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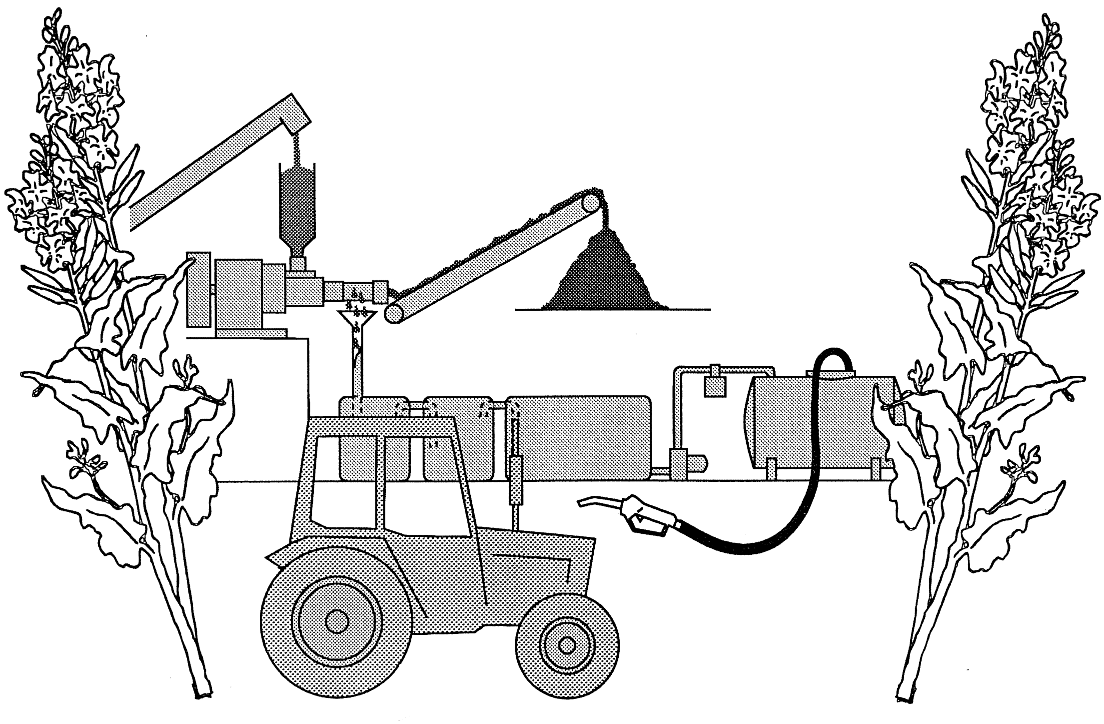
EXTRACTION OF RAPE SEED OIL AND FARM OPERATION OF AN ELSBETT ENGINE TRACTOR

Sven Bernesson



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ABSTRACT

This Licentiate thesis deals with small-scale extraction of rape seed oil and the use of this oil in an Elsbett engine tractor.

Small-scale extraction of rape seed oil was studied in practical tests in the laboratory at Ultuna, Uppsala. The influence of the speed of the press screw, nozzle size and nozzle performance, the distance between the press screw and the press chamber head, the ambient temperature, and preheating of the seed with air was studied.

At Sjösa farm a small plant for on-farm extraction of rape seed oil was built. The processing of three bigger batches of oil seed was studied. Data of interest were registered in an operating log. Capacity and oil extraction efficiency were studied.

A tractor with an Elsbett engine was operated at Sjösa farm on the processed rape seed oil. Data of interest were registered in an operating log and with an automatic data collection system.

The data obtained on the farm were used to conduct an energy analysis.

The oil press has higher capacity with bigger nozzles and higher screw speeds. However, the amount of oil extracted from each seed increased if the nozzles were smaller and/or the press screw speed was lower. Nozzles with a long press nozzle channel gave a more solid meal. It was important that the temperature in the press chamber head reached a temperature of about 70°C. The optimum seed moisture content (wet basis) was 7-8 per cent. Preheating with air usually improved the capacity, but there is a risk of over-drying so it must be done with care. Preheated seed involves a risk of getting too high levels of phosphorus in the oil.

On the farm, the simplest way of cleaning the oil is settling. This can be done in three series-coupled sedimentation tanks. If the ambient temperature is +20°C and the settling height is 0.6 m, about 18 days are needed for the settling.

A tractor with an Elsbett engine can be operated almost in the same way as a conventional tractor. The differences are rape seed oil fuel, separate starting fuel, more frequent fuel filter exchange, electrical heating of the fuel system and about 10 per cent higher fuel consumption. Problems may occur when the rape seed oil stiffens at -15°C.

To obtain a good energy balance it is important to have a high yield and low moisture contents. It is important also to have uses for the meal and straw. Direct seeding also improves the energy balance.

The main conclusion of the project is that a system involving rape seed oil and the Elsbett engine works well technically. The system is not, however, competitive as there are cheap fossil fuels on the market, and the Elsbett engine has not yet entered serial production. In addition, the supply of rape seed oil in Sweden is limited, and the oil produced could be used for better purposes than as vehicle fuel.

CONTENTS

1 LIST OF INCLUDED REPORTS

The Licentiate thesis consists of the present report, summarizing the project, and the two earlier reports listed below. In the text, they are denoted by Roman numerals.

I Bernesson, S. 1990. Pressning av rapsfrö på gårdsnivå - en studie över möjligheter och begränsningar. Praktiska försök och litteraturstudier - en förstudie. (Extraction of rape seed oil on the farm level - a study of possibilities and limitations. Practical experiments and a literature review - a pilotstudy). (In Swedish). Inst. medd. 90:16. Dept. of Agr. Engineering. The Swedish University of Agricultural Sciences.

II Bernesson, S. 1993. Studie av rapspressning och körning med en traktor med elsbettmotor på Sjösa gård. Extraction of rape seed oil and farm operation of an Elsbett engine tractor. (In Swedish). Inst. medd. 93:03. Dept. of Agr. Engineering. The Swedish University of Agricultural Sciences.

Report I deals with a literature review of small-scale extraction of rape seed oil and with laboratory experiments on extraction of rape seed oil in a small screw press.

Report II deals with on-farm experiments with small-scale extraction of rape seed oil and the use of this oil as fuel in an Elsbett engine tractor. The results of this practical study were used as a base for an energy balance study of on-farm production of rape seed oil.

2 INTRODUCTION

The thesis deals with small-scale extraction of rape seed oil and the use of this oil in an Elsbett engine tractor. Small-scale extraction of rape seed oil was studied in the laboratory with practical tests where different press parameters have been examined. Oil press (or oil expeller) capacity and oil extraction efficiency were studied. The results from the laboratory study were tested in practical operation for two years on the farm. The oil was used as fuel in an Elsbett engine tractor that was operated as a normal tractor in the ordinary work on the farm. Finally, an energy balance study was made from on-farm extraction of rape seed oil on the basis of the results from the laboratory and the on-farm experiments.

The aim of this project was to develop a system for production and use of rape seed oil as fuel in agricultural vehicles. The basis for the study was to conduct experiments with a small oil press and to operate a tractor with an Elsbett engine on a farm. The system was evaluated from technical, economical and energy aspects.

The aim of the prestudy for report I was to learn how to operate the oil press to get a suitable oil extraction capacity, oil extraction efficiency, and to get an oil suitable for fuel in a tractor with an Elsbett engine.

