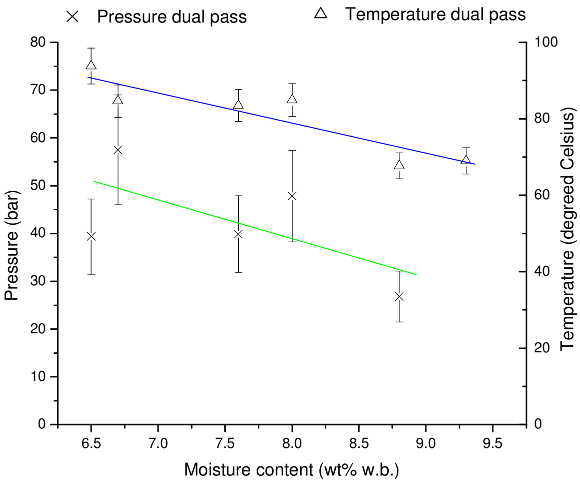

Figure 5-6 c Influence of moisture content on temperature and pressure for Sayari press (dual pass)

5.5 Influence of hull fraction

BT50

As the oil-point pressure is lower for softer oilseeds the same will probably hold for de-hulled seeds compared to normal seeds as the bulk material becomes softer (Faborode and Favier, 1996, 335-345). Based on this assumption a higher oil recovery is expected although Figure 5-7 a clearly shows the opposite. What happens when de-hulling the seeds is that the material inside the press becomes fattier and due to a difference in shape friction between the mixture and the barrel drops below the friction between the mixture and the worm. When the hull content is reduced to 66% of its original value causes slip in the feed section and the solid-oil mixture starts to stick to the worm. The result is a sharp decrease in throughput (Figure 5-7 a) which can even drop to zero. The same problem was also brought forward by Ward (1976) when dealing with high oil content seeds. Khan & Hanna (1983) suggest the use of a low friction shaft combined with higher friction cage bars for softer seeds like de-hulled Jatropha. Decrease in pressure and temperature are as before due to reduced friction (Figure 5-7 b).

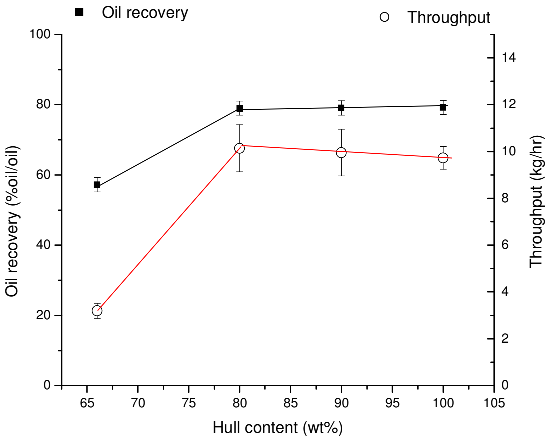

Figure 5-7 a Influence of hull content on oil recovery and throughput for BT50 press

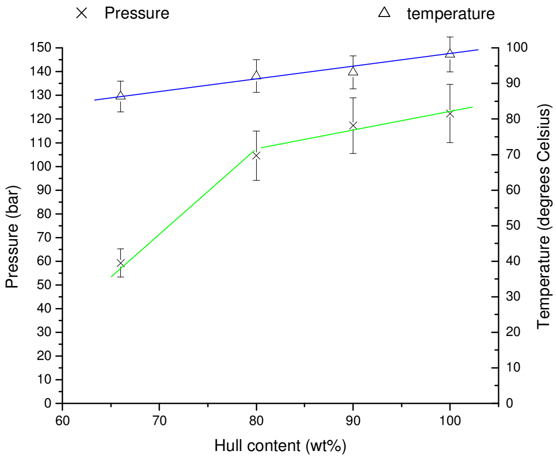

Figure 5-7 b Influence of hull content on temperature and pressure for the BT50 press

The required energy input decreases for lower hull content as indicated by Figure 5-7 c. The data points for 66% hull content are too high due to slip and rotation movement of the solid-oil mixture instead of horizontal conveyance. Throughput reduced to zero during the experiment thereby causing the deviant result. Difficulties experienced during testing demonstrate that in standard screw presses a reduction of the hull fraction is applicable up to 80% of the original hull fraction. The combined effect of a decrease in power consumption (expressed in Watt) and an increase in throughput at comparable oil yield is increased energy efficiency of the process (less kJ/litre) when hull fraction is reduced to 80%. Below a certain threshold value between 66-80% hull the press performance is sharply reduced due to deteriorating mixture conveyance.

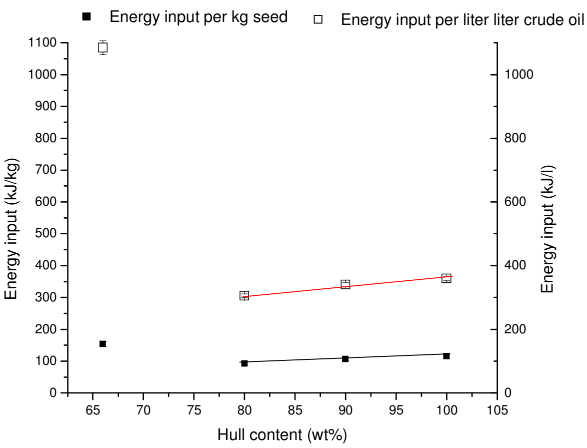

Figure 5-7 c Influence of hull content on energy requirement for the BT50 expressed per kg and per litre crude oil

Sayari

The test results on hull content for the Sayari expeller were only limited. Nevertheless the results in Figure 5-8 a and Figure 5-8 b indicate a dependence on hull fraction comparable to the BT50 press. Only dual pass values are given as they tend to show less variance than single pass values as was also observed in Figure 5-6 a.

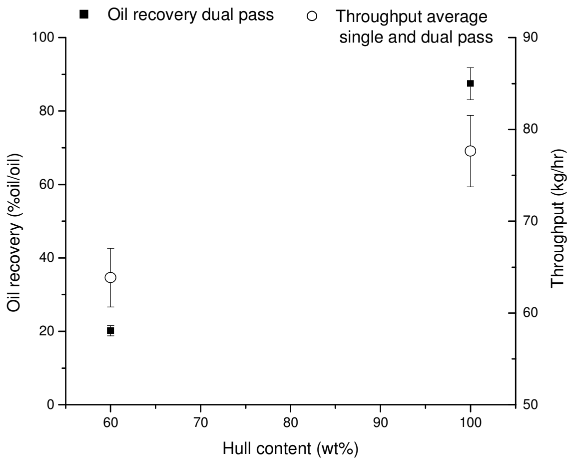

Figure 5-8 a Influence of hull content on oil recovery and throughput for Sayari press

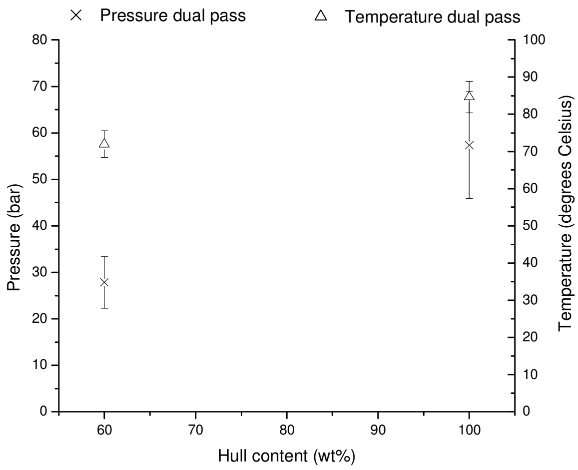

Figure 5-8 b Influence of hull content on temperature and pressure for the Sayari press

5.6 Influence of seed preheating

BT50

Heating of the input material can be applied to increase compressibility of the seed material and thus lower the oil-point pressure (Faborode and Favier, 1996, 335-345). The effect of preheating of the seeds before pressing was tested by preheating standard seeds (6.7% moisture) during 30 minutes at various temperatures. Moisture content of the seeds was not determined before pressing. The inner structure of the Jatropha seeds was not visibly affected after heating. The influences on oil content and temperatures inside the press are depicted in Figure 5-9 a and Figure 5-9 b. The effect on oil recovery and throughput is negligible. Increase in temperature can be explained through a combination of the heated input material and minor increase in friction as the material is dryer for higher preheating temperatures.

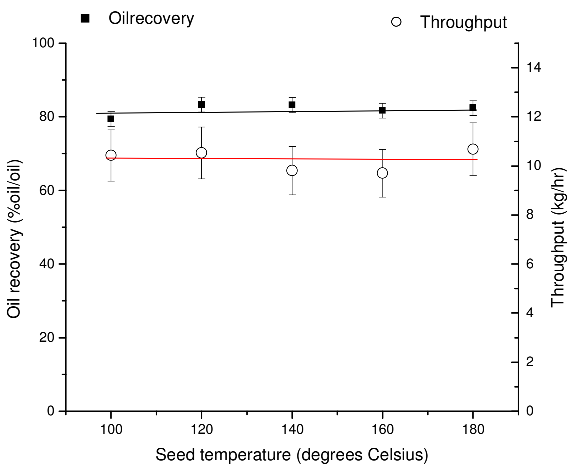

Figure 5-9 a Influence of seed input temperature on oil recovery and throughput for the BT50 press

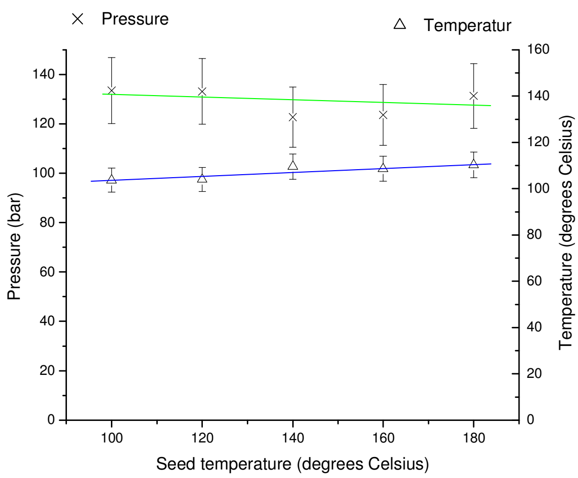

Figure 5-9 b Influence of seed input temperature on temperature and pressure for the BT50 press

The assumption of minor friction increase is supported by Figure 5-9 c, which shows a small increase in the amount of energy required for pressing seed that were pre-heated at higher temperatures while processing time is constant. This indicates that the engine encounters slightly more resistance. The upper line in Figure 5-9 c indicates a small decrease in energy use per litre oil at a preheating temperature of 140°C. The reduction in energy use would not balance the energy needed for preheating and is thus not advisable for Jatropha seeds. Furthermore the variation is within the error margin and therefore uncertain.

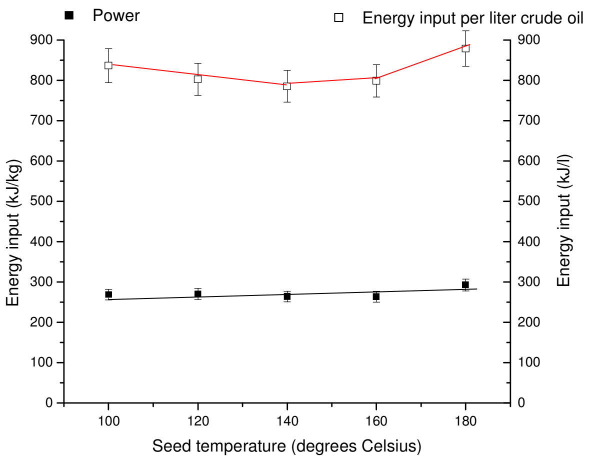

Figure 5-9 c Influence of seed input temperature on energy requirement for the BT50 press expressed per kg and per litre crude oil

5.7 Influence of other pre-treatments

In addition to the previously mentioned variables some other test were conducted although in less detail. The results are presented in Table 5-2. Cracking was expected to decrease energy use and reduce the oil-point pressure (Faborode and Favier, 1996, 335-345). The results show that the assumptions do not hold for Jatropha as the energy reduction is negligible and the oil recovery is lower at pressures comparable to the standard situation. The BT50 data in Table 5-2 suggest that the oil-point pressure is lower for the cooked samples as their oil recovery is highest while pressure are significantly lower than those for dry seeds. The cooking pre-treatment also shows a positive effect in the Sayari expeller.

Table 5-2 General test results for additional experiments on seed pre-treatment. * Samples were dried to certain moisture content before pressing. Oil recovery values for Sayari expeller are after dual pass. The temperatures indicated for the Sayari expeller are the highest temperatures that occurred, which was during dual pass. Boiling showed a very high oil recovery after single pass in the Sayari press of 88.7%.

	Residual oil	Oil recove	Press head t	Oil tempera	Pressure [bar]	Throughput [kg/hr]	Energy [kJ/l]
BT50							
normal	11.0%	79.2%	98	85	122	9.7	142
crushed	11.9%	77.2%	92	82	120	9.8	139
water 70°C	6.1%	89.0%	120	100	220	9.2	312
water 80°C	6.3%	88.7%	141	115	198	9.4	279
Sayari							
normal	6.9%	87.5%	84	-	39	54	-
crushed	7.4%	86.4%	84	-	36	63	-
water 80°C	5.0%	91.2%	103	-	86	69	-

5.8 The effects on foots

A striking characteristic of the crude Jatropha oil obtained by screw pressing is the very high amount of foots or sediments in the oil. After one week settling time approximately 30 to 50% of the volume consists of sedimentary deposits. For normal filtering techniques only 5-10% sediment is acceptable (Ferchau, 2000), which is also the amount of sediments present in most other plant oils after mechanical extraction. It was not possible to determine if and how pre-treatments affect the amount of sediments. The table in Appendix K shows more detailed values of the amount of foot for various samples.