2.1 Background

Interest in using rape seed oil as a fuel for engines has increased during recent years as the demand for environmentally considerate fuels has become evident. Biofuels, like rape seed oil, can be used as fuel in vehicles to reduce overall carbon dioxide emissions. They give no additional contribution of carbon dioxide to the atmosphere when burnt. Rape seed oil does not contain other environmentally dangerous constituents like heavy metals or sulphur.

In the situation of today, where Swedish agriculture faces a big demand to reduce the areas for cereal grains and find new alternatives for the use of farm land, oil seed crops for production of fuel oil may be an alternative. There are numerous advantages in using vegetable oil in farm vehicles. The farmer will become less dependent on import fuels, with their uncertainty in supply and prices. To have his own fuel may be of considerable value with regard to preparedness aspects.

The use of rape seed oil in Elsbett engines does not need a widespread infrastructure for processing and distribution. The oil can be extracted on the farm and, after settling and filtration, can be used directly in the vehicles. The meal (or cake, the remnants of the seed after oil extraction) can be used as a feedstuff, fuel for heating, fertilizer (most of the nutriment is left in the meal) or for digestion to biogas.

Rape seed oil used as fuel in conventional diesel engines with direct injection may cause certain problems, for example coke deposits in diesel engines. The Elsbett engine does not have these problems as it has been developed for running on pure vegetable oils.

The Elsbett engine is a variant of the direct injected diesel engine. It has a different combustion system with pistons divided into two parts (a upper ferrum part and a lower aluminium part) and duothermic combustion (inside a spherical combustion chamber a cold layer of rotating excess air insulates the wall of the combustion chamber from the hot central combustion area. Inside this central combustion area the air swirls and the fuel jet is mixed under controlled conditions and combustion takes place, see Fig. 3). The Elsbett engine is cooled by the engine lubrication oil. The efficiency is high, almost as high as in conventional direct-injected diesel engines. Exhaust emissions are low.

2.2 Nature and scope of the problem

The first objective of this project was to study:

* How a small screw oil press should be operated to give suitable oil extraction efficiency, oil extraction capacity, and give an oil suitable for fuel in tractors with Elsbett engines.

* Problems that may occur when a small screw press is operated on a farm and how these problems can be solved.

* How the oil should be cleaned after being extracted in order to be a suitable fuel in Elsbett engines.

* The annual fluctuations in seed yield and seed quality, and how important these fluctuations are.

The next objective was to study:

* The operation of an Elsbett engine tractor to see if it could be operated on a farm in the same way as a conventional tractor.

* Problems that may occur when an Elsbett engine tractor is operated on a farm and how these problems can be solved.

* The amount of service required by an Elsbett engine tractor.

* The effects of cold weather operation.

The final objective was to identify:

* Feasible energy balances when rape seed oil is produced at farm level.

* The influence of different yields and moisture content in the seed.

* The most important energy expenditures when rape seed oil is produced.

3 LITERATURE

3.1 Literature review, oil extraction

In Germany, at the Institut für Landtechnik in Freising Wiehenstephan, small-scale extraction of rape seed oil has been studied in the laboratory (Widmann, 1988). Capacity, oil extraction efficiency, requirements for power and energy, optimal adjustment, cleaning of the oil, and settling have been studied.

Similar investigations have been made in the USA (Blake, 1982; Jacobsen & Backer, 1986; Thompson & Peterson, 1982) in Germany, Stuttgart - Hohenheim (Maurer et al., 1990), as well as the prestudy for report I.

There is also a study of on-farm oil extraction at Logården in Västergötland in Sweden (Lagerfelt, 1992). A tractor with an Elsbett engine was also studied on this farm. This project was on a smaller scale but similar to the present project.

A detailed literature review is included in report I.

This study is the first in which the whole system with on-farm extraction of rape seed oil as fuel for tractors on the farm has been studied in detail, in practice, during agricultural operations on the same farm.

3.2 Literature review, tractor running on rape seed oil

There are several examples of experiments using mixtures of rape seed oil and diesel oil in conventional diesel engines. One example is the test with 33 per cent rape seed oil mixed with diesel oil that was made at the National Swedish Testing Institute for Agricultural Machinery in the beginning of the 1980s (SMP, 1987). In all these tests, there were deposits of coke residues in the combustion chamber of the engines. The build-up of coke residues in the engine's combustion chamber caused engine failure in the long run.

Numerous tests, and also commercial operation, have been made with trans-esterified rape seed oil (rape methyl ester, RME) as fuel in conventional diesel engines. Here, no deposits of coke residues have been observed in the engines. With this fuel, the engines run, in principal, without problems. Austria has been the leading nation in the utilization of transesterified rape seed oil as engine fuel (Wörgetter et al., 1991a; Wörgetter et al., 1991b).

Rape seed oil can be used directly in Elsbett engines provided that the amount of phosphorus is not too high in the oil. The drawback with this engine is that it is a new sort of diesel engine and existing engines are very expensive to rebuild (if at all possible) to Elsbett engines. At the moment, several tests with such engines are being conducted in Europe. Germany has been the leading nation in the utilization of rape seed oil in Elsbett engines (Schön et al., 1992).

In Sweden a similar, but slightly simpler, study has been done on the farm Logården in Västergötland (Lagerfelt, 1992), where a tractor was operated on rape seed oil extracted on the farm.

A detailed literature review of the utilization of vegetable oil as engine fuel is presented in Bernesson (1990a).

This is the first study where both an operating log was made and data were collected by an automatic data collection system on a tractor with an Elsbett engine, in practical utilization on a farm, where the fuel oil for the tractor has also been extracted.

4 METHODS AND MATERIALS

In both the oil extraction experiments at Ultuna and at Sjösa farm, the same oil press was used. The oil press was a small screw oil press, Komet S87G, made by Monforts in Germany, see Fig. 1.

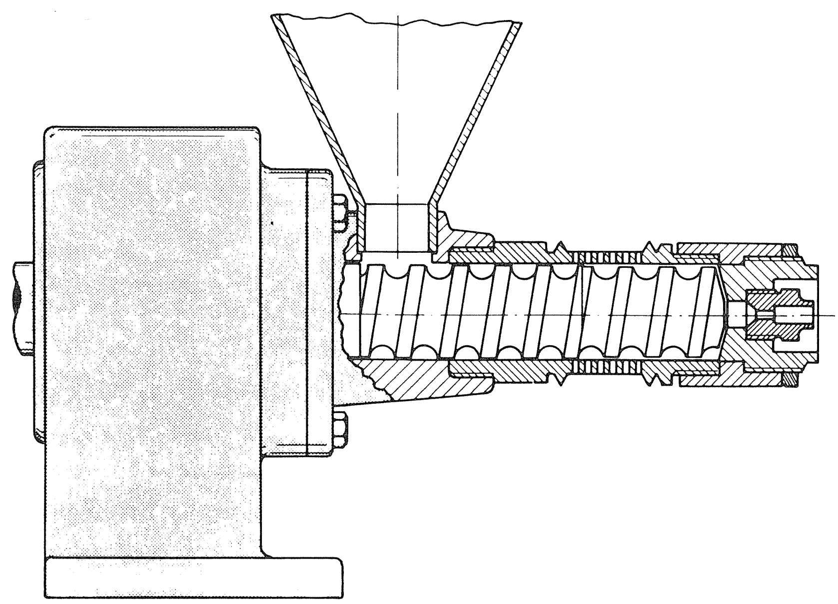

Figure 1. Cut away view of the screw and press chamber head to the oil press type Komet S87G, from Monforts. Illustr: Kim Gutekunst.

In this report the term oil extraction efficiency (%) is used frequently. It can be defined as: 100 * amount of expressed oil (kg) / total amount of oil in the seed before processing (kg).

4.1 Methods and materials for the oil extraction at Ultuna

A small screw oil press, Komet S87G, from Monforts in Germany, was used for the oil extraction. It had a capacity of about 5 litres of oil per hour. The seed, oil and meal was weighed on an electronic weighing-machine with an accuracy of ±0.1 g. The oil was sent to EXAB Foder AB for analysis of its phosphorus content.

The experiments were carried out in five parts.

In the first part, the temperature in the press room was varied in a climate chamber. The oil press was operated at about -10°C, ±0°C, +10°C and +20°C. In each sample 140-1400 g of rape seed was processed to oil and meal. The oil press was operated at 10, 20, 30 and 40 rev/min with nozzles of 6, 8, 10 and 12 mm inner diameter. At +20°C a nozzle with 15 mm inner diameter was also tested. Only one sample was pressed with each combination of variables.

In the second part, the ambient temperature was about +20°C. In each sample 1000-1500 g of rape seed was processed to oil and meal. The oil press was operated at 50, 60, 70, 80 and 90 rev/min with nozzles of 6, 8 and 10 mm inner diameter. Only one sample was pressed with each combination of variables.

In the third part, the ambient temperature was about +20°C. In each sample 500-1500 g of rape seed was processed to oil and meal. The oil press was operated at 40 rev/min with nozzles of 6, 8 and 10 mm inner diameter and at 30 rev/min with a nozzle of 10 mm inner diameter. Five samples were pressed with each combination of variables.

In the fourth part, the ambient temperature was about +20°C. The seed was preheated to 35, 40 or 45°C with hot air. In the experiments with preheating, the oil press was working continuously with a continuous supply of rape seed. It was not possible to weigh the seed, and only the oil and the meal could be weighed. One reference experiment was made without preheating, and here 1000 g rape seed was processed to oil and meal in each sample. In the experiments with preheating, the oil press was running in 5 minutes for each sample before the oil and meal was weighed. Five samples were pressed with each combination of variables.

In the fifth part, the ambient temperature was +10-14°C. In most of the experiments the seed was not preheated. In some sub-experiments the seed was preheated to just above 30°C or just above 40°C. The oil press was working continuously with an unbroken supply of rape seed. It was not possible to weigh the seed, and only the oil and the meal could be weighed. The press was run for 5 minutes (300 s) for each sample before the oil and meal was weighed. In this experiment, the press nozzle temperature was registered as it gave a good indication of whether the oil press was running under stable pressing conditions. The five samples for each experiment were taken consecutively without break. Between each experiment the press was allowed to run for at least 25 minutes, without any measurements, while waiting for stable pressing conditions in the oil press. When the seed was preheated with air, the oil press had to run at least 60 minutes before a stable temperature was registered in the seed and at the press nozzle. The oil press was operated at 60, 70, 80 and 90 rev/min with nozzles of 6, 8 and 10 mm inner diameter. As a variant of the nozzles, a long press nozzle channel was also tested. All the nozzles were also tested with and without an adjusting spacer that moved the press screw 0.51 mm closer to the press chamber head. At the end of this part, the two best experiments (6 and 8 mm inner diameter nozzle with a long press nozzle channel at 80 and 90 rev/min with an adjusting spacer) were selected for the test with preheating of the seed for the oil press.

After the fifth part, the oil press was allowed to run continuously for 63 hours at full production. The oil press was operated at 90 rev/min with a 6 mm inner diameter nozzle with a long press nozzle channel. The press screw was moved closer to the press chamber head with an adjusting spacer. No interruptions of production occurred.

4.2 Methods and materials for oil extraction at Sjösa farm

At Sjösa farm, a farm plant for extraction of rape seed oil was built in a separate insulated room, see Fig. 2. The same oil press was used as in the oil extraction experiments at Ultuna. The seed was supplied with an auger from a seed container. For settling of the oil after extraction, three series-coupled settling tanks were used. The first two were empty oil drums (220 l, 0.9 m high), the last consisted of three parallel-connected old milk tanks (400 l, 0.6 m high). Finally, the oil was pumped into a 2 m^3 storage tank. The meal was transported to a store down a tipping chute and on to a band conveyor.

It was also possible to preheat the seed with air before the oil extraction using the same equipment as in the experiments with seed preheating at Ultuna.

The quantity of seed and meal were batch-weighed on a vehicle weighing-machine. The quantity of oil was measured by volume with a gauge rod in the third group of sedimentation tanks or with a rotary flowmeter. The quantity of sediment was weighed on a mechanical balance.

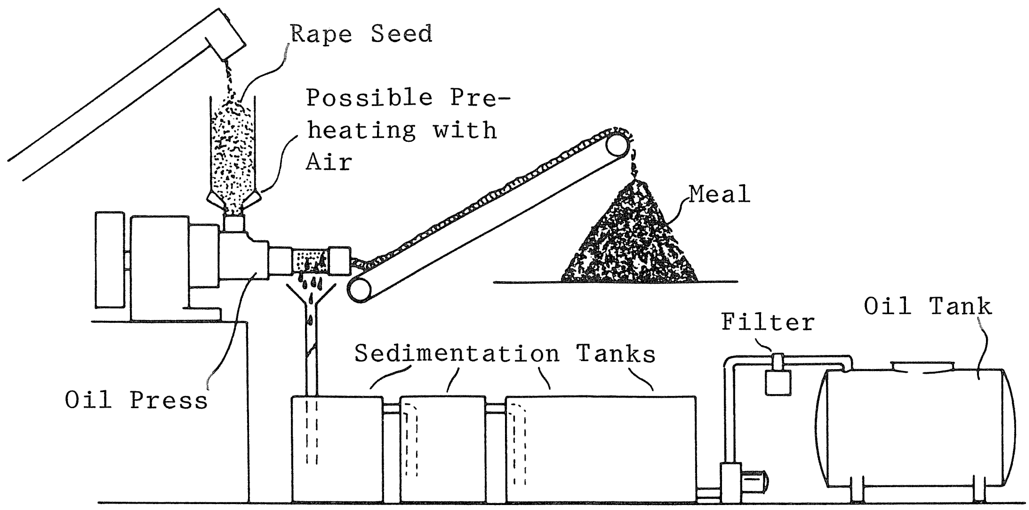

Figure 2. Schematic picture of the small plant for oil extraction at Sjösa farm. Illustr: Kim Gutekunst.

The temperature of the seed, the press nozzle, settling tanks, meal store and oil extraction room were recorded. Energy consumption for the whole oil extraction plant, and for the oil press only, was measured with two kWh-meters.

The following data were registered daily in an operating log: date, time, sort of work with the oil extraction plant, problems and their cause, amount of seed weighed into the seed container, amount of meal and oil out, amount of oil in sedimentation tank no. three, electrical consumption as mentioned above, temperatures as mentioned above, and observations.

Sometimes samples for analysis were taken of the seed, oil, meal and sediment. The moisture content was analysed in the seed and meal. The oil content was analysed in the seed, meal and sediment. The amount of phosphorus was analysed in the oil.

Three larger batches of spring rape seed were processed, the 1990 and 1991 harvests from Sjösa farm and a batch of purchased seed from the 1991 harvest of Brunnsholms Säteri.

When the batch of the 1990 harvest from Sjösa was processed the oil press was running at 80 rev/min with a 6 mm inner diameter nozzle with a long press nozzle channel. The seed was not preheated before processing.