5.9 Oil quality parameters

Oil quality was judged base don the five parameters shown in Table 5-3. Three very diverse samples of filtered oil were analyzed by ASG (Analytik-Service Gesellschaft mbH, Neusäss, Germany). These samples cover both the widest range in oil temperature and moisture content, which are assumed to be the parameters that affect oil quality most strongly. None of the samples comply with the PPO norm for rapeseed in Appendix B. For 6.7% moisture acid value and phosphorous content are too high. The other values are in range. At decreased moisture level of 2.14% phosphorous content reduces close to 15 as required by the standard at the cost of acid value. At 13.3% moisture acid value and water content are unacceptable and other values are within limits. The data in Table 5-3 does not provide proper trends as most parameters decrease between 2.14-6.7% and then decrease form 6.7%-13.3% or vice versa. Acid value tends to increase with moisture content. Some possible explanations are given here. The strong decrease in phosphorous content at 13.3% is probably due to lower temperature. Oxidation stability is increased by increased water content. The higher carbon residue for 13.3% moisture might be related to the darker colour of the oil due to dissolved pigments.

Table 5-3 Oil quality analysis performed by ASG

Parameter	Unit	Method	Rapeseed standard	2.14% moisture	6.7% moisture	13.3% moisture
Acid value	[mg KOH/g]	DIN EN 14104	2.0	**3.5**	**3.1**	**25.8**
Phosphorous content	[mg/kg]	DIN EN 14107	15	**16.2**	**23.2**	**2.4**
Water content	[mg/kg]	DIN EN ISO 12937	750	**741**	**733**	**1622**
Oxidation stability 110°C	[h]	DIN EN 14112	5.0	**12.6**	**10.4**	**21.3**
Carbon residue	[%]	DIN EN ISO 10370	0.4	**0.2**	**0.2**	**0.4**
Processing oil temperature	[℃]			97	85	52

5.10 Comparison of suitability for Jatropha processing between BT50 and Sayari

Based on the results presented in this chapter higher oil recovery is achieved in the Sayari expeller. At high residual oil content of around 12-15% repressing of the press cake is possible, resulting in high oil recovery. The BT50 reaches higher oil recovery after a single pass. However due to the lower residual oil content and the different press geometry dual pass is not possible for Jatropha in the BT50. For research purposes the BT50 is preferable because of its small capacity. Batches of around two kg are sufficient for stable operation and relatively easy to condition. Severe jamming problems were however experienced when operating at restriction sizes below 9mm and moisture levels below the natural 6.7%. At 2.14% moisture level, the point at which oil recovery was highest, continuous processing is not possible in the BT50 due to overheating and jamming. The Sayari expeller is less suited for experimental use but operates much better for full time large capacity production. When properly operated jamming of the press can be avoided whereas this is not possible in most cylinder-hole presses like the BT50.

5.10.1 Test conducted by industrial press manufacturers

To gain additional knowledge on the pressing process the two German press manufacturers Keller (KEK EGON Keller GMBH & Co, Remscheid, Germany) and Reinartz (Maschinenfabrik Reinartz GmbH & Co. KG , Neuss, Germany) were contacted for press tests with Jatropha seeds. Testing results are shown in Table 5-4. More details on the presses used for testing are given in Appendix L together with a table showing industrial oil recovery rates for oilseeds. Rienartz additionally reported seed input temperature of 20°C and oil temperature between 30 and 60 °C increasing from feed section towards the cake discharge. Oil recovery of these machines is higher than for the BT50 and similar to the Sayari press. The advantage of the Keller and Reinartz presses compared to the Sayari expeller is that they require only single pass of the material to reach a high oil recovery.

Table 5-4 Results from tests at KEK Keller and Reinartz conducted in 2007. * [% oil/oil] means the percentage of the oil present in the seeds that has been obtained by pressing

KEK Keller p0101	date	sample description	moisture	oil contentpress cake	oil yield [oil/oil]*
1	4/6/2007	standard settings start sample	6.7%	14.3%	72%
2	4/6/2007	standard settings end sample	6.7%	11.0%	79%
3	6/7/2007	changed pressure cones	6.7%	6.0%	89%
Reinartz AP08					
	3/7/2007	standard settings	6.7%	5-6.5%	88.3-91.1%

5.11 Conclusions

The most important findings based on the practical research conducted for this study is presented here. Seed moisture content shows the strongest effect on oil recovery from Jatropha. The natural moisture content of the seeds (6.7 wt.% w.b.) appears to be close to optimal. Depending on the desired oil recovery pre-treatments might therefore not be necessary. Restriction size and rotational speed of the screw are two other influential parameters. Restriction size should be reduced as far as possible taking into consideration both operational limits of the press and the effect of temperature on oil quality. Lower rotational speeds lead to higher oil recovery, which is mainly attributed to higher residence time. Speed can only be reduced to a limited extent as below 20 RPM operation is not possible. The choice of rotational speed varies with the demands of the user. For high production capacity rotational speed should be high and for high oil recovery per kg input material it should be low. Decrease in hull content below a threshold value between 66-80% has a strong, although negative, effect on oil recovery. The influence of seed pre-heating and flaking/crushing proved to be insignificant for Jatropha seeds. A pre-treatment of one hour cooking followed by seed drying results in the highest oil recovery for both presses. Single pass pressing of cooked and dried seeds resulted in the highest measured oil recovery of 89% for both BT50 and Sayari press. After dual pass oil recovery for the Sayari increased to 91%, being close to the theoretic maximum of 95%. For comparison normal seeds yields were 79% for the BT50 (single pass) and 88% for the Sayari (dual pass). Single pass pressing of cooked seeds in the Sayari expeller thus leads to higher yields than normal seeds after dual pass pressing. This pre-treatment can thus be used to decrease energy consumption and increase processing capacity. The energy requirement is of subordinate importance as for the BT50 the energy input per litre oil varies between 1% and 2.5% of the calorific value of Jatropha oil.

Taking into consideration all the test results optimal oil recovery is expected at a moisture content of 2-4% after cooking at 70°C, 100% hull content and the smallest restriction size and lowest speed possible for a certain press type. Unfortunately the oil yield using this setup could not be determined due to unexpected breakdown of the press in the final testing stages. To summarize an overview of the effects of pressing parameters on the efficiency and conditions inside the press barrel is visible in Table 5-5.

Table 5-5 Overview of the effects of press settings and seed pre-treatment on oil recovery, pressure, temperature, throughput and energy use

		Oil recovery	Pressure	Temperature	Throughput	Energy/liter
Press parameters						
RPM	↓	↑	↑	-	↓	↑
restriction size	↓	↑	↑	↑	-	↑
Seed treatments						
heating	↑	-	↓	↑	-	↓
flaking		↓	-	↓	-	↓
moisture content	↓	↑	↑	↑	↓	↑
hull fraction	↓	↓	↓	↓	↓	↓
boiling		↑	↑	↑	-	↑

6 Possibilities for oil pressing in rural Tanzania

This chapter puts the results on Jatropha expression from previous chapters into a broader context. Some of the experimental results were used to make recommendations on how to set up Jatropha oil production in rural Tanzania.

6.1 Introduction

Occasion

Over the last decades the western approach of setting up development projects in less developed countries has proven extremely ineffective (Douthwaite, 2002). Is Jatropha just another opportunistic outburst trying to find a solution to global poverty problems or is it really possible to fight poverty using Jatropha? Despite all euphoria concerning Jatropha knowledge on how to actually process it into oil as to make it profitable for rural communities is fairly limited.

Goal

To see whether Jatropha has potential to improve the situation in poor tropical countries one should think of how to setup local production. The main goal of this chapter is therefore to find out whether it is preferable to centralize or decentralize Jatropha oil production when decentralized cultivation of Jatropha is assumed? Furthermore calculations are done to determine if Jatropha can be more than just a primary agricultural product in rural areas in less developed countries

Approach

For local communities to financially benefit from Jatropha cultivation probably requires cooperation between investors and small farmers. Centralized and decentralized production of Jatropha oil are compared using the cost benefit analysis (CBA) method. As an extension another CBA was conducted to judge the viability of oil production on village level. However economic viability in itself is not sufficient to establish successful projects thus some local circumstances are taken into consideration before making recommendations.

Data on the costs and benefits of small scale Jatropha oil processing for rural communities was gathered during a visit in Tanzania from January to April 2007. Most of the data was obtained by interviewing, taking questionnaires and the writers interpretation of the situation at hand. Prices of machinery were obtained from the German screw press manufacturers Reinartz and Keller. Prices for transport and labour are estimates based on Tanzanian prices.

Structure

The setup of the rest of this chapter is as follows. Paragraph 6.2 shortly explains CBA theory. Research outcomes are presented and discussed in paragraph 6.3. Subsequently paragraph 6.4 passes judgement on the viability of Jatropha oil production on village level. Conclusions are drawn in paragraph 6.5.

6.2 Cost Benefit Analysis: Theory

The CBA is designed as a tool to help investors to select projects that will contribute most to their objectives while keeping in mind their limited financial resources (Romijn and Biemond, 2005). This method has been developed by the World Bank and the United Nations Industrial Development Organisation (UNIDO) and is often referred to as project appraisal. Although one can distinguish between a financial, economic, social and environmental CBA this report will only focus on the financial aspect as this is relevant for the question at hand and fits well to the available data.

In a CBA the distinction between cost and expenditures, and between income and revenues is not relevant. As a CBA takes the entire life-time of a project as its time horizon total costs will be equal to total expenditures by definition (Romijn and Biemond, 2005). The same holds for benefits and income. This is best explained looking at depreciation. Depreciation is not taken into account in a CBA as it leads to costs without leading to expenditures. Normally a CBA consists of the following three steps:

1. Profitability assessment
2. Liquidity assessment and determination of a financial plan
3. Sensitivity analysis

6.2.1 Profitability assessment

When judging project profitability the way of financing determines the interest rate to be used to judge the investments profitability. For borrowed money the interest rate on loans is applied while for own money the interest rate on savings is used. The core of the CBA analysis is to compare the earnings profile of the project to the going interest rate which represents the costs of financing as discussed above (Romijn and Biemond, 2005). The most frequently used criteria in this comparison are the Net Present Value (NPV) and the Internal Rate of Return (IRR). Both criteria use discounting techniques which take into account the effect of interest that would be received if the money was in the bank. Multiplying non-financial cash flows by the discount factor yields discounted cash flows.

NPV

The NPV is the sum of the discounted non-financial cash flows during the projects lifetime, thus providing the exact sum of money which a project is expected to generate. For an NPV > 0 a project is expected to yield more than the interest rate. Therefore the project is viable in principle although liquidity and risk assessment should be conducted. A NPV =< 0 indicates no commercial reason to embark in the project.

IRR

The IRR is a measure for the extent of profitability of the project compared to the going interest rate and is determined by setting the NPV to zero. For IRR > market interest rate 'i' the project is more profitable than the cost of financing the project. For IRR =< market interest rate 'i' the yield is equal to or less than the cost of financing.

Inflation

Because of Tanzania's significant inflation rate it is convenient to work with so called constant prices. High inflation rates make it difficult to estimate prices of inputs 5 or 10 years from now. Constant prices are the prices in the base year of the CBA. The advantage of using constant prices is that the same prices can be used without taking inflation into account. The effects of inflation and interest are then combined in the discount factor:

$$Discount\ factor = \frac{1}{(1+r)^t}$$

with t = number of years
r = real discount rate

$$r = \frac{(1+i)}{(1+p)} - 1$$

with i (interest rate) = 15.54%[1]
p (rate of inflation) = 6.9%[2]

[1] Source: website of the Bank Of Tanzania: http://www.bot-tz.org/publications/EconomicIndicators/InterestRates.htm, visited 04-06-2007
[2] Source: Website of the Bank Of Tanzania: http://www.bot-tz.org/publications/inflationDevelopments.htm, visited 04-06-2007

6.2.2 Liquidity assessment

In principle the liquidity assessment determines whether a project is able to fulfil payment obligations from its cash inflows during its entire lifetime (Romijn and Biemond, 2005). As liquidity does not add anything to the question asked in this chapter it will not be taken into further consideration.

6.2.3 Sensitivity analysis

As projects are always subjected to uncertainty one should assess the sensitivity of the results of the CBA to changes in specific costs and benefits. This is done by executing a sensitivity analyses in which only one variable at a time can be changed to see how this affects NPV and IRR. By calculating so called switching values (the degree of change in a value that sets NPV to zero) one can determine the risk of a project.

6.3 CBA results: comparison of centralized and decentralized production

This paragraph focuses on the most viable production options for centralized and decentralized production. The CBA was used to compare centralized and decentralized processing of Jatropha seeds into oil and press cake. The difference between central and dispersed positioning of pressing facilities is represented in Figure 6-1. Obviously the distance along which input material has to be transported is considerable reduced in case of decentralized processing. The main variables included in the CBA are investment cost for equipment, seed purchasing price, labour costs, equipment maintenance costs and revenues. Table 6-1 shows the input values used for calculations. As can be seen in the table a comparison is made between three different processing configurations. More details on the different presses is given in Appendix C, F and K. In case of decentralized pressing the values represent expenses for all machines at multiple locations. The cases for centralized pressing incorporate only one location and one machine. Prices are all given in dollars as this is the foreign monetary unit used in Tanzania. In addition to difference in press type and size different oil cleaning methods were compared. The results for different types of presses and filtering methods can be found in Appendix M. The values in Table 6-1 were computed with a combination of data sources, assumptions and calculations. The main assumptions are listed below.

Main assumptions

- From previous chapters the oil recovery is set at 85%. Sediment level is 40 vol% and contains 55 wt.% oil.
- Production capacity is a measure for the oil production. Supply of seeds is not taken into account in this respect.
- Lifetime of German presses is 20 years, while Tanzania Sayari expeller needs to be replaced after 5-10 years. In CBA calculations write-off in 5 years is assumed for the Sayari.
- The selling price for Jatopha oil is 750 TZS/l which is equivalent to $0.59. This price is reasonable taking into account that fuel taxes have not yet been included in the calculation.
- Cost price of an 8 ton capacity truck is $15,000 based on a small Mercedes truck and reducing the price to Tanzanian levels. For increased production capacity the amount of kilometres a truck cover per year remain the same. Instead the number of trucks needed changes with travel distance and production capacity.