When the batch of the 1991 harvest from Sjösa was processed the oil press was running at different adjustments: when the oil press was running at 80 rev/min with a 6 mm inner diameter nozzle with a long press nozzle channel, experiments were conducted without preheating of the seed, preheating of the seed to 30-40°C and with preheating of the seed to 40-50°C. The seed was not preheated when the oil press was running with a 10 mm inner diameter nozzle with a normal press nozzle channel.

When the batch of purchase seed from the 1991 harvest of Brunnsholms Säteri was processed, a 6 mm inner diameter nozzle with a long press nozzle channel was used. When the oil press was running at 80 rev/min, experiments were conducted with (as normal here) and without heating of the press chamber head to 70°C. Experiments were also conducted with the oil press running at 50 rev/min.

4.3 Methods and materials for the tractor study

The tractor used was a Valmet 805 with a three cylinder engine from a Valmet 605. This engine was rebuilt to an Elsbett engine by Elsbett-Konstruktion at Hilpoltstein, Germany. Engine power, fuel consumption and exhaust emissions were measured on an engine dynamometer by the National Swedish Testing Institute for Agricultural Machinery in Uppsala (Zetterström, 1993). Subsequently, the tractor was used in practical farm work mainly at Sjösa farm, near the city of Nyköping. Data collection was made on the one hand with an automatic data collection system, when it has worked, and on the other hand with a manual operating log in which entries were made each time the tractor was in operation.

The tractor was used for two growing seasons 1991 and 1992 at Sjösa farm and at Skuttunge north of Uppsala the spring winter 1993.

The Elsbett engine (Fig. 3) is a variant of the direct-injected diesel engine. Differences from other direct-injected diesel engines are that the pistons are divided in two parts, an upper part of cast iron and a lower part of aluminium, one-hole self-rinsing pintle nozzles and a duothermic combustion system. During the combustion, two zones take form in the rotating air in the combustion chamber: An inner central combustion zone where the fuel is injected and burnt, and an outer insulating air coat that prevents heat from being conducted away from the combustion zone. It also prevents deposits from the combustion on the walls in the combustion chamber. In the Elsbett engine, the engine lubrication oil is also used for cooling of the engine.

Log entries were made each time the tractor was in operation, at the end of a working day or when the work operation was changed. The following were registered in the operating log: date, time, work operation, which implement was used, tractormeter (hours), refuelling (rape seed oil or diesel oil in litres), engine lubrication oil, work site, and remarks.

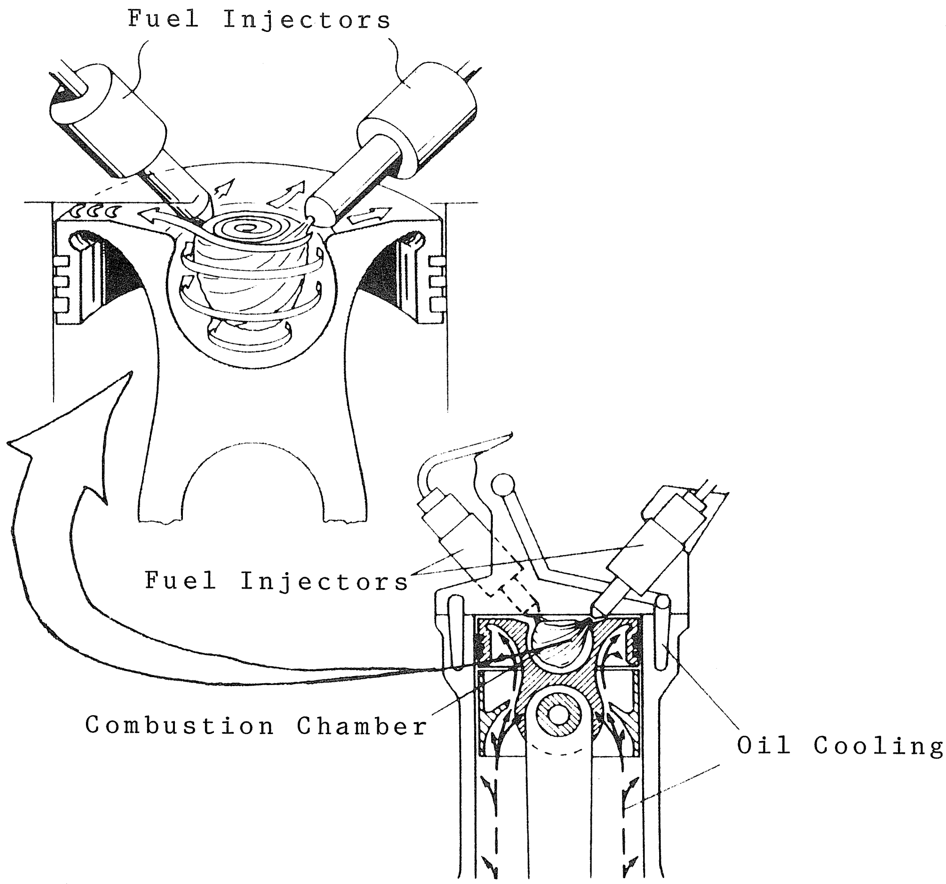

Figure 3. The combustion and oil cooling in an Elsbett engine. Illustr: Kim Gutekunst.

The automatic system for data collection registered the following data: engine revolutions (rev/min), ambient temperature, rape seed oil fuel tank temperature, fuel temperature at the fuel injection pump, engine temperature (lubrication and cooling oil after the cooler going to the cylinder linings), induction air temperature (after the intercooler), and exhaust temperature.

The automatic data collection system was in operation only for a few days in 1991 and in April and May 1992.

4.4 Methods for the energy analysis

For energy analysis, the energy input for all operations and the energy content in all products needed to produce rape seed oil from the field and to convert it into tractor fuel were analysed. The energy yields in the rape seed oil, meal and straw were analysed.

For Sjösa farm the production of winter and spring rape was studied more carefully in the growing seasons of 1990-1992. Yields of seed and oil were registered, the yields of straw were calculated. The seed moisture content was supposed to be 18 per cent (wet basis) at harvest and needed to be dried to 8 per cent before processing.

Results from the oil extraction study and the tractor study at Sjösa and Ultuna were used in the calculations.

For a standard yield of 2400 kg/ha of spring rape, the influence on the energy balance of oil extraction efficiency and the moisture content in the seed was studied. Sensitivity analyses were made for different yields, oil extraction efficiency and moisture content in the seed.

The energy balance can be defined as: energy output / energy input.

Energy output in this report is: the low heat value in the produced products * amount (kg) produced of each product.

Energy input is: direct and indirect energy demand for the production.

Analyses were also made of the production of rape seed oil with different cultivation methods, more efficient production of the nitrogen fertilizer, and a better oil extraction in a well insulated room.

5 RESULTS

5.1 Results from the oil extraction at Ultuna

The ambient temperature had little or no influence on the oil extraction efficiency and the capacity of this oil press. With bigger nozzles the capacity rises somewhat when the ambient temperature rises.

The capacity of the oil press (kg oil/hour or kg seed/hour) is dependent on nozzle size (inner diameter mm) and rotation speed of the oil press screw (rev/min). Bigger nozzles give a higher capacity than smaller ones up to 10 mm inner diameter. The difference is larger for nozzles with 8 and 10 mm inner diameter than for nozzles with 6 and 8 mm inner diameter. Nozzles with 6 and 8 mm inner diameter are very close to each other and nozzles with 10, 12 or 15 mm are very close to each other, see Fig. 4 and report I. The capacity increases with increasing speed of rotation in the studied interval, see Fig. 5. At low rotational speed the capacity is unacceptably low. Capacity is normally somewhat lower for nozzles with a long press nozzle channel than for nozzles with a normal press nozzle channel, see Fig. 6. The capacity is also normally somewhat lower when the press screw is moved 0.5 mm closer to the press chamber head with an adjusting spacer, see Fig. 6. However, for 6 mm (see Fig. 6) and 8 mm nozzles the capacity was higher for nozzles with a long press nozzle channel than for nozzles with a normal press nozzle channel when the press screw was moved 0.5 mm closer to the press chamber head with an adjusting spacer.

The oil extraction efficiency is dependent on nozzle size (inner diameter mm), see Fig. 4 and rotation speed of the oil press screw (rev/min), see Fig 5, see also report I. There is almost no difference between nozzles with 8 or 6 mm inner diameter. Bigger nozzles give, in general, lower oil extraction efficiency than smaller ones. In the measurements for Fig. 4, nozzles with 8 mm inner diameter were better than nozzles with 6 mm inner diameter, but in most other measurements there are no differences between nozzles with 6 and 8 mm inner diameter, see report I. The oil extraction efficiency is normally somewhat higher for nozzles with a long press nozzle channel compared with nozzles with a normal press nozzle channel, see Fig. 6. The oil extraction efficiency is also normally somewhat higher when the press screw is moved 0.5 mm closer to the press chamber head with an adjusting spacer, see Fig. 6. With an adjusting spacer there is no difference between nozzles with a long press nozzle channel and nozzles with a normal press nozzle channel, see Fig. 6.

In Figs. 4-6 share of oil (%) means: 100 * weight oil out / weight seed in.

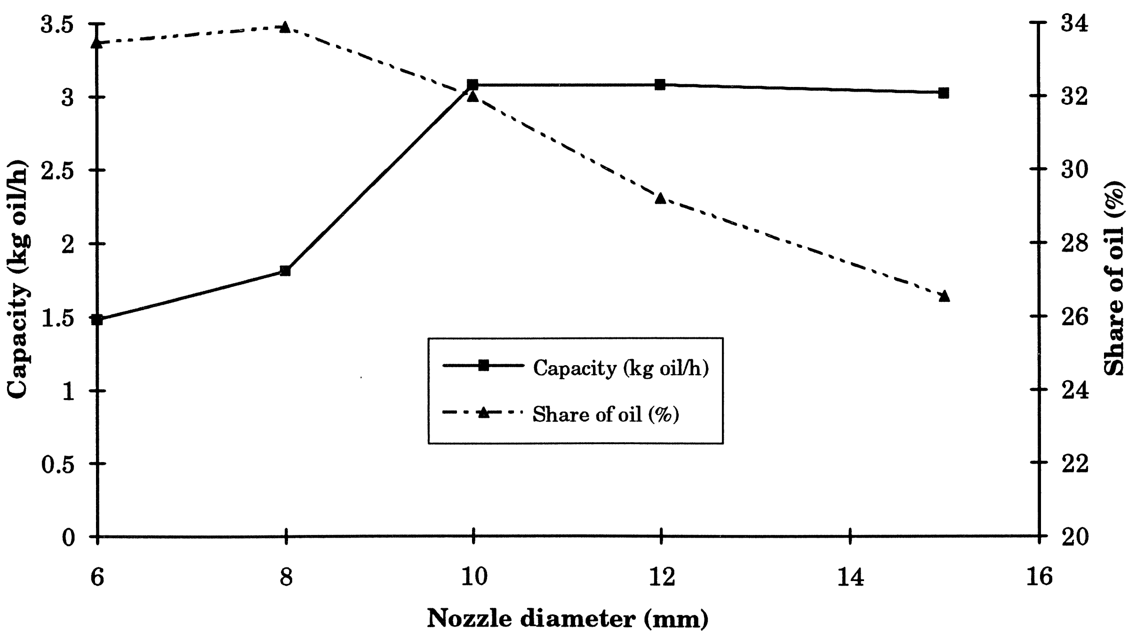

Figure 4. Capacity and oil extraction efficiency with press nozzles with different inner diameter. Rotation speed 40 rev/min.

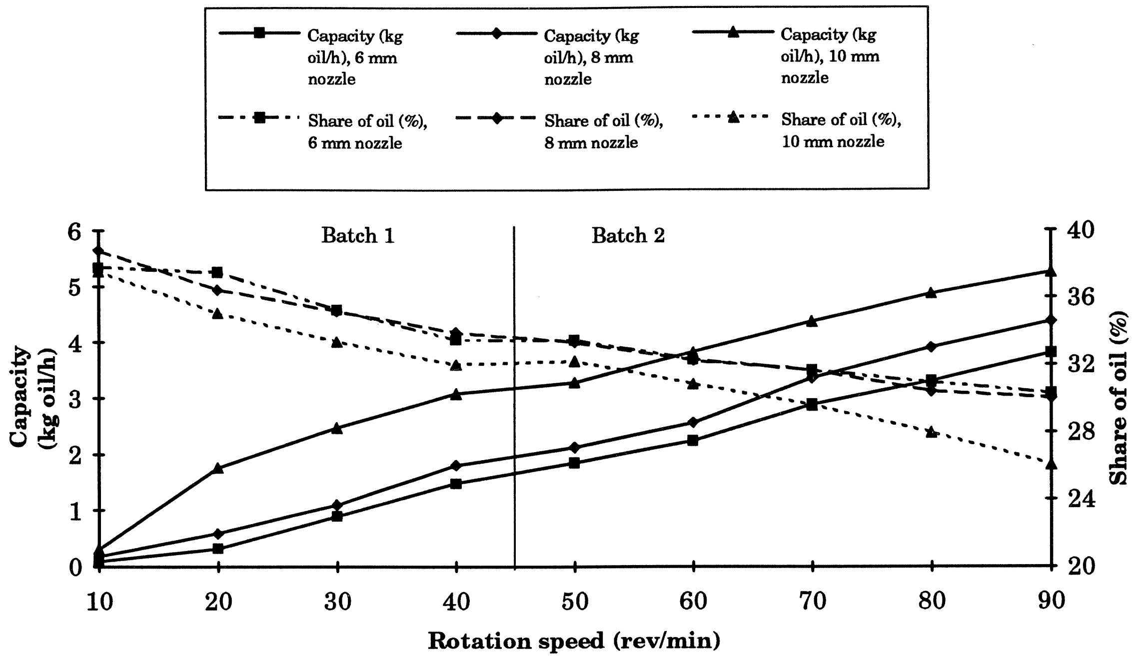

Figure 5. Capacity and oil extraction efficiency with different rotation speed of the press screw.