Therefore write-off is 10% in all cases. 3, 6 and 12 trucks are assumed for decentralized, centralized and large scale centralized 24h/day production respectively.

- Press cake is sold for $0.05/kg without further processing.
- One operator is required for each press independent of its size.
- Two seed collectors are assumed to be on each truck.

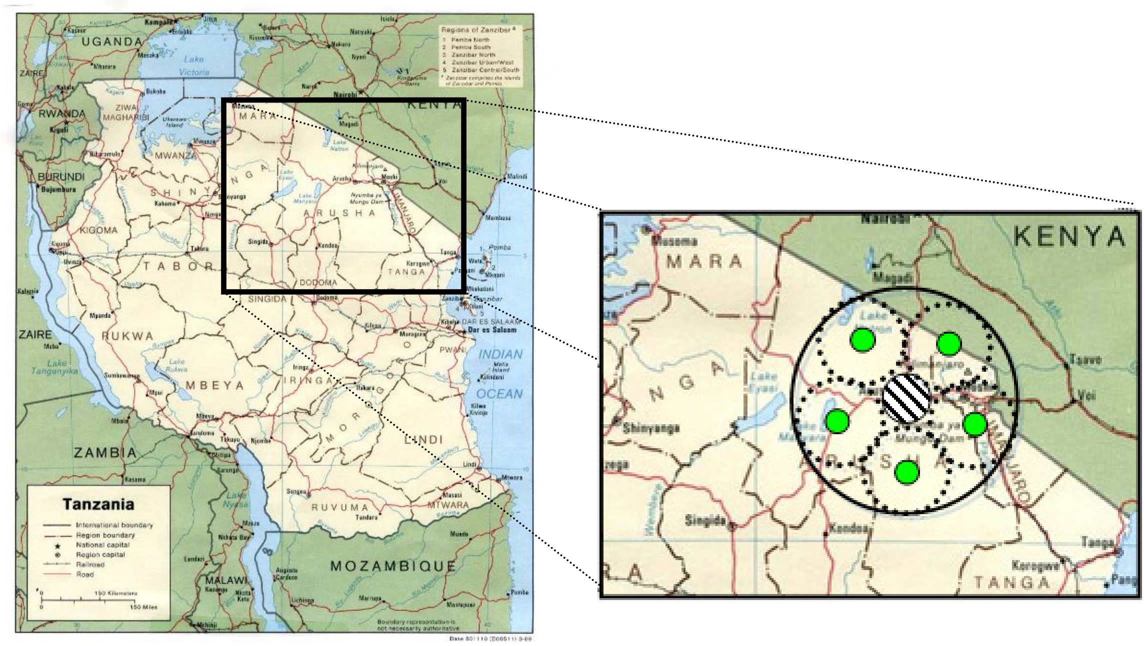

Figure 6-1 Area division for centralized and decentralized production. The 5 dotted circles indicate the areas for decentralized production with their own pressing facility. The large circle represents centralized pressing which is located at the hatched circle.

Table 6-1 Input values for the cost benefit analysis

Monetary		Reference
exchange rate (dollar to chilling)	1268	www.bot-tz.org
discount factor	20.31%	www.bot-tz.org
interest rate	15.54%	www.bot-tz.org
inflation rate	6.90%	www.bot-tz.org
real discount rate	8.08%	

Press type	5 x KEK P0101 (decentralized)	1 x Reinartz AP14/30 (centralized)	1 x Reinartz AP15/45 (centralized)	Data Source
Investment				
press	$126,965	$87,125	$101,243	Reinartz & KEK Egon Keller
cyclone filter	$232,704	$101,914	$140,411	Reinartz
storage	5000L	8000L	14000L	
	$115,765	$26,304	$32,606	Reinartz
Maintenance				
annual maintenance (5%)	$6,348	$4,356	$5,062	
capacity (kg Jatropha/hr)	350	350	700	Reinartz & KEK Egon Keller
annual capacity ton (8 h operation)	658	658	1,316	
annual capacity ton (24 h operation)	2,764	2,764	5,527	
Seed buying costs				
price/kg	$0.09	$0.09	$0.09	Diligent Tanzania LTD
8h	$62,271	$62,271	$124,543	
24h	$261,539	$261,539	$523,079	
Fuel use for pressing				
Annual fuel use 8h (liter)	9,400	5,640	11,280	Reinartz & KEK Egon Keller
Annual fuel use 24h (liter)	39,480	23,688	47,376	Reinartz & KEK Egon Keller
Amount usable oil				
8h (liter)	205,165	208,925	417,850	
24h (liter)	861,694	877,486	1,754,972	
Fuel costs				
capacity (ton/truck) 8h	8	8	8	Mercedes 815 Atego
number of rides 8h	82	82	165	
average km/ride	300	750	750	
total km 8h	24,675	61,688	123,375	
km/liter	6	6	6	Mercedes 815 Atego
price /liter	$0.99	$0.99	$0.99	
total fuel 8h	$4,071	$10,178	$20,357	
total fuel 24h	$12,214	$30,535	$61,071	
truck price	$15,000	$15,000	$15,000	Mercedes 815 Atego
Labour cost				
wage dollar/month	$80.00	$80.00	$80.00	
wage /hr	$0.45	$0.45	$0.45	
8h				
press operator	$5,054	$842	$842	Diligent Tanzania LTD
seed collectors	$1,893	$11,356	$22,713	Diligent Tanzania LTD
manager	$41,100	$41,100	$41,100	
total	$48,047	$53,299	$64,655	
24h				
press operator	$21,229	$3,538	$3,538	Diligent Tanzania LTD
seed collectors	$5,678	$34,069	$68,139	Diligent Tanzania LTD
manager	$82,200	$82,200	$82,200	
total	$109,107	$119,808	$153,877	
Revenues				
oil 8h	$121,352	$123,576	$247,151	
oil 24h	$509,677	$519,018	$1,038,035	
presscake 8h	$23,030	$23,030	$46,060	
prescake 24h	$96,726	$96,726	$193,452	

6.3.1 Decentralized pressing

Decentralized processing in all cases showed negative NPV at 8 hour operation per day as can be seen in Appendix M. Centralized processing was possible at 8 hour operation although 24 hours was also strongly preferred. The values in Table 6-2 to Table 6-8 are best guesses. Rounded numbers would only increase inaccuracy. Table 6-2 shows a positive NPV for decentralized processing during 24 hours a day. When comparing the real IRR of 34% to the real interest rate of 8.08% shows this option is quite profitable. The positive value for equipment in year 5 represents the NPV of the equipment taking into consideration the difference in write of period between German and Tanzanian machines. Write-off periods of 5, 10 and 20 years are taken for respectively Tanzanian machines, trucks and German machines.

Table 6-2 Calculation of NPV and IRR for decentralized oil production capacity of 350kg/hr

5 x KEK P0101 (70kg/hr) **24** hours operation per day with **cyclone filter**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$567,977						-$567,977	1.000	-$567,977
1		-$261,539	-$13,436	-$105,569	-$12,696	$606,403	$213,163	0.925	$197,227
2		-$261,539	-$13,436	-$105,569	-$12,696	$606,403	$213,163	0.856	$182,482
3		-$261,539	-$13,436	-$105,569	-$12,696	$606,403	$213,163	0.792	$168,840
4		-$261,539	-$13,436	-$105,569	-$12,696	$606,403	$213,163	0.733	$156,218
5	$379,076	-$261,539	-$13,436	-$105,569	-$12,696	$606,403	$592,238	0.678	$401,578
								NPV	**$538,367**
								IRR	**34%**

Investment cost can be reduced by selecting local technologies like the Sayari expeller. Table 6-3 shows a significant increase in both NPV and IRR compared to using the more expensive German technology.

Table 6-3 Calculation of NPV and IRR for decentralized oil production capacity of 350kg/hr using the cheap Sayari expeller

5 x Sayari (70kg/hr) **24** hours operation per day with **cyclone filter** and **cheaper storage**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$329,575						-$329,575	1.000	-$329,575
1		-$261,539	-$12,214	-$105,569	-$12,696	$606,403	$214,384	0.925	$198,357
2		-$261,539	-$12,214	-$105,569	-$12,696	$606,403	$214,384	0.856	$183,528
3		-$261,539	-$12,214	-$105,569	-$12,696	$606,403	$214,384	0.792	$169,807
4		-$261,539	-$12,214	-$105,569	-$12,696	$606,403	$214,384	0.733	$157,113
5	$197,029	-$261,539	-$12,214	-$105,569	-$12,696	$606,403	$411,413	0.678	$278,966
								NPV	**$658,196**
								IRR	**63%**

6.3.2 Centralized pressing

Centralized production at equal production capacity results in a higher NPV due to reduced investment costs. As can be seen from the IRR of 61% in Table 6-4 profitability of the project increases significantly when production is centralized compared to the situation in Table 6-2.

Table 6-4 Calculation of NPV and IRR for centralized oil production capacity of 350 kg/hr

1 **x Reinartz AP 14/30** (350kg/hr) **24** hours operation per day with **cyclone filter**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$310,760						-$310,760	1.000	-$310,760
1		-$261,539	-$30,535	-$119,808	-$7,247	$615,744	$196,614	0.925	$181,915
2		-$261,539	-$30,535	-$119,808	-$7,247	$615,744	$196,614	0.856	$168,315
3		-$261,539	-$30,535	-$119,808	-$7,247	$615,744	$196,614	0.792	$155,732
4		-$261,539	-$30,535	-$119,808	-$7,247	$615,744	$196,614	0.733	$144,090
5	$195,518	-$261,539	-$30,535	-$119,808	-$7,247	$615,744	$392,132	0.678	$265,892
								NPV	**$605,185**
								IRR	**61%**

Judging from Table 6-5 economies of scale seem to have more effect on profitability than the way production is organized. At doubled production the IRR increases from 61% to 99% making the much more profitable. Comparing Table 6-4 and Table 6-5 five years NPV increased with over $1,000,000 for a $170,000 increase in initial investment.

Table 6-5 Calculation of NPV and IRR for centralized oil production capacity of 750 kg/hr

1 **x Reinartz AP15/45** (750kg/hr) **24** hours operation per day with **cyclone filter**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$481,686						-$481,686	1.000	-$481,686
1		-$523,079	-$61,071	-$153,877	-$10,124	$1,231,487	$483,337	0.925	$447,203
2		-$523,079	-$61,071	-$153,877	-$10,124	$1,231,487	$483,337	0.856	$413,770
3		-$523,079	-$61,071	-$153,877	-$10,124	$1,231,487	$483,337	0.792	$382,837
4		-$523,079	-$61,071	-$153,877	-$10,124	$1,231,487	$483,337	0.733	$354,216
5	$271,240	-$523,079	-$61,071	-$153,877	-$10,124	$1,231,487	$754,577	0.678	$511,654
								NPV	**$1,627,994**
								IRR	**99%**

6.3.3 Sensitivity analysis

A sensitivity analysis (see table 6-6 to 6-8) of the different cases shows centralized production is less sensitive to fluctuating values than decentralized production. In addition Table 6-8 shows sensitivity decreases for larger production scale, which is to be expected. The project shows very little sensitivity to changes in most variables. Changes in raw material price and oil selling price and revenues show the biggest impact. The extremely high switching value for fuel costs in all three cases suggests underestimation of travel distances and fuel consumption. Normally transport costs are expected to contribute to a larger extent. Revenues have the lowest switching variable which still has a margin of >20% in all cases. For 24hr/day operation the project shows little risk for both centralized and decentralized production according to the sensitivity analysis and can therefore be implemented in any of the three setups. Clearly the larger the production scale the less sensitive the process is to the changes taken into account in this paragraph.

Table 6-6 Sensitivity analysis decentralized production

Sensitivity analyses 24h operation KEK P0101				
Cash flow item	Assume	Effect IRR	Effect NPV	Switching value
Equipment costs	5% increase	-2%	-$30,000	+ 95%
Seed costs	25% increase	-12%	-$260,000	+52%
Fuel costs	10% increase	0%	-$4,000	+1116%
Labour costs	10% increase	-2%	$40,000	+129%
Revenues	10% decrease	-11%	-$240,000	-23%
Jatropha oil price	20% increase	+29%	$400,000	-27%

Table 6-7 Sensitivity analysis centralized production

Sensitivity analyses 24h operation Reinartz AP14/30				
Cash flow item	Assume	Effect IRR	Effect NPV	Switching value
Equipment costs	5% increase	-3%	-$15,000	+195%
Seed costs	25% increase	-22%	-$260,000	+58%
Fuel costs	10% increase	-1%	-$12,000	+497%
Labour costs	10% increase	-4%	-$50,000	+127%
Revenues	10% decrease	-21%	-$245,000	-25%
Jatropha oil price	20% increase	+34%	400,000	-29%

Table 6-8 Sensitivity analysis centralized production

Sensitivity analyses 24h operation Reinartz AP15/45				
Cash flow item	Assume	Effect IRR	Effect NPV	Switching value
Equipment costs	5% increase	-5%	-$25,000	+338%
Seed costs	25% increase	-26%	-$520,000	+78%
Fuel costs	10% increase	-1%	-$25,000	+669%
Labour costs	10% increase	-3%	-$60,000	+266%
Revenues	10% decrease	-26%	-$490,000	-33%
Jatropha oil price	20% increase	54%	$830,000	-39%

6.3.4 Non financial consideration

Determination of the optimal pressing arrangement should not solely be based on financial considerations. Some additional factors that should be taken into account during decision making are listed here:

- The oil recovery for large presses is only slightly higher than for smaller presses because the design is often very similar. Table L-3 in Appendix L shows that the differences are expected to be within 1-2% for most oilseeds

- When production is centralized large presses should be used to reduce investment costs. Local people in less developed countries are generally unfamiliar with these large and complicated machines. In case of centralized pressing operational mistakes could cause the whole production to come to a halt or cause expensive machine damage. For decentralized pressing 80% of the production capacity remains in case of a single breakdown and repair cost will be lower.