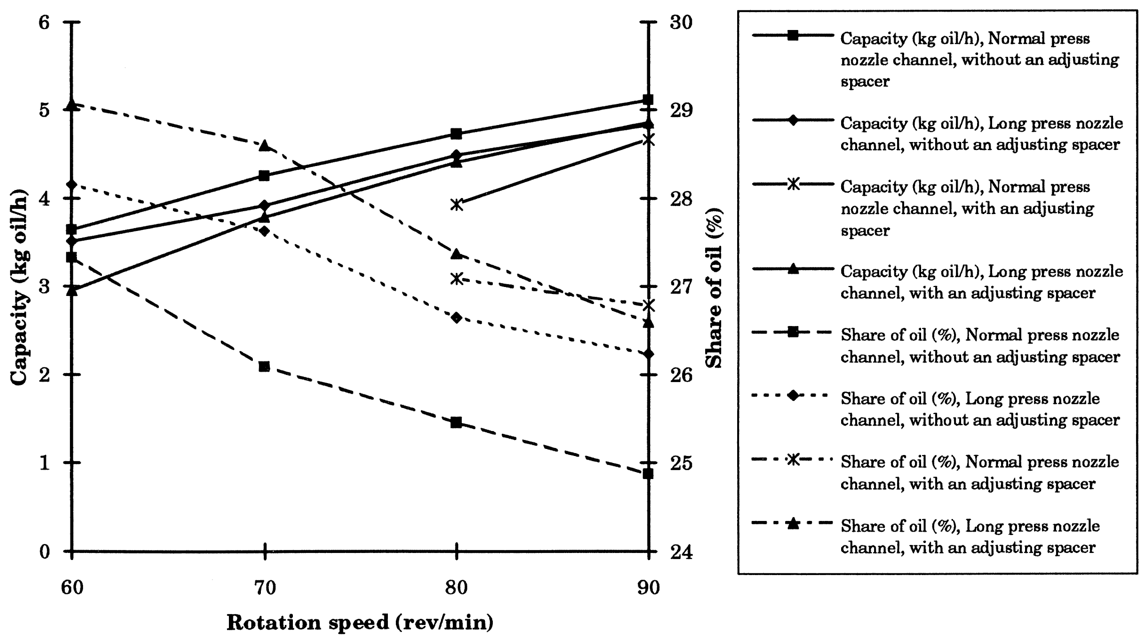

Figure 6. Capacity and oil extraction efficiency with different sorts of nozzles and with or without an adjusting spacer. Nozzles with 6 mm inner diameter.

In the fourth part of the experiment, when the seed was preheated with air before oil extraction, the capacity increased with higher temperature (20-45°C) for a nozzle with 6 mm inner diameter, see Table 1. For a nozzle with 10 mm inner diameter the capacity decreased somewhat under the same conditions. The oil extraction efficiency was relatively constant with the preheating temperature with an optimum at 35°C for a nozzle with 6 mm inner diameter at 90 rev/min. For nozzles with 10 mm inner diameter at 60 rev/min the differences were bigger, with an optimum at 40°C. Nozzles with 10 mm inner diameter achieved a better oil extraction efficiency than 6 mm nozzles at 40 and 45°C. The moisture content (wet basis) in the seed (after the preheating equipment) was 8 per cent without preheating and 5 per cent with preheating to 45°C. Consequently, there is uncertainty if the heating or the drying of the seed had the biggest influence on the pressing characteristics of the seed.

Table 1. Influence of preheated air on oil extraction

Nozzle diameter (mm)	Capacity (kg oil/h) at different temperatures				Share of oil (%) * at different temperatures			
	20 °C	35 °C	40 °C	45 °C	20 °C	35 °C	40 °C	45 °C
6, (90 rev/min)	5.2	5.2	5.6	5.9	29.9	31.3	30.8	30.2
10, (60 rev/min)	4.3	4.2	4.0	3.9	28.9	30.5	33.0	31.7

* Share of the total amount of seed with the moisture content at extraction.

In the fifth part of the experiment the capacity rose for both nozzles with 6 and 8 mm inner diameter when the seed was preheated. The oil extraction efficiency rose somewhat for the 6 mm nozzle and decreased for the 8 mm nozzle. The moisture content in the seed decreased from 9 to 7 per cent (wet basis) when the seed was preheated to 45°C.

The amount of phosphorus in the oil was normally 30-40 ppm. Sometimes it rose much higher. When the seed was preheated, at about 50°C the amount of phosphorus in the oil rose suddenly to about 160-220 ppm. So much phosphorus in the oil may be harmful if used as a fuel in engines. Without preheating the seed, there was a tendency for larger amounts of phosphorus at lower speeds of the press screw with a nozzle of 6 mm inner diameter. At 40 rev/min the amount of phosphorus in the oil was about 160 ppm.

The meal from smaller nozzles was more solid than from larger ones. Nozzles with a long press nozzle channel gave meal that was more solid than nozzles with a normal press nozzle channel. The meal from the oil press, type Komet S87G, is a rather soft pellet, the diameter of which depends on the inner diameter of the nozzle.

Sometimes interruptions occurred, generally in two ways:

* When the material flow through the oil press stops, the temperature at the nozzle rises to about 110°C and meal comes out through the small holes for the oil. Suddenly an explosion takes place, burnt dry meal is thrown out of the press nozzle at high speed, followed by foaming and sizzling meal at 110-120°C. The oil is also foaming. Later everything returns to normal conditions. This sort of interruption is probably caused by seed that is too dry.

* Secondly, the material flow stops almost completely, the oil flow through the press cylinder decreases almost completely and instead, oil slowly flows out at the seed supply hopper. With this sort of interruption the press nozzle temperature rises to about 90°C and the oil press usually does not start again by itself. This sort of interruption may partly be prevented by continuously heating the press cylinder head to about 70°C. This is probably caused by seed that is too wet.

The experience is that the oil press is working well without interruptions at a moisture content in the seed of 7-8 per cent on a wet basis.

5.2 Results from the extraction at Sjösa farm

At Sjösa farm the oil press was used to extract oil in 1991 and 1992, the results are presented in Table 2. The oil extraction at Sjösa farm gave an average efficiency (see page 9 for an explanation) of 59 per cent. At Ultuna, with the oil press running with the same settings, an oil extraction efficiency of 67 per cent was obtained. A possible reason for the difference is that the seed processed at Sjösa farm was not as clean (polluted with weed seed) as the seed processed at Ultuna.

The oil extraction efficiency rose if the seed was preheated with air (it rose from 62.5 per cent to about 69 per cent). It is not clear if this depends on the warmer seed processed or if it depends on the drier seed processed, or a combination of the two. A bigger nozzle made the oil extraction efficiency fall, see report II (when a nozzle with 6 mm inner diameter was changed to a nozzle with 10 mm inner diameter the oil extraction efficiency fell from about 62.5 per cent to about 58 per cent).

Table 2. The total amount of processed rape seed and the obtained products

Product	Amount (kg)	Share (%)	Volume (liter)
Rape seed	43530	100	
Meal	31505	72.4	
Rape seed oil	10452	24.0	11360
Sediment	716	1.6	
Missing	857	2.0	

The quality of the three processed seed batches varied widely and therefore the resulting amount of oil varied, see Table 3.

Table 3. Compilation of results, extraction of rape seed oil at Sjösa farm

Seed batch	Share of oil (%)*	Oil extraction efficiency (%)	Press capacity (l/hour)
1990 Sjösa	24.6	59.0	4.3-5.1
1991 Sjösa	19.7	62.4	3.1-6.1
1991 Brunnsholm	24.8	57.8	2.7-5.5

* Share of the total amount of seed with the moisture content at extraction.

At Sjösa farm, experiments with preheating the seed before oil extraction with the oil press were also conducted. The capacity was only slightly affected but the oil extraction efficiency increased. The capacity of the oil press varied between 2.7 and 6.1 litres of rape seed oil per hour, see Table 3. Without preheating, the oil press consumes about 0.30 kWh electricity for each litre of rape seed oil produced, see report II.

The amount of phosphorus in the oil varied between 7 and 38 ppm. No damage due to phosphorus was discovered in the Elsbett engine in the tractor. The manufacturer claims that Elsbett engines can endure rape seed oil with 30 ppm phosphorus without any risk of damage.

At the oil extraction at Sjösa farm there were few stoppages and the oil extraction plant operated reliably.