- Small decentralized presses allow more flexibility in the expansion of production capacity. Investments costs are relatively low and capacity can be gradually increased.

- Expansion into new geographic areas is easier with decentralized production as fewer investments are required to setup new pressing units at other locations.

- In case of problems Tanzanian people prefer personal visits over telephone or email. Scattered production locations reduce the distance between farmer and oil producer and can therefore improve communication between both parties. This could in turn lead to improved product quality and yield as pressing locations could function as knowledge centres.

Incorporating some points mentioned in the 'learning selection model' from Douthwaite (Douthwaite, 2002) gives rise to some additional comments:

- Judging from experiences during field trips in Tanzania local farmers seemed moderately motivated to grow Jatropha or collect seeds from wild Jatropha trees. The fact that most trees were not harvested in areas where Diligent was actively buying suggest lack of motivation on the side of the farmer. This might be caused by low prices or the inability of local farmers to judge the long term benefits.

- Although locals are perhaps unable to technologically modify the screw press they are able to come up with new applications. An example is the use of a multi functional platform for pressing, milling and electricity generation. Linking Jatropha to such directly noticeable benefits can increase motivation in local communities.

- According to Douthwaite the need of an innovation should be great. This issue is questionable fro Jatropha oil. Most remote villages have no direct application for Jatropha oil and to them Jatropha is just another cash crop. There might of course be a need for the advantages of using Jatopha for electricity or cooking, but one should take care not to confuse our needs with the needs of the local population.

- The last point mentioned here is the necessity of a product champion. This is someone who is respected in his community and who works with users and producers to identify and solve problems in order to increase the fitness of a technology. The innovation champion will also promote the beneficial applications of the new technology. With respect to Jatropha the activities of a product champion could be to motivate farmers to grow Jatropha and to make them aware of long term benefits of increased income security. The role of product champion could for example be filled by a village leader.

This short consideration of innovation theory was restricted to some of the significant success factors. However the innovation theory discussed by Douthwaite contains many other factors that should be satisfied.

6.4 Viability of community level processing: Engaruka case

The village of Engaruka consists of two separate parts: northern and southern Engaruka. Most of the 9000 inhabitants of this Maasai village make a living as farmers or keeping feedstock. As is the case for the village Temi ya Simba there is no grid connection present in the village. Therefore a Multi Functional Platform (MFP) was installed by a

Tanzanian NGO named TaTedo in November 2006 to combine seed pressing with electricity generation and grain milling. The MFP operates five hours a day generating roughly 6 kWh. In total 20 shops, 3 houses and a campsite are provided with energy from this platform. In addition to the grain mill connected to the MFP seven more diesel powered grain mills are present in the village. Together with the diesel driven generator these machines constitute the potential Jatropha consumption in Engaruka. As Jatropha was already grown in Engaruka for fencing most seeds still stem from hedges. Over 30 farmers are growing Jatropha on small plots between 0.5-3 acres in size (Zheng and others, 2005, 193-202). The first harvest in 2007 produced approximately 2400 kg Jatropha seeds. The total land area available for Jatropha is around 100 acres. Figure 6-2 shows a model for Jatropha utilization in Engaruka. A press cooperation consisting of maybe 5-10 people could start production of Jatropha oil and grain millers could also benefit from this cheaper locally produced fuel to power their engines. The investment required to setup a press-cooperation probably exceed the amount of money available to the local investors. Most of the villagers cannot get any loans from the bank as farming is excluded from the definition of enterprises the bank uses when judging loan requests. Therefore Savings and Credit Co-operatives (SACCOs) are included in this system. The SACCO system is a mutual membership organization, which involves pooling of voluntary savings from members in the form of shares. These savings or shares form the basis for providing credit to members. The available credit is normally around three times the level of savings or shares. The importance of this market segment is underlined by a SACCOs market of nearly US$1 billion in Kenya.

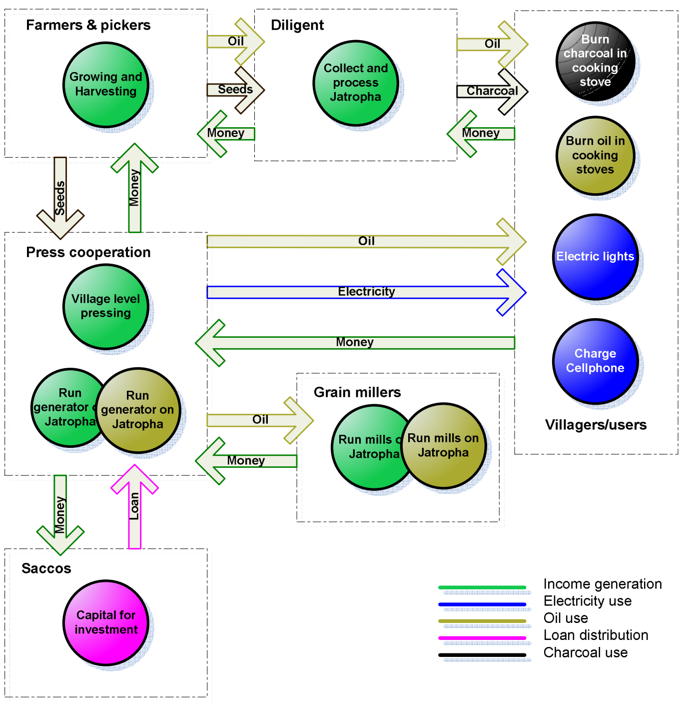

Figure 6-2 Jatropha utilization in Engaruka

The possibility of village level processing of Jatropha seeds into oil was evaluated using a method similar to the previous paragraph. Calculations shown in Appendix N show that although village level pressing is profitable larger profits are achieved by just selling seeds. Assumptions in this comparison are:

- 100 acres is available for growing Jatropha without decreasing food production.
- In case of local processing Jatropha oil is sold at $0.59 and press cake is used as fertilizer.

- When only selling seeds investment costs are assumed to be zero and fertilizer costs are equal to the value of the fertilizer produced in case of processing seeds to oil ($0.05 /kg).

- Labour costs are zero as farmers grow Jatropha for additional income besides their normal activities.

- Calculations for Jatropha pressing assume a small village cooperation that uses an MFP to press seeds, produce electricity and mill maize. The availability of oil and electricity are of additional value to the whole village.

- Calculations for selling seed include no local electricity and oil production.

Table 6-9 NPV and IRR for various situations in Engaruka

	50 acres low yield	100 acres low yield	100 acres good yield	100 acres low yield seeds	100 acres good yield seeds
NPV	$2,950	$14,500	$51,500	$12,750	$54,500
IRR	33%	115%	353%	-	-

Judging from Table 6-9 pressing on village level can contribute to the welfare level in Engaruka, especially when taking into account the increase in welfare due to availability of oil and electricity. For good yields the additional income can amount up to one hundred annual wages. In case of 100 acres and low yield the increased revenues are equivalent to 19 monthly salaries. As was the case when comparing centralized and decentralized processing in the previous paragraphs larger production means higher returns (see Table 6-9).

Initially two other villages were reviewed on Jartopha application. Jatropha use in these villages was not as extensive as in Engaruka. One of the villages only sells seeds and in the other limited quantities of oil could be pressed to fuel cooking stoves. Because of its small scale village level production of Jatropha for cooking is expected to be inefficient taking into account the modest profits in the much larger Engaruka case. The CBA for Engaruka suggests that Jatropha activities on a scale smaller than this should be restricted to direct selling the primary product. More information on all three villages can be found in Appendix O.

6.5 Conclusions

One should keep in mind that the CBA explained in this chapter provides insight in the profitability of a project. This method was used to select the best option from a range of possibilities. Calculated NPVs are no indication for the absolute value of commercial profits. The initial investment costs for Jatropha oil production are high compared to expected revenues. Daily production time of 8 hours is expected not to be profitable based on the executed CBA. When production is running 24 hours a day, 7 days a week production showed profitable. Based on purely financial results from the CBA large scale centralized processing is preferred over decentralized pressing. For similar production scale centralization allows an IRR of 61% compared to 30-40% in case of decentralization. However, reviewing both financial and non-financial aspects shifts preference to decentralized pressing for Tanzania and similar countries. In case of non-commercial projects the use of local technology is desirable as this creates financial activity and potentially yields higher revenues. Commercial firms might prefer more robust technology, which is much more reliable and durable at the cost of higher initial investments. For projects to become successful care should be taken to bear in mind the importance of local circumstances such as motivation, need of a technology and the presence of a product champion.

Jatropha has significant added value for rural communities in Tanzania. For a village of 9000 inhabitants and 100 acres of available land the NPV of Jatropha cultivation appears to be between $12,750 and $54,500 per year depending on seed yields, which is equivalent to approximately 100 annual minimum wages. Oil processing on village scale without the intervention of commercial firms seems preferable to mere seed selling if coupled to electricity generation and maize milling. Oil processing for 100 acres of Jatropha could easily provide an additional $1,500 per annum, which is equivalent to 19 monthly salaries to be divided between the initiators. With this extra income comes the availability of electricity and cheap fuel. In depth investigation of financing possibilities through micro-credit is advisable.

7 Conclusions and recommendations

The main question to be answered by this study is as follows:

- How can oil recovery, energy input and cost of Jatropha seed expression in screw presses be optimized while retaining a quality that complies with international fuel standards?

Three main options to increase oil recovery have been identified: pre-treatment of seeds before pressing, changes in press operation and changes in press design. Only the first two could be included in the present study, although two different press types were included in this study. Both seed pre-treatment and press operation showed significant impact in oil recovery and energy requirement. Quality was mostly affected by moisture content and temperature, the latter of which can be due to both seed pre-treatment and press operation. None of the samples tested for quality met standards for Pure Plant Oil. However standard treatments are likely to bring the quality parameters within the range of these standards. Seed moisture content (varied from 2-13%) shows the strongest effect on oil recovery from Jatropha. Oil yield for different moisture levels varies from 33-88%. The natural moisture content of the seeds (6.7 wt.% w.b.) appears to be close to optimal with an oil yield of 79%. Depending on the desired oil recovery pre-treatments might therefore not be necessary. Restriction size and rotational speed of the screw are two other influential parameters. If high yield are required restriction size should be reduced as far as possible taking into consideration both operational limits of the press and the effect of temperature on oil quality. Lower rotational speeds lead to higher oil recovery, which is mainly attributed to longer residence time. Speed can only be reduced to a limited extent as below 20 RPM operation is not possible with the BT50. The choice of rotational speed varies with the demands of the user. For high production capacity rotational speed should be high and for high oil recovery per kg input material it should be low. Oil yields drastically decrease below 80% hull content, from 80-100% the yield is hardly influenced. The influence of seed pre-heating and flaking/crushing proved to be insignificant for Jatropha seeds. A pre-treatment of one hour cooking followed by seed drying results in the highest oil recovery for both presses. Single pass pressing of cooked and dried seeds resulted in the highest measured oil recovery of 89% for both BT50 and Sayari press. After dual pass oil recovery for the Sayari increased to 91%, being close to the theoretic maximum of 95%. For comparison normal seeds yields were 79% for the BT50 (single pass) and 88% for the Sayari (dual pass). Single pass pressing of cooked seeds in the Sayari expeller thus leads to higher yields than normal seeds after dual pass pressing. This pre-treatment can thus be used to decrease energy consumption for pressing and increase processing capacity. The energy requirement is of subordinate importance as for the BT50 the energy input per litre oil varies between 1% and 2.5% of the calorific value of Jatropha oil. For all tests the amount of foots (30-50 vol.%) in the crude oil was problematic for filtering.

Taking into consideration all the test results optimal oil recovery is expected at a moisture content of 2-4% after cooking at 70°C, 100% hull content and the smallest restriction size and lowest speed possible for a certain press type.

Additional consideration of the practical application of screw presses for the production of Jatropha oil in Tanzania led to answers to the following two additional questions.

- What is the optimal setup for the production of Jatropha oil in Tanzania?

- In what way can rural areas in which their use is anticipated benefit from Jatropha cultivation?

A 'Cost Benefit Analysis' (CBA) was used to answer both questions. One should keep in mind that the CBA explained in this chapter provides insight in the profitability/viability of a project. Calculated 'Net Present Values' (NPVs) are no indication for the absolute value of commercial profits. The CBA method was used to select the best option from a range of possibilities (decentralized, central and high capacity central). The initial investment costs for Jatropha oil production are high compared to expected revenues. Daily production time of 8 hours is expected not to be profitable based on the executed CBA. When production is running 24 hours a day, 7 days a week production showed profitable. Based on purely financial results from the CBA large scale centralized processing is preferred over decentralized pressing. For similar production scale centralization allows an 'Internal Rate of Return' IRR of 61% compared to 30-40% in case of decentralization. However, reviewing both financial and non-financial aspects shifts preference to decentralized pressing for Tanzania and similar countries. In case of non-commercial projects the use of local technology is desirable as this creates financial activity and potentially yields higher revenues. Commercial firms might prefer more robust technology, which is much more reliable and durable at the cost of higher initial investments.

Jatropha appears to have significant added value for rural communities in Tanzania. For a village of 9000 inhabitants and 100 acres of available land the NPV of Jatropha cultivation appears to be between $12,750 and $54,500 per year depending on seed yields, which is equivalent to approximately 100 annual minimum wages. Oil processing on village scale without the intervention of commercial firms seems preferable to mere seed selling if coupled to electricity generation and maize milling. Oil processing for 100 acres of Jatropha could easily provide an additional $1,500 per annum, which is equivalent to 19 monthly salaries to be divided between the initiators. With this extra income comes the availability of electricity and cheap fuel in rural areas.

Some recommendations for further research are listed below:

- This study was only related to screw pressing process, which is only part of the production process of Jatropha oil. Additional research aimed at designing the total production process would provide better insight on process efficiencies and viability. Solutions for filtering the crude oil could for example result in higher yields of clean oil than optimizing the oil recovery yield of a screw press.

- Optimization of industrial presses for Jatropha seeds might still be interesting to recover a few additional percentages of oil and reduce the amount of foot in the crude oil.

- Decentralized setup of Jatopha press plants is preferred over centralized processing although CBA analysis predicts higher profits in case of centralization. The main reason is higher flexibility to adapt to various local circumstances.

- Repetition of press tests and measurements on oil recovery would increase the reliability of the results.

- In depth investigation of financing possibilities through micro-credit is advisable with a view to planning community Jatropha projects in Tanzania. A closer look at the success factor given by Douthwaite is advisable when actually starting a project for Jatropha processing in any developing country.

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Appendix A: Properties of Jatropha seeds and oil

Different parts of the Jatropha plant can be used as either solid or liquid fuel. The energy content and recovery percentage of several Jatropha products are shown in Table A-1. Recovery percentage of jatropha oil is expressed with respect to the whole fruit weight.

Table A-7-1 Energy values of varies Jatropha products and (Openshaw, 2000, 1-19).

Fuel	Ash content (wt% d.b.)	Moisture content (wt% w.b.)	Energy value (MJ/kg)	Recovery percentage
wood	1	15	15.5	95-100
whole fruit	6	8	21.2	95-100
whole nut	4	5	25.5	67-70
coat	13	15	11.1	28-30
hull	5	10	17.2	23-24
kernel	3	3	29.8	44-46
wood charcoal	3	5	30	15-25
hull charcoal	15	5	26.3	15-25
plant oil	< 0.1	0	40.7	11-18
press cake	4	3	25.1	29-35

The composition of different components of the seed/nut are

Table A-2 gives an indication of the composition of seed and press cake. Approximately 34 wt.% of the seed is hull and the other 66 wt.% consists of the seed kernel (Openshaw, 2000, 1-19).

Table A-7-2 Composition of Jatropha seed and press cake (Gubitz, Mittelbach, and Trabi, 1999, 73-82) [1](Openshaw, 2000, 1-19) [2](Akintayo, 2004, 307-310).

Parameter	seed [1]	kernel	shell	press cake
crude protein (%)	24.6-27.4	22.2-27.2	4.3-4.5	56.4-63.8
lipid (%)	48.7-51.4	56.8-58.4	0.5-1.4	1.0-1.5
ash (%)	4.6-4.9	3.6-4.3	2.8-6.1	9.6-10.4
neutral detergent fibre (%)	10.2-11.2 (all three fibre rows)	3.5-3.8	83.9-89.4	8.1-9.1
acid detergent fibre (%)		2.4-3.0	74.6-78.3	5.7-7.0
acid detergent lignin (%)		0.0-0.2	45.1-47.5	0.1-0.4
Gross energy (MJ/kg)	25.5 [2]	30.5-31.1	19.3-19.5	18.0-18.3

Some of the physical and chemical characteristics of Jatropha oil are represented in Table A-3. Striking is the much lower viscosity encountered by Akintayo compared to Agarwal (17.1 vs 35.98 cST). The Iodine value given in indicates application in the manufacturing of alkyd resin, shoe polish, varnish etc. The high saponification value denotes good properties for soap and shampoo production.

Table A-3 Physico-chemical characteristics of Jatropha oil (Akintayo, 2004, 307-310).

Parameter	Jatropha oil
Colour	Light yellow
Free fatty acid (mg/g)	1.76±0.10
Acid value (mg KOH/g)	3.5±0.1
Saponification value (mg KOH/g)	198.85±1.40
Iodine value (mg iodine/g)	105.2±0.7
Mean molecular mass (g)	281.62
Unsaponifiable matter (%)	0.8±0.1
Refractive index (25 °C)	1.468
Specific gravity (25 °C)	0.919
Hydroxyl value	2.15 ±0.10
Acetyl value	12 2.16±0.10
Viscosity (30°C) cST or mm^2/s	17.1

Appendix B: German quality standard for Pure Plant Oil

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 min.**	**max.**	**Testing Method**
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

00 1ER 100e

Appendix C: Data on BT 50 bio press setup

Dimensions and other specifications of the BT50 biopress are shown in Table C-1. Channel height and width are indicated by H and W in the right side of Figure C-1. Angle φ is visible in the left image of Figure C-1.

Table C-1 BT50 specifications

Srew dimensions	
Screw diameter	48.6mm
Screw length	160mm (groove), 173 total length in contact with seed
Channel height H (const	11.5mm
Channel width W	11mm
Number of parallel grov	7 (6 full windings)
Flight thickness	5.75mm top, 11.6mm bottum
Angle φ	8 degrees
Cage diameter	50mm
Cage length	195mm

Other specifications	
RPM	0-70
Engine nominal power	1.1kW

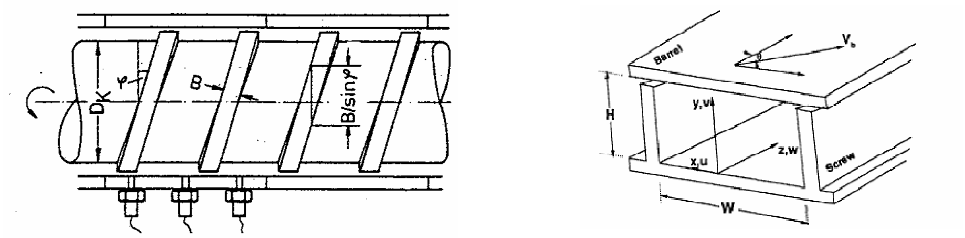

Figure C-1 Visualization of screw dimensions (Eggers, Broeck, and Stein, 2006, 494-499)

Pictures of the pressure sensor are visible in Figure C-2.

Figure C-2 Kistler 6152 mold cavity pressure sensor, amplifier and mounting method (Kistler 6152 user manual)

Appendix D: Maximum power output and thermocouple calibration

The peak in Figure D-1 shows the Altivar 31 power output signal in Watts at the moment the BT50 is jammed. The power indicated is around 2200-2300 W, which is twice the nominal power of the electric motor as predicted by the Altivar 31 producer. This proves that values from the variable speed drive are reliable.

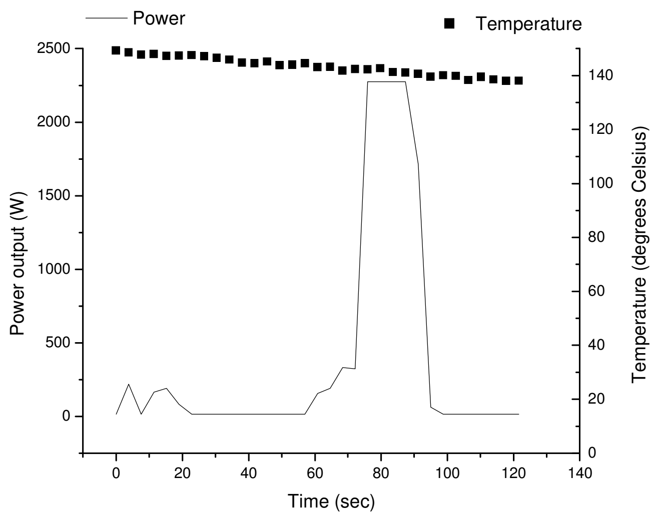

Figure D-1 Maximum power peak at press jamming

The type J thermocouples were calibrated using a thermostatic bath and a liquid mercury thermometer. Results are shown in Figure D-2. Accuracy at low temperatures was within 1%, while for higher temperatures 2.5% was found.

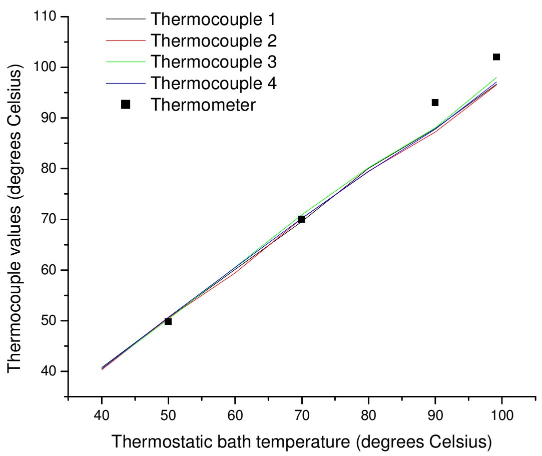

Figure D-2 Thermocouple calibration graph

Appendix E: Measurement equipment in Tanzania

The figures below give the reader an impression of the measurement equipment used for soxhlet extraction and the determination of moisture content during experiments in Tanzania. Equipment used for the determination of moisture content is shown in Figure E-1.

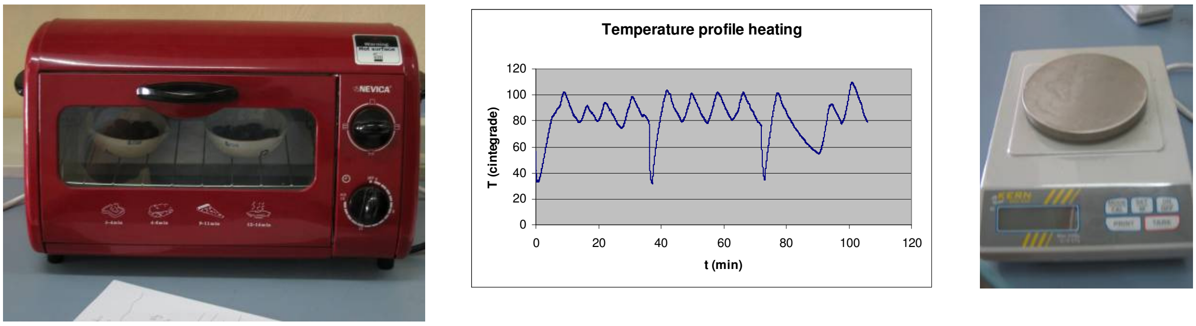

Figure E-1 equipment used for the determination of moisture content from left to right: oven, oven drying profile, balance (0.01 g accuracy).

Equipment used for soxhlet extraction is shown in Figure E-2. Figure E-3 shows that the accuracy of the determination of foot levels was mainly due to the type of storage container available.

Figure E-2 equipment used for soxhlet extraction from left to right: mortar and pestle to grind samples before extraction, soxhlet setup, filter paper instead of extraction thimble.

Figure E-3 Left: oil containers. Right: determination of oil volumes and foot levels performed by Diligent co-workers.

Appendix F: Sayari expeller and Intermech workshop

Designs of the Sayari screw and press cage are shown more clearly in Figure F-1. One can clearly see that transport sections and pressure cones are alternately positioned along the worm shaft. Rotational speed of the Sayari expeller was 55RPM powered by a standard 5.5kW electric motor (MA132SA4, MarelliMotori, Vicenza, Italy).

Figure F-1 Detailed views of the Sayari expeller. Left: the press cage made from separate lining bars. Right top: worm positioned in the bottom part of the cage. Right bottom: separate worm with clear distinction between cones and transport screw. The wheel on the left is for manual adjustment of the outlet restriction.

Production of the press took place at the Intermech workshop (Morogoro, Tanzania). This workshop produces several machines for agricultural applications. The assembly and final product look as shown in Figure G-2.

Figure F-2 Assembly of Sayari expeller at Intermech workshop and final product.

Appendix G: Overview of variables included in this research

The table below shows all the variations included in the present study. Limitations were encountered by trial and error and were determined by the operational restrictions of both presses. The table shows that the Sayari expeller could only be operated at a single speed. Less hull fractions were tested in Tanzania because sample sizes were to big (10-20 kg) for manual de-hulling. A wider range of moisture contents was tested at Eindhoven University as better equipment was available to condition the seeds. The temperature ranges for pre-heating the seeds were restricted to the point where no visible alteration of the structure of the kernel was observed. The moisture content of these pre-heated samples was not determined.

BT50 (Netherlands)	Sayari (Tanzania)
Speed	**Speed**
28RPM	56RPM
42RPM	
49RPM	
56RPM	
70RPM	
Restriction	**Restriction**
7mm	4.5mm
9mm	3.7mm
12mm	2.7mm
	1.3mm
	0.6mm
Hull fraction	**Hull fraction**
66%	60%
80%	100%
90%	
100%	
Moisture content	**Moisture content**
2.14%	6.6%
5.40%	7.6%
6.30%	8.0%
6.70%	8.7%
7.30%	9.3%
8.50%	
9.00%	
13.30%	
In addition	**In addition**
Crushed	Crushed
Torrefaction (100, 120, 140, 160, 180, 200 °C)	Preheating in water 80°C
Preheating in water (70 & 80 °C)	

Appendix H: Calculation of oil recovery from soxhlet extraction

The following equations are required to calculate how much oil is recovered from the seeds after pressing. The residual oil content in the press cake is compared to the oil content in the seeds before pressing.

$$W_0 = \frac{O_0}{O_0 + S},\ W_s = \frac{O_s}{O_s + S},\ Y = 1 - \frac{O_s}{O_0}$$

with:

Oo	amount of oil in Jatropha seed sample (g)
Os	amount of oil in Jatropha press cake sample (g)
S	amount of solid material present in the sample
Wo	oil content in original (g/g)
Ws	oil content in sample (g/g)
Y	oil recovery (or oil yield) (g/g)

Os and Oo are determined through soxhlet extraction. (Oo+S) the sample weight before soxhlet extraction. The difficulty is that Os en Oo were determined from samples with differing weight and can therefore not directly be inserted to the formula for Y.

The starting formulas can be rewritten into the following expression:

$$Y = 1 - \left[\frac{\left(\frac{Ws}{1 - Ws} \right) \cdot S}{\left(\frac{Wo}{1 - Wo} \right) \cdot S} \right]$$

The S can be removed from the formula because the amount of solid material before and after pressing is assumed equal. The S can be crossed out as the amount of oil is compared per gram of solid material.

Appendix I: Initial measurement data

The graphs represented below give an indication of the accuracy of the output signals for temperature, power and pressure. The temperature graph in Figure I-1 shows only slight fluctuations in the range of ±5%.