The disturbances that occurred during the extraction of the oil were caused by problems in the oil press. Possible reasons are that the press chamber head was improperly inserted, the presence of poorly cleaned seed, or that the processed seed was either too wet or too dry. Oil stopped flowing in the hose between sedimentation tanks two and three on some occasions because of air bubbles in the hose, but was fixed when a hole (at about 3 mm diameter) was drilled in the upper part of the hose. Problems with the oil press because of pieces of metal in the seed occurred twice, but can be avoided if a magnet is placed along the flow of the seed to the press. Some plastic fittings in direct contact with the oil were exposed to some damage caused by the oil.

Suitable sedimentation time for cleaning the oil in a 0.6 m high tank is about 18 days, if the temperature is about +20°C (at +10°C, 30 days and at +30°C, 12 days). It is important that the sedimentation tanks are not exposed to large temperature variations. Big temperature variations in the sedimentation tanks may create convection movements in the oil that counteract sedimentation. Fully settled oil contains about 0.012-0.065 g of particles per litre. The oil press was subjected to some wear when the seed was processed but no parts had to be changed.

The oil extraction fits well into the work on the farm. It was possible to keep the oil press in operation even during the spring seedbed preparations. The oil press needs, on average, about 30 minutes of work for every 24 hours of operation according to information received from Sjösa farm and the operating log.

5.3 Results from the tractor study

The operating log shows that the tractor has been used for different tasks on the farm. The tractor has been driven in practical work for 339 hours (276 hours at Sjösa farm and 63 hours at Skuttunge). In the tests at Ultuna the tractor was driven for 94 hours. During the time it was at our disposal, it was driven 433 hours totally. In practical use, the tractor consumed 2440 litres of rape seed oil totally, corresponding to an average fuel consumption of 7.2 litres of rape seed oil per hour. According to test carried out at the testing station in Uppsala, the fuel consumption of the Elsbett engine, on a volume basis, was measured to be 12 per cent higher with rape seed oil than the diesel oil consumption of an equivalent diesel-oil fuelled tractor (Zetterström, 1993).

The Elsbett engine in the tractor suffered some mechanical problems. On one occasion a valve plate broke loose and caused a major engine breakdown. None of these running problems was caused by the use of rape seed oil as fuel in the engine. Running disturbances due to unclean rape seed oil occurred during the first month the tractor was used at Sjösa farm. These problems disappeared when one fuel tank for rape seed oil was replaced and the sedimentation time in sedimentation tank 3 was somewhat prolonged. After these measures, the fuel filters in the tractor needed to be replaced after about 100 hours of running time.

Winter operation posed no problem to the tractor (temperatures not below -12°C). A test in a climate chamber showed that the tractor could not be run on rape seed oil at -15°C. The rape seed oil in the fuel system was then stiff or partly stiff. At -10°C it was possible to run the tractor with rape seed oil without any problems.

It was possible to operate the tractor in the same way as a normal tractor. One difference however, was that a separate fuel, diesel oil, was used for cold starting the engine. It was possible to switch over to rape seed oil immediately the engine had started and was running smoothly. Just before the engine was stopped for the day, or for a couple of hours, it must be switched over to diesel oil and the fuel system filled up with diesel oil to facilitate easy starting.

The automatic system for data collection was never able to record any abnormal temperatures. Due to low reliability, it was not working when such breakdowns happened that would have been of interest to record.

The relationship between ambient temperature and the temperature in the fuel tank could be studied using the data received from the automatic system for data collection for some types of weather with different temperatures between day and night. The temperature in the fuel tank lags a couple of hours (2-3 hours) behind the ambient temperature. The peaks and depressions in the ambient temperature are smoothed by 2-3°. Short peaks and depressions are smoothed by 6-7°. One conclusion of this is that a tractor fuelled on rape seed oil can operate in ambient temperatures below the rape seed oil pour point for a few hours before the rape seed oil in the tractor's fuel system begins to solidify.

5.4 Results from the energy analysis

The energy balance calculations for Sjösa farm show that the energy balance for spring rape is about 1.9 while it is about 3.0 for winter rape.

The yield has a major influence on the energy balance. The energy balance is almost proportional to the yield. In Table 4, energy balances are given for spring rape grown in the middle of Sweden (in the flat Svealand region) with constant input (expected yield 2400 kg/ha (at 18 per cent moisture (wet basis) content in the seed), but 25 per cent less or 25 per cent more is obtained) and with inputs of fertilizer directly proportionally to the received yield in the studied interval. The energy balances in Table 4 also include the meal.

Table 4. Energy balances at different received yields

Received yield (kg/ha)*	Energy balance**		Energy balance***	
	excl. straw	incl. straw	excl. straw	incl. straw
1800	2.1	3.7	2.2	4.0
2400	2.6	4.7	2.6	4.7
3000	3.1	5.6	2.9	5.2

* 18 per cent moisture (wet basis) content in the seed.
** Energy balance with constant inputs.
*** Energy balance with inputs of fertilizer proportional to the received yield.

The moisture content in the seed at harvest is important for the energy balance. Energy is required for drying the seed. The suitable moisture content in rape seed for extraction in a small oil press is about 7-8 per cent (wet basis). In Table 5, examples of some energy balances are given (incl. meal) when the moisture content in the seed varies.

Tables 5 and 6 illustrate examples of spring rape with a yield of 2400 kg/ha (18 per cent moisture, wet basis) and an oil extraction efficiency of 59 per cent.

Table 5. Energy balances at different moisture content in the seed

Moisture content (%)	Energy balance	
	excl. straw	incl. straw
8	2.8	5.1
18	2.6	4.7
24	2.5	4.4

The energy balance is only very slightly affected by the oil extraction efficiency because the oil that is not extracted gives an energy return in the meal.

When a cultivation technique with reduced tillage (direct seeding) is used, the energy balance for production of rape seed oil (incl. meal) will improve, see Table 6.

There is some potential to produce rape seed oil with a lower input of energy, but the potential is not very large, see Table 6. The columns in Table 6 have the following designations:

* Reference: spring rape at a yield of 2400 kg/ha (at 18 per cent moisture) and an oil extraction efficiency of 59 per cent, normal cultivation.

* Oil press with better energy efficiency, better insulation: the same as "reference" but lower maintenance and with a more efficient transmission, 25 per cent lower energy consumption. Energy for heating 75 per cent less because of the insulation. See report II.

* More efficient production of nitrogen fertilizer: the same as with "the more energy efficient oil press" but 8 kWh/kg nitrogen (best technique of today) instead of 12 kWh/kg nitrogen (average of today production in Sweden).

* Direct seeding, lower yield: the same as with "more efficient production of nitrogen fertilizer" but lower input of machines and fuel in the cultivation because of the direct seeding. 25 per cent lower yield and fertilizer consumption.

* Direct seeding, normal yield: the same as with "direct seeding, lower yield" but with normal yield and normal consumption of fertilizer.