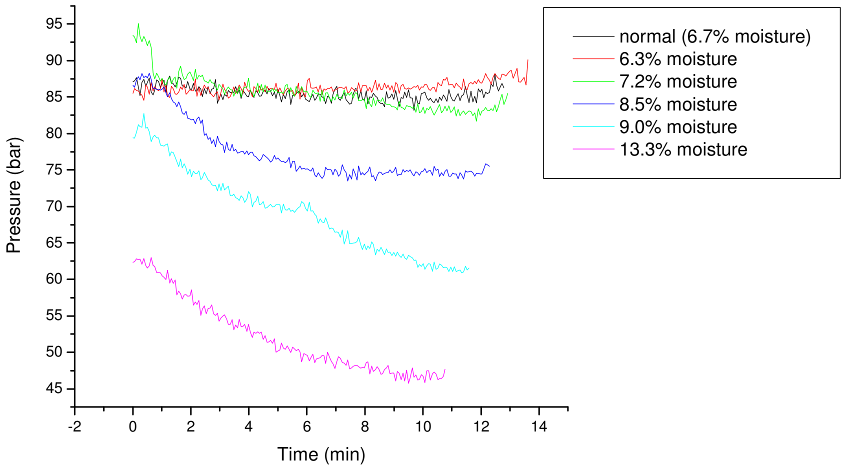

Figure I-1 Temperature profiles for different moisture contents at standard conditions for BT50 press (9mm, 70RPM, 100% hull)

The power data closely resembles pressure data as can be seen when comparing Figure I-2 and Figure I-3. The output signals of power and pressure are more turbulent and can vary about ±10%. Average values of graphs similar to the ones in this appendix were used to construct the results in chapter 5.

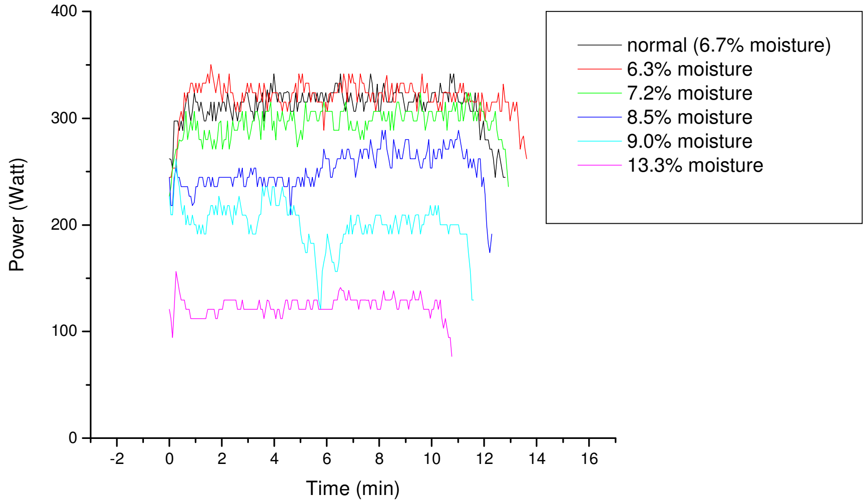

Figure I-2 Power requirement at different moisture contents at standard conditions for BT50 press (9mm, 70RPM, 100% hull)

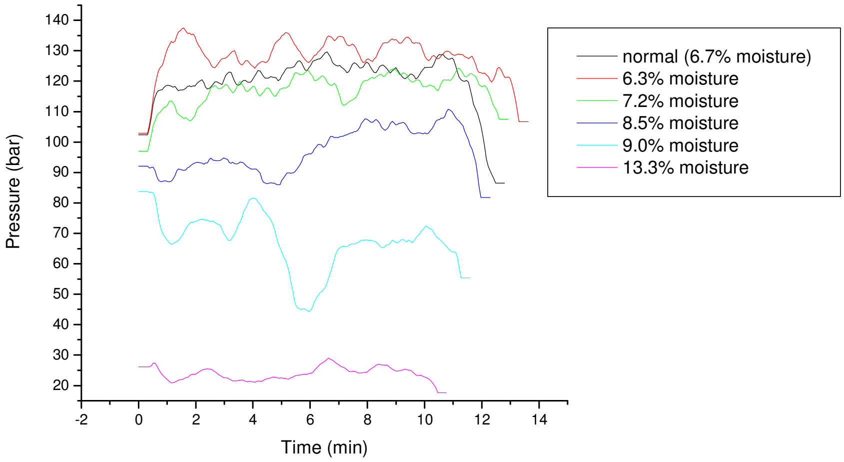

Figure I-3 Smoothed pressure curves for different moisture contents at standard conditions for BT50 press (9mm, 70RPM, 100% hull)

Appendix J: Calculation of energy requirement

The energy equation for the BT50 press provides insight in the amount of energy that is needed to separate the oil form the solids. Comparing the required energy input to the energy content of the oil results in an indication of the energy efficiency of the mechanical extraction process. The calculations should be interpreted as a rough calculation due to the use of natural materials like the Jatropha seeds. Properties like oil yield and specific heat value can easily vary per batch. The steady state energy balance is as follows:

$$M_s C_{p,s} T_s + W = M_c C_{p,c} T_c + M_o C_{p,o} T_0 + Q_{conv} + Q_{cond} + Q_{rad}$$

where M is the mass flow in kg/s, C_p is the specific heat value in J/kgK, T temperature in °C and W the mechanical energy input to the screw in J/s. Subscripts 's', 'c' and 'o' refer to seeds, press cake and oil respectively. The Q terms indicate heat losses through convection, conduction and radiation in J/s. In addition the mass balance equation is:

$$M_s = M_0 + M_c$$

Solving the energy equation results in an approximation for W. This value is compared to the value measured by the volt output of the Altivar 31 (variable speed drive) that regulates the power supplied to the BT50's electric motor. For proper analysis of the energy balance of pressing Jatropha seeds in the BT50 screw press the specific heat values have to be properly estimated. One method to approximate C_p-values is by using the following expression (Zheng and others, 2005, 193-202):

$$C_p = 1.424 m_c + 1.549 m_p 1.675 m_f + 0.837 m_a + 4.187 m_t$$

where m is the mass fraction on a wet basis and the subscripts indicate the following: 'c', carbohydrate; 'p', protein; 'f', fat; 'a', ash; and 't' water. M, T and W are easily measured. The calculation of specific heats of seeds and cake is based on the composition shown in Table J-1. The value for Jatropha oil was based on values for Canola (Ramaswamy, Balasubramaniam, and Sastry, 2007, 444-451).

Table J-1 Composition of Jatropha seed and press cake used to calculate Cp

Component	Jatropha seed	cake
Crude fat	0.47	0.6
Crude protein	0.25	0.01
Crude fibre	0.10	0.1
Moisture	0.06	0.085
Ash	0.05	0.065
Carbohydrate (by difference)	0.08	0.14

The amount of energy needed per amount of seeds is expressed by the term 'specific mechanical energy (SME), which is commonly used for extrusion processes. SME denotes the amount of energy that remains within the products and is calculated by rearranging the energy equation (Zheng and others, 2005, 193-202):

$$SME = (W - Q_{conv} - Q_{cond} - Q_{rad}) / M_s = (M_c C_{p,c} T_c + M_o C_{p,o}, T_o - M_s C_{p,s} T_s) / M_s$$

Because of the low temperatures, radiation heat losses are negligible compared to convective and conductive heat losses and are therefore not taken into account.

The conductive heat losses can be estimated using Fourier's law for steady state one-dimensional heat conduction (Zheng and others, 2005, 193-202):

$$Q_d = -(k_b A_b + k_s A_s)\frac{dT}{dl}$$

with:
Q_d = conductive heat loss
k_b = k_s = thermal conductivity of screw and barrel which are assumed to be made of stainless steel
A_b and A_s = barrel and screw outer surface area
dT/dl = heat loss per unit of length

Convective heat losses are approximated by the following equation also taking into account the variation in outside diameter along the press (Zheng and others, 2005, 193-202):

$$h = 1.32\left(\frac{T_{hs} - T_r}{D}\right)^{0.25}$$

with:
h = convective heat loss
T_{hs} = hot surface temperature
T_r = reference temperature /room temperature
D = Outer diameter of hot surface

The actual values used for estimating required energy input for screw pressing are shown in Table J-2. The calculation done using previously estimated Jatropha values show a power requirement of 170 kJ/kg seed for normal seeds. For comparisons sake calculations using known Cp-values of cottonseed result in 97kJ/kg as can be seen in Table J-2. The value measured by the Altivar 31 is 112kJ/kg for normal seeds and 303kJ/kg for seeds with 2.14% moisture. The model of Zheng et al does not approach the values measured during testing. This might be due to inaccurate Cp-values or limitations of the model. No effort was therefore made to calculate power requirements for the Sayari expeller.

Table J-2 Input values and results for the calculation of power requirement for Jatropha pressing in the BT 50 press

	normal seeds	dry seeds 2.14% moidture
M_{cake} (kg/s)	0.67	0.67
M_{oil} (kg/s)	0.33	0.33
M_{seed} (kg/s)	1	1
$Cp_{jatrophacake}$ (J/kgK)	1630	1630
$Cp_{jatrophaoil}$ (J/kgK)	1910	1910
$Cp_{jatrophaseed}$ (J/kgK)	1556	1556
$Cp_{cottoncake}$ (J/kgK)	1494	1494
$Cp_{cottonoil}$ (J/kgK)	1787	1787
$Cp_{cottonseed}$ (J/kgK)	2176	2176
T_{cake} (K)	371.8	394.9
T_{oil} (K)	358.5	369.9
T_{seed} (K)	298.0	298.0
SME for Jatropha estimated Cp values (J/kg seed)	**168337**	**200806**
SME for cottonseed Cp values (J/kg seed)	**94882**	**124771**
Conductive heat losses		
k (w/mC)	16.3	16.3
A barrel (m2)	0.0093	0.0093
A screw (m2)	0.0019	0.0019
DT/dl	125	343
Conductive losses (W)	23	63
Conductive losses (J/kg seed)	**1173**	**3218**
Convective heat losses		
$T_{hotsurface}$ (degrees Celsius)	98	121.9
T_{barrel} (degrees Celsius)	85	96.9
$T_{reference}$ (degrees Celsius)	25	25
$h_{presshead}$	7.25	7.79
h_{barrel}	7.28	7.61
L_{barrel}	0.03	0.03
D_{barrel}	0.065	0.065
$L_{presshead}$	0.065	0.065
$D_{presshead}$	0.08	0.08
Convective heat loss (W)	11	16
Convective heat loss (J/kg seed)	**582**	**806**
Power requirement for Jatropha estimated Cp (kJ/kg seed)	**170**	**205**
Power requirement for cottonseed Cp (kJ/kg seed)	**97**	**129**

Appendix K: Foot levels in oil from the Sayari expeller and BT50 press

Foot levels of the oil produced by the Sayari expeller are shown in Table K-1. For the BT50 values are provided in Table K-2. Foot content in both tables proved too high for normal filtering techniques applied by Liquid Filtration Consultants (LFC Lochum BV, Lochem, The Netherlands) and suggested by Ferchau (2000). Foot contents for oil from the BT50 seem to be somewhat lower than for the Sayari judging from both tables. Some of the BT50 samples showed an additional 'slimy' component located in between oil and sediments. The composition of this 'slimy' component was not studies into further detail as filtering seemed to remove most of it from the oil.

Table K-1 Foot levels/sedimentation for oil from the Sayari expeller

Sample description	oil (l)	foot (l)	total (l)	foot content	colour
6.6% moisture press cake	0.87	0.53	1.4	37.9%	normal
6.6% moisture seeds	1	0.7	1.7	41.2%	light
total 6.6% moistre	**1.87**	**1.23**	**3.1**	**39.7%**	
6.7% moisture press cake	1.47	0.44	1.91	23.0%	light
6.7% moisture seeds	1.14	0.63	1.77	35.6%	light
total 6.7% moisture	**2.61**	**1.07**	**3.68**	**29.1%**	
8% moisture cake	0.75	0.16	0.91	17.6%	normal
8% moisture seeds	1.13	0.69	1.82	37.9%	normal
total 8% moisture	**1.88**	**0.85**	**2.73**	**31.1%**	
8.8% moisture seeds	0.52	0.58	1.1	52.7%	light
8.8% moisture press cake	0.57	0.43	1	43.0%	light
total 8.8% moisture	**1.09**	**1.01**	**2.1**	**48.1%**	
9.3% moisture seeds	0.42	0.52	0.94	55.3%	light
9.3% moisture press cake	0.37	0.42	0.79	53.2%	light
total 9.3% moisture	**0.79**	**0.94**	**1.73**	**54.3%**	
moist 2 seeds	1.47	1.13	2.6	43.5%	light
boiled seeds	2.33	1.32	3.65	36.2%	normal
normal 0 turns	1.875	0.85	2.725	32.3%	light
normal 1 turn	1.5	1	2.5	40.0%	light
normal 2 turn	1.7	1.33	3.03	43.9%	light
normal 3 turn	1.68	2	3.68	54.3%	light
cracked seeds	0.76	0.55	1.31	42.0%	normal
cracked cake	0.77	0.4	1.17	34.2%	normal
total cracked	**1.53**	**0.95**	**2.48**	**38.3%**	
dehulled (60%) seeds	0.49	0.57	1.06	53.8%	light
dehulled (60%) cake	0.4	0.34	0.74	45.9%	light
total dehulled	**0.89**	**0.91**	**1.8**	**50.6%**	

Table K-2 Foot levels for oil from BT50

Sample description	total (cm)	oil (cm)	foots (cm)	slime' (cm)	foot content	slime' content	total impurities
normal 28 RPM	9.5	6.8	2.7	3.8	28.4%	11.6%	40.0%
normal 42 RPM	9.7	6.7	3	4.2	30.9%	12.4%	43.3%
normal 49 RPM	10.2	6.8	3.4	4.4	33.3%	9.8%	43.1%
normal 56 RPM	9.6	6	3.6	4.4	37.5%	8.3%	45.8%
normal 70 RPM	10.1	5.7	4.4	4.7	43.6%	3.0%	46.5%
100% hull	10.2	6.8	3.4		33.3%		
90% hull	5.1	3.4	1.7		33.3%		
80% hull	-		-				
66% hull	5.1	2.5	2.6		51.0%		
		0					
13.3% moisture	6.7	2.7	4		59.7%		
9% moisture	-		-				
8.5% moisture	6.3	3.9	2.4		38.1%		
7.3% moisture	8.1	5.5	2.6		32.1%		
5.4% moisture	9.8	6.5	3.3		33.7%		
100℃ preheated	6.8	4.3	2.5		36.8%		
120℃ preheated	6.9	4.4	2.5		36.2%		
140℃ preheated	7.3	4.6	2.7		37.0%		
160℃ preheated	7.2	4.5	2.7		37.5%		
180℃ preheated	7.2	4.7	2.5		34.7%		

Appendix L: Reinartz & Keller presses and industrial oil recovery percentages

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The AP03, shown in Figure L-1, is particularly suited for soft oilseeds like rapeseed, linseed, sunflower and jojoba. Tests were done under standard settings. When the Jatropha seeds were de-hulled before pressing the amount of sediments appeared to increase. Specific values on the amount of sediment have to be determined by amafiilter (amafiltergroup Alkmaar B.V., Alkmaar, The Netherlands).

technical data:

length	1800 mm
width	500 mm
height	800 mm
net weight	400 kg
performance	3-4 KW
processing capacity for rapeseed	
hourly throughput	40 kg/h
annual throughput (approx. 8000h / year)	320.000 kg
processing capacity for other oil seeds	
hourly throughput	30 kg/h
annual throughput (approx. 8000h / year)	240.000 kg

Figure L-1 Technical details of the AP08 expeller

KEK Keller

Remscheid / Germany
Phone: +49-2191-8410-24
Fax: +49-2191-8628

Tests with Jatropha seeds were executed to find out whether high quality expellers would yield more oil than their Tanzanian counterparts. Details on the press used for these tests are shown in Figure L-2. Two separate tests were carried out with Jatropha seeds from Tanzania. The first test was under standard press settings for rapeseed and the second was optimized for Jatropha by inserting two larger pressure cones and changing the feed section for more transport capacity.

TECHNICAL DETAILS P0101		
Screw Press	Type:	P0101
Capacity	appr. kg/hr:	100
Drive Motor	kW:	7,5
Net Weight	appr. kg:	920
Gross Weight	appr. kg:	950
Crate Volume	appr. m^3:	3,7
Crate Dimensions	appr. mm W: appr. mm H: appr. mm D:	2240 1500 1100

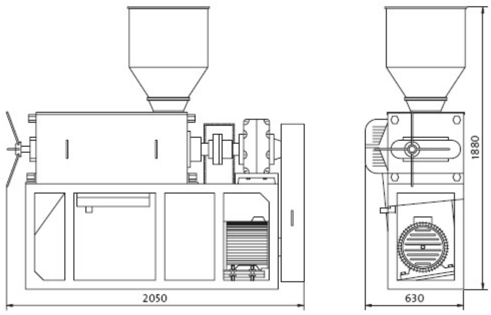

Figure L-2 Technical details of KEK P0101 expeller

Some detailed pictures of some of the Keller press components are shown in Figure L-3 to underline the quality difference with the Sayari expeller shown in Appendix F.

Figure L-3 Detailed view of some of the KEK P0101 components. From left to right: press cage made from separate bars, worm with cones for pressure build-up, adjuster for outlet restriction

Table L-1 gives an impression on the residual oil content of industrial oil expellers for various oilseeds. The residual oil contents are comparable to those achieved for Jatropha in BT50, Sayar, AP08 and P0101 presses. This finding indicates that Jatropha processing should be profitable.

Table L-1 Capacities and residual oil contents for three press types applied in industrial oil mills

DATA SHEET PRESSING RESULTS COLD PRESSING

OIL SEED	OIL CONTENT	KEK-P0020 SCREW PRESS				KEK-P0101 SCREW PRESS				KEK-P0500 SCREW PRESS			
		Seed kg/hr	Cake kg/hr	Oil kg/hr	Residual Oil Content	Seed kg/hr	Cake kg/hr	Oil kg/hr	Residual Oil Content	Seed kg/hr	Cake kg/hr	Oil kg/hr	Residual Oil Content
Apricot Kernels	42 %	10*	6,5	3,5	10 %	50	32	18	9 %	250*	160	90	9 %
Borrage	34 %	20	15	5	12 %	80	60	20	12 %	300*	225	75	12 %
Brazil Nuts	63 %	10	5	5	26 %	44	22	22	20 %	250*	125	125	25 %
Cameline	41 %	15	10	5	13 %	90	60	30	11 %	350*	232	118	11 %
Corn Germs	50 %	15	9	6	16 %	80	47	33	13 %	350	240	110	13 %
Evening Primrose	25 %	15	13	2	13 %	90	74	16	8 %	300*	250	50	10 %
Hemp	34 %	10	8	2	13 %	75	55	20	10 %	250	200	50	13 %
Jojoba	50 %	10	6	4	16 %	60	34	26	12 %	250*	140	110	12 %
Karité / Shea Nut	39 %	26	19	7	17 %	100*	71	29	14 %	400*	280	120	13 %
Linseed / Flax	38 %	10	7,5	2,5	13 %	65	45	20	11 %	300	210	90	11 %
Mustard	35 %	20	15	5	13 %	100	75	25	14 %	300*	220	80	11 %
Neem	47 %	20	12	8	13 %	100	60	40	11 %	400*	238	162	11 %
Niger Seed	40 %	20	14	6	14 %	100	67	33	13 %	350*	235	115	11 %
Palm Kernels	45 %	15*	10	5	17 %	70	45	25	13 %	300*	190	110	13 %
Paprika Kernels	25 %	15*	10	5	16 %	80	70	10	14 %	350*	300	50	13 %
Peach Kernels	40 %	10*	6,5	3,5	10 %	50	30	20	8 %	250*	160	90	9 %
Poppy	45 %	20*	13	7	15 %	100	65	35	14 %	350*	230	120	15 %
Rape Seed / Canola	42 %	20	13,0	7,0	14 %	100	66	34	12 %	500	340	160	11 %
Safflower	35 %	15	11	4	12 %	80	54	26	9 %	350	255	95	9 %
Sesame	50 %	25	15	10	16 %	120	70	50	14 %	400	230	170	13 %
Soybeans	19 %	20	18	2	11 %	100	89	11	9 %	350	315	35	10 %
Sunflower	42 %	30	20	10	13 %	100	66	34	12 %	400	260	140	11 %

The mentioned values are depending on the type and condition of the oil seed and may vary.

Appendix M: CBA results for different process setup

Decentralized processing

case 1: 5 **x KEK P0101** (70kg/hr) **8** hours operation per day with **cyclone filter**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$537,977						-$537,977	1.000	-$537,977
1		-$62,271	-$4,071	-$47,205	-$6,348	$144,382	$24,486	0.925	$22,655
2		-$62,271	-$4,071	-$47,205	-$6,348	$144,382	$24,486	0.856	$20,962
3		-$62,271	-$4,071	-$47,205	-$6,348	$144,382	$24,486	0.792	$19,395
4		-$62,271	-$4,071	-$47,205	-$6,348	$144,382	$24,486	0.733	$17,945
5	$364,076	-$62,271	-$4,071	-$47,205	-$6,348	$144,382	$388,561	0.678	$263,471
								NPV	**-$193,550**
								IRR	**-2%**

case 2: 5 x KEK P0101 (70kg/hr) **24** hours operation per day with **cyclone filter**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$567,977						-$567,977	1.000	-$567,977
1		-$261,539	-$13,436	-$105,569	-$12,696	$606,403	$213,163	0.925	$197,227
2		-$261,539	-$13,436	-$105,569	-$12,696	$606,403	$213,163	0.856	$182,482
3		-$261,539	-$13,436	-$105,569	-$12,696	$606,403	$213,163	0.792	$168,840
4		-$261,539	-$13,436	-$105,569	-$12,696	$606,403	$213,163	0.733	$156,218
5	$379,076	-$261,539	-$13,436	-$105,569	-$12,696	$606,403	$592,238	0.678	$401,578
								NPV	**$538,367**
								IRR	**34%**

case 3: **5 x KEK P0101** (70kg/hr) **8** hours operation per day with **sedimentation** (oil recovery is 0.2 instead of 0.3)

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$282,003						-$282,003	1.000	-$282,003
1		-$62,271	-$4,071	-$47,205	-$6,348	$105,368	-$14,528	0.925	-$13,442
2		-$62,271	-$4,071	-$47,205	-$6,348	$105,368	-$14,528	0.856	-$12,437
3		-$62,271	-$4,071	-$47,205	-$6,348	$105,368	-$14,528	0.792	-$11,507
4		-$62,271	-$4,071	-$47,205	-$6,348	$105,368	-$14,528	0.733	-$10,647
5	$189,548	-$62,271	-$4,071	-$47,205	-$6,348	$105,368	$175,020	0.678	$118,675
								NPV	**-$211,360**
								IRR	**-14%**

case 4: 5 **x KEK P0101** (70kg/hr) **24** hours operation per day with **sedimentation** (oil recovery is 0.2 instead of 0.3)

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$312,003						-$312,003	1.000	-$312,003
1		-$261,539	-$12,214	-$12,696	-$105,569	$442,545	$50,526	0.925	$46,749
2		-$261,539	-$12,214	-$12,696	-$105,569	$442,545	$50,526	0.856	$43,254
3		-$261,539	-$12,214	-$12,696	-$105,569	$442,545	$50,526	0.792	$40,020
4		-$261,539	-$12,214	-$12,696	-$105,569	$442,545	$50,526	0.733	$37,028
5	$204,548	-$261,539	-$12,214	-$12,696	-$105,569	$442,545	$255,073	0.678	$172,957
								NPV	**$28,005**
								IRR	**11%**

case 5: 5 **x Sayari** (70kg/hr) **8** hours operation per day with **cyclone filter** and **cheaper storage**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$299,575						-$299,575	1.000	-$299,575
1		-$62,271	-$4,071	-$47,205	-$800	$144,382	$30,034	0.925	$27,789
2		-$62,271	-$4,071	-$47,205	-$800	$144,382	$30,034	0.856	$25,711
3		-$62,271	-$4,071	-$47,205	-$800	$144,382	$30,034	0.792	$23,789
4		-$62,271	-$4,071	-$47,205	-$800	$144,382	$30,034	0.733	$22,011
5	$182,029	-$62,271	-$4,071	-$47,205	-$800	$144,382	$212,063	0.678	$143,793
								NPV	**-$56,481**
								IRR	**3%**

case 6: 5 x Sayari (70kg/hr) **24** hours operation per day with **cyclone filter** and **cheaper storage**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$329,575						-$329,575	1.000	-$329,575
1		-$261,539	-$12,214	-$105,569	-$12,696	$606,403	$214,384	0.925	$198,357
2		-$261,539	-$12,214	-$105,569	-$12,696	$606,403	$214,384	0.856	$183,528
3		-$261,539	-$12,214	-$105,569	-$12,696	$606,403	$214,384	0.792	$169,807
4		-$261,539	-$12,214	-$105,569	-$12,696	$606,403	$214,384	0.733	$157,113
5	$197,029	-$261,539	-$12,214	-$105,569	-$12,696	$606,403	$411,413	0.678	$278,966
								NPV	**$658,196**
								IRR	**63%**

case 7: 5 **x Sayari** (70kg/hr) **8** hours operation per day with **cloth filter** and **cheaper storage**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$51,850						-$51,850	1.000	-$51,850
1		-$62,271	-$4,071	-$47,205	-$800	$105,368	-$8,980	0.925	-$8,308
2		-$62,271	-$4,071	-$47,205	-$800	$105,368	-$8,980	0.856	-$7,687
3		-$62,271	-$4,071	-$47,205	-$800	$105,368	-$8,980	0.792	-$7,113
4		-$62,271	-$4,071	-$47,205	-$800	$105,368	-$8,980	0.733	-$6,581
5		-$62,271	-$4,071	-$47,205	-$800	$105,368	-$8,980	0.678	-$6,089
								NPV	**-$87,628**
								IRR	**-**

case 8: 5 **x Sayari** (70kg/hr) **24** hours operation per day with **cloth filter** and **cheaper storage**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$81,800						-$81,800	1.000	-$81,800
1		-$261,539	-$12,214	-$105,569	-$12,696	$442,545	$50,526	0.925	$46,749
2		-$261,539	-$12,214	-$105,569	-$12,696	$442,545	$50,526	0.856	$43,254
3		-$261,539	-$12,214	-$105,569	-$12,696	$442,545	$50,526	0.792	$40,020
4		-$261,539	-$12,214	-$105,569	-$12,696	$442,545	$50,526	0.733	$37,028
5		-$261,539	-$12,214	-$105,569	-$12,696	$442,545	$50,526	0.678	$34,260
								NPV	**$119,510**
								IRR	**55%**

Centralized processing

case 9: 1 **x Reinartz 14/30** (350kg/hr) **8** hours operation per day with **cyclone filter**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$250,760						-$250,760	1.000	-$250,760
1		-$62,271	-$10,178	-$53,299	-$3,624	$146,606	$17,233	0.925	$15,945
2		-$62,271	-$10,178	-$53,299	-$3,624	$146,606	$17,233	0.856	$14,753
3		-$62,271	-$10,178	-$53,299	-$3,624	$146,606	$17,233	0.792	$13,650
4		-$62,271	-$10,178	-$53,299	-$3,624	$146,606	$17,233	0.733	$12,630
5	$165,518	-$62,271	-$10,178	-$53,299	-$3,624	$146,606	$182,751	0.678	$123,918
								NPV	**-$69,865**
								IRR	**0%**

case 10: 1 **x Reinartz AP 14/30** (350kg/hr) **24** hours operation per day with **cyclone filter**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$310,760						-$310,760	1.000	-$310,760
1		-$261,539	-$30,535	-$119,808	-$7,247	$615,744	$196,614	0.925	$181,915
2		-$261,539	-$30,535	-$119,808	-$7,247	$615,744	$196,614	0.856	$168,315
3		-$261,539	-$30,535	-$119,808	-$7,247	$615,744	$196,614	0.792	$155,732
4		-$261,539	-$30,535	-$119,808	-$7,247	$615,744	$196,614	0.733	$144,090
5	$195,518	-$261,539	-$30,535	-$119,808	-$7,247	$615,744	$392,132	0.678	$265,892
								NPV	**$605,185**
								IRR	**61%**

case 11: 1 **x Reinartz AP15/45** (750kg/hr) **8** hours operation per day with **cyclone filter**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$361,686						-$361,686	1.000	-$361,686
1		-$124,543	-$20,357	-$53,299	-$3,695	$293,211	$91,318	0.925	$84,491
2		-$124,543	-$20,357	-$53,299	-$3,695	$293,211	$91,318	0.856	$78,175
3		-$124,543	-$20,357	-$53,299	-$3,695	$293,211	$91,318	0.792	$72,330
4		-$124,543	-$20,357	-$53,299	-$3,695	$293,211	$91,318	0.733	$66,923
5	$211,240	-$124,543	-$20,357	-$53,299	-$3,695	$293,211	$302,558	0.678	$205,155
								NPV	**$145,387**
								IRR	**20%**

case 12: 1 **x Reinartz AP15/45** (750kg/hr) **24** hours operation per day with **cyclone filter**

Year	Equipment	Seeds	Fuel	Labour	Maintenance	Revenues	Total	Discount factor	Dicounted Cash flow
0	-$481,686						-$481,686	1.000	-$481,686
1		-$523,079	-$61,071	-$153,877	-$10,124	$1,231,487	$483,337	0.925	$447,203
2		-$523,079	-$61,071	-$153,877	-$10,124	$1,231,487	$483,337	0.856	$413,770
3		-$523,079	-$61,071	-$153,877	-$10,124	$1,231,487	$483,337	0.792	$382,837
4		-$523,079	-$61,071	-$153,877	-$10,124	$1,231,487	$483,337	0.733	$354,216
5	$271,240	-$523,079	-$61,071	-$153,877	-$10,124	$1,231,487	$754,577	0.678	$511,654
								NPV	**$1,627,994**
								IRR	**99%**

Appendix N: Calculation of the Engaruka case

Poor yield 100 acres						
Year	Equipment	Running costs	Revenues	Total	Discount factor	Discounted cash flow
0	-$4,795			-$4,795	1.000	-$4,795.06
1		-$7,314	$13,095	$5,781	0.925	$5,348.71
2		-$7,314	$13,095	$5,781	0.856	$4,948.73
3		-$7,314	$13,095	$5,781	0.792	$4,578.67
4		-$7,314	$13,095	$5,781	0.733	$4,236.28
					NPV	**$14,317.33**
					IRR	**115%**

Standard situation 100 acres						
Year	Equipment	Running costs	Revenues	Total	Discount factor	Discounted cash flow
0				$0	1.000	$0.00
1		-$2,450	$6,300	$3,850	0.925	$3,562.10
2		-$2,450	$6,300	$3,850	0.856	$3,295.73
3		-$2,450	$6,300	$3,850	0.792	$3,049.28
4		-$2,450	$6,300	$3,850	0.733	$2,821.25
					NPV	$12,728.36

Poor yields 50 acres						
Year	Equipment	Running costs	Revenues	Total	Discount factor	Discounted cash flow
0	-$4,795			-$4,795	1.000	-$4,795.06
1		-$4,002	$6,344	$2,343	0.925	$2,167.51
2		-$4,002	$6,344	$2,343	0.856	$2,005.42
3		-$4,002	$6,344	$2,343	0.792	$1,855.46
4		-$4,002	$6,344	$2,343	0.733	$1,716.71
					NPV	**$2,950.03**
					IRR	**33%**

Optimistic yields 100 acres						
Year	Equipment	Running costs	Revenues	Total	Discount factor	Discounted cash flow
0	-$4,795			-$4,795	1.000	-$4,795.06
1		-$23,132	$40,097	$16,965	0.925	$15,696.24
2		-$23,132	$40,097	$16,965	0.856	$14,522.49
3		-$23,132	$40,097	$16,965	0.792	$13,436.51
4		-$23,132	$40,097	$16,965	0.733	$12,431.73
					NPV	**$51,291.91**
					IRR	**353%**

Standard situation 100 acres optimistic yield						
Year	Equipment	Running costs	Revenues	Total	Discount factor	Discounted cash flow
0				$0	1.000	$0.00
1		-$2,450	$18,900	$16,450	0.925	$15,219.88
2		-$2,450	$18,900	$16,450	0.856	$14,081.75
3		-$2,450	$18,900	$16,450	0.792	$13,028.73
4		-$2,450	$18,900	$16,450	0.733	$12,054.45
					NPV	$54,384.80

Appendix O: Villages for case study

Case studies

Rural areas could potentially benefit from the products coming from the Jatropha plant. However most of these products, except the seeds themselves, require processing equipment for production. The example that leaps to the eye is oil production. In any case a machine to press the oil from the seeds in necessary. Storage tanks and filters are also required. Before the oil is ready to put into an engine neutralizing and filtering should be conducted, although in case of older Lister engines crude filtering is sufficient. To a lesser extent these investments also hold for soap, fertilizer and briquette production. One can imagine that most rural communities in Tanzania are unable to invest in such machinery and therefore end up selling yet another primary product at unrewarding prices. In an attempt to depict to what extend local people can exploit the benefits associated with Jatropha without a strong dependence on European and North American investors three different Jatropha cases are developed. The cases represent three villages in Northern Tanzania with a different level of potential to use Jatropha. Their classification is as follows:

Temi ya Simba

This small village of approximately 600 inhabitants close to Arusha has no electricity grid connection and for cooking the inhabitants use mostly wood, which they collect outside the village. Charcoal stoves or the more sophisticated plant oil stoves are not yet introduced to this region. Two farmers are growing Jatropha and around 100 people grow trees in hedges throughout the village and around agricultural land. During the first harvest 170 kg of Jatropha seeds were collected for Diligent and 600kg was used by the women group for soap production. According to Mr Rubanze the total Jatropha production potential for this village is around 4-6 tons/year two years from now (in case of two harvest seasons per year). Local applications for Jatropha oil are substitution of conventional diesel for the five village maize mills and soap production by a local women group supported by Kakute. It is interesting to find out if the people are interested in electricity, charcoal or even soap production on a larger scale. **Error! Reference source not found.** shows diagram clarifying the Jatropha applications and the flow of goods between actors in Temi ya Simba. The colours classify the benefits of Jatropha to a certain actor. Farmers are the only village members assumed to generate additional income form Jatropha. The user experience more practical advantages like increases fuel availability and healthier cooking methods due to decreased smoke production.

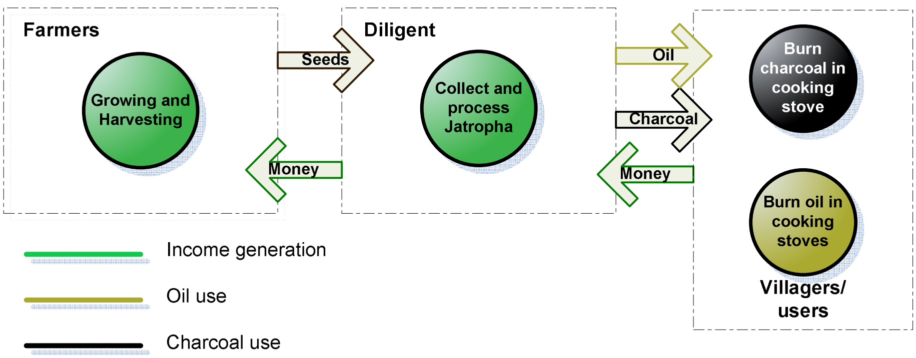

Figure 0-1 Jatropha utilization in Temi ya Simba

Maji ya Chai

In the region of Maji ya Chai many people are enthusiastic about the introduction of oil fuelled Bosch-Siemens Protos plant oil stoves by the German NGO GTZ. One reason for the introduction of the stoves is to get people to use renewable oils instead of fossil fuels or wood. The use of cooking wood is one of the most important causes fro deforestation in Tanzania. However villagers cannot afford to pay for the oil to fuel the stove as Jatropha oil and sunflower oil are more expensive than both wood and kerosene. This village serves as a case to check if growing Jatropha solely for cooking purposes is feasible. As can be seen in the model in **Error! Reference source not found.** the farmers gain additional income by processing the seeds into oil at farm level.

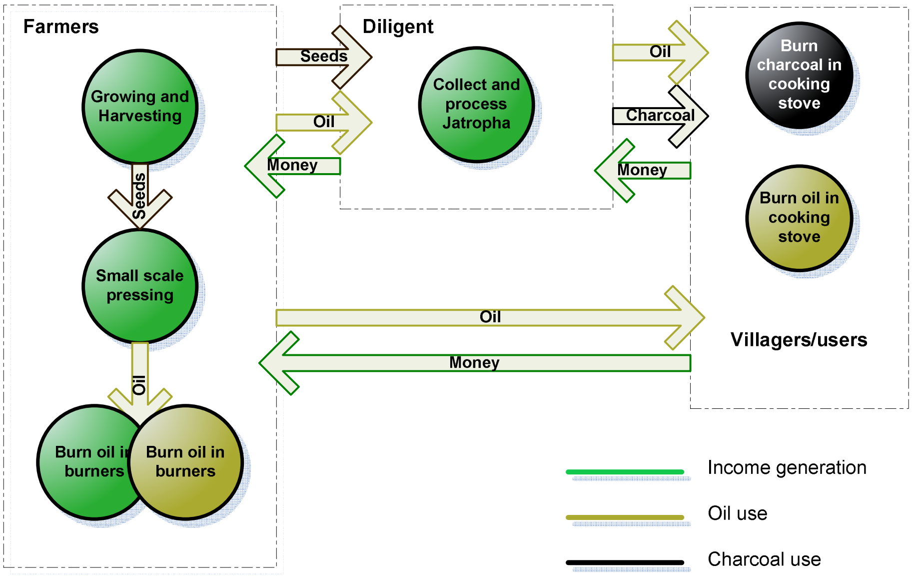

Figure 0-2 Jatropha utilization in Maji ya Chai

Engaruka

The village of Engaruka consists of two separate parts: northern and southern Engaruka. Most of the 9000 inhabitants of this Maasai village make a living as farmers or keeping feedstock. As is the case for Temi ya Simba there is no grid connection present in the village. Therefore a Multi Functional Platform (MFP) was installed by a Tanzanian NGO named TaTedo in November 2006 to combine seed pressing with electricity generation and grain milling. An impression of the MFP is given in Figure 7-1. The MFP operates five hours a day generating roughly 6 kWh. In total 20 shops, 3 houses and a campsite are provided with energy from this platform. In addition to the grain mill connected to the MFP seven more diesel powered grain mills are present in the village. Together with the diesel driven generator these machines constitute the potential Jatropha consumption in Engaruka. As Jatropha was already grown in Engaruka for fencing most seeds still stem from hedges. Over 30 farmers are growing Jatropha on small plots between 0.5-3 acres in size(2007). The first harvest in 2007 produced approximately 2400 kg Jatropha seeds. The total land area available for Jatropha is around 100 acres. As can be seen in Figure 6-2 the model for Engaruka shows most economical activities as a result of Jatropha processing. The most important expansions are the inclusion of electricity production and a larger group of people generating additional income from Jatropha. A press cooperation consisting of maybe 5-10 people could start production of Jatropha oil and grain millers could also benefit from this cheaper locally produced fuel to power their engines. The investment required to setup a press-cooperation probably exceed the amount of money available to the local investors. Most of the villagers cannot get any loans from the bank as farming is excluded from the definition of enterprises the bank uses when judging loan requests. Therefore Savings and Credit Co-operatives (SACCOs) are included in this system. The SACCO system is a mutual membership organization, which involves pooling of voluntary savings from members in the form of shares. These savings or shares form the basis for providing credit to members. The available credit is normally around three times the level of savings or shares. The importance of this market segment is underlined by a SACCOs market of nearly US$1 billion in Kenya. (Enterprising Solutions Global Consulting, 2003)

Figure 7-1 Left hand picture: A TaTEDO test MFP near Dar es Salaam with from left to right a Sayari screw press, Lister engine and a maize mill. Between the engine and the maize mill normally a generator is fitted like the blue one shown in the right hand picture that was taken in Engaruka.

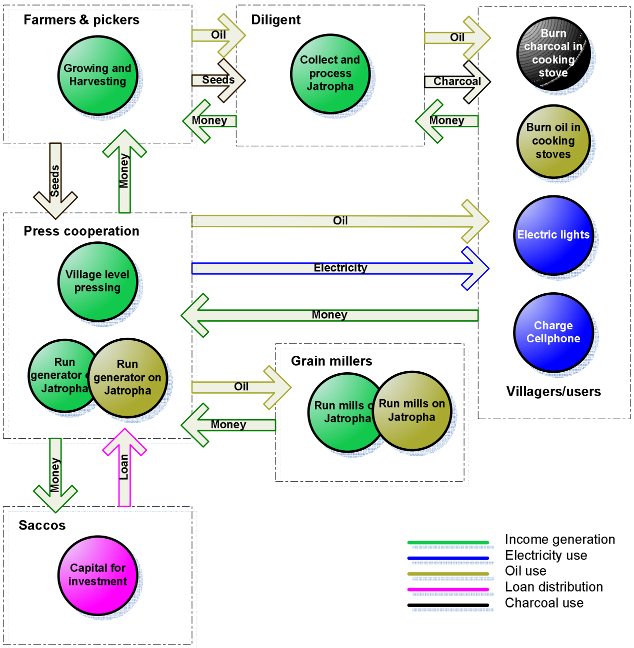

Figure 7-2 Jatropha utilization in Engaruka