Table 6. Energy consumption in rape seed oil production

Energy input	Reference		Oil press with better energy effic., better insulation		More efficient production of nitrogen fertilizer		Direct seeding, lower yield		Direct seeding, normal yield	
	MWh/ ha	Share (%)	MWh/ ha	Share (%)	MWh/ ha	Share (%)	MWh/ ha	Share (%)	MWh/ ha	Share (%)
Cultivation:	4.60	82.3	4.60	86.3	4.01	84.6	2.27	80.4	2.59	78.0
of which nitrogen	1.59	28.5	1.59	29.9	1.06	22.4	0.80	28.1	1.06	31.9
of which fuel and oil	1.17	21.0	1.17	22.0	1.17	24.8	0.50	17.8	0.50	15.2
of which machines	1.20	21.5	1.20	22.5	1.20	25.3	0.52	18.4	0.52	15.6
Drying	0.41	7.3	0.41	7.7	0.41	8.6	0.31	10.9	0.41	12.3
Transports	0.02	0.4	0.02	0.5	0.02	0.5	0.02	0.7	0.02	0.7
Oil extraction:	0.55	9.9	0.30	5.6	0.30	6.3	0.23	8.0	0.30	8.9
of which pressing	0.29	5.2	0.22	4.1	0.22	4.6	0.16	5.8	0.22	6.6
of which heating	0.24	4.3	0.06	1.1	0.06	1.3	0.05	1.6	0.06	1.8
of which press machines	0.01	0.2	0.01	0.2	0.01	0.3	0.01	0.4	0.01	0.4
of which buildings	0.01	0.1	0.01	0.1	0.01	0.1	0.01	0.2	0.01	0.2
Total sum	5.58	100.0	5.33	100.0	4.75	100.0	2.83	100.0	3.32	100.0
Energy balance excl. straw	2.62		2.75		3.08		3.88		4.40	

6 DISCUSSION OF THE EXPERIMENTAL RESULTS

If rape seed is processed, a small oil press should be operated with a small nozzle (6 or 8 mm inner diameter) if a good oil extraction efficiency is desired. The number of revolutions should be relatively high (70-80 rev/min) if a high capacity is expected. It is an advantage for the oil extraction efficiency if nozzles with a long press nozzle channel are used.

The processed seed should have a moisture content of 7-8 per cent (wet basis) if it is to be processed without stoppages.

The amount of phosphorus in the oil is normally low. It may rise to levels that are hazardous for engines if the seed is preheated too much or if the oil press is operated at a low speed (about 40 rev/min) with a small press nozzle.

For cleaning the oil, settling is the simplest way at the farm level. Three series-coupled sedimentation tanks can be recommended. In the first tank, most of the solid particles in the oil will settle. In the second tank, some medium-fine particles settle, and in the last tank the finest particles will settle. The first two tanks should be capable of receiving about twice the daily oil production. The third tank may consist of several tanks connected in parallel, and with a volume that suits the individual situation. If the temperature is about +20°C the settling time in practice for the third group of tanks is about 18 days if the settling height is 0.6 m. Settling time is proportional to settling height and reciprocally proportional to temperature. It is an advantage if the oil is released into the sedimentation tanks at the lowest possible level.

Some problems may occur when the oil is extracted. Interruptions in the oil press may occur if the seed is too wet or too dry. It is therefore important to dry the seed carefully before processing. Straw or weed seed in the seed decrease the capacity and the oil extraction efficiency. The seed must therefore be carefully cleaned before processing. Pieces of metal are sometimes found in the seed and can be removed by a magnet in the seed flow. Sometimes air bubbles prevent the oil from flowing in the pipes between the settling tanks. This problem can be corrected if a hole (at about 3 mm diameter) is drilled in the upper part of each pipe. Plastic details in direct contact with the oil must be of oil-resistant plastic in order to avoid the risk of being exposed to damage from the oil.

Oil extraction fits well into the work on the farm. The oil press needs about half an hour of work for every 24 hours of operation.

There are annual fluctuations in the quality and the oil content in rape seed. The result of the oil extraction may therefore differ between different batches.

The yield may vary considerably between years for the same crop and among different oil crops. The entire fuel demand of the farm could not, in the Sjösa case, be covered with rape seed oil (if rape seed is grown every sixth year) because the yield of seed and the oil extraction efficiency were both too low. If the oil extraction efficiency is increased from 59 to 65 per cent when spring rape is pressed, and increased from 62 to 68 per cent when winter rape is pressed, the available amount of oil increases by 10 per cent. The fuel requirement is then covered in the alternative with winter rape. This increase can be attained if the seed is cleaned better before it is pressed and the moisture content in the seed is kept at an optimum level. The yield of oil can probably be increased by 20 per cent if a different kind of oil press is used and if the seed is preheated before extraction.

A tractor with an Elsbett engine running on rape seed oil can operate in the same way as a conventional tractor. One difference however, is that a separate fuel, usually diesel oil, is used for cold starting the engine. It is possible to switch over to rape seed oil immediately when the engine has started and is running smoothly. Just before the engine is stopped for the day, or for a couple of hours, it must be switched over to diesel oil so the fuel system can fill with diesel oil. The engine then will be easy to start the next time it is to be used. The Elsbett engine needs about 10 volume per cent more rape seed oil than a diesel engine needs diesel oil.

When an Elsbett engine is running on settled rape seed oil, the fuel filters in the engine usually need to be changed after about 100 working hours. This is more frequent than on a diesel engine running on diesel oil. The fuel filters are also somewhat larger than on a diesel engine.

The engine can run on pure rape seed oil without problems down to about -15°C, when the rape seed oil begins to solidify. The engine cannot run on rape seed oil if the oil is stiff. The engine can manage a few hours at temperatures below -15°C before the oil stiffens, so it can cope with a night frost at a few degrees below -15°C. This problem can be solved with electrical heating in the fuel tank, fuel piping and fuel filters for rape seed oil. The rape seed oil is rather viscous at temperatures below ±0°C, the fuel filters should therefore be heated electrically if such temperatures occur.

To obtain a good energy balance in the production of rape seed oil it is important that the seed yield is high and does not fluctuate too much between different years, and also that the seed is not harvested at high moisture contents. It is also important to have a use for the meal. The energy balance would be further strengthened if there were also a use for the straw.

When a cultivation technique with reduced tillage (direct seeding) is used, the energy balance for production of rape seed oil will improve, see Table 6. In the production of rape seed oil, the greatest energy inputs are: nitrogen, fuel and machines in the cultivation.

7 GENERAL DISCUSSION

The following requirements must be placed on a farming system supplying its own fuel from oil crops:

* The oil must be produced with an oil crop with a reliable and high annual yield and therefore produces oil at a low cost.

* The oil production should be in a farming system that does not need a supply of nitrogen (that requires a high energy input to produce) from outside.

* The oil extraction must be done with a high oil extraction efficiency.

* A system with production of pure rape seed oil will need Elsbett engines (or other engines that can run on pure rape seed oil) on the market.

* There must be enough oil left for fuel when the requirement for oil in other applications (where the oil has a higher price than if used as fuel) is satisfied.

The above requirements can be fulfilled in the following way:

* In central Sweden rape seed cannot give a reliable and high annual yield. In south Sweden and in central Europe the situation is better but not good enough. The rape needs more plant breeding improvements to fulfil this demand. Perhaps other oil crops can be used.

* Rape seed can be grown without a supply of nitrogen from outside if it is grown in a crop rotation with nitrogen-fixing leguminous plants for animal production or biogas production, provided that the nitrogen produced from the nitrogen fixing leguminous plants is used in the crop rotation.

* The oil extraction efficiency can be improved if the seed is carefully dried and cleaned before processing. More efficient oil presses are also available on the market.

* Elsbett engines have not yet entered serial production. They are similar to and not more complicated than ordinary diesel engines and will therefore not be technically complicated to introduce on the market. The sluggishness of the market today may be a serious hindrance.

* Vegetable oils can be used in a wide variety of applications apart from fuel. A lot of vegetable oil is used as food. Vegetable oil can also be used in numerous technical applications. In the applications mentioned here, the oil has a higher price than when used as fuel. The amount of vegetable oil is limited, and therefore there is a risk that no vegetable oil will be left for use as fuel in engines.

Technically, the production of rape seed oil on the farm level and the use of the oil in vehicles with Elsbett engines is working well with the techniques known today. There are still problems in the breeding of rape seed that need to be solved in order to get higher and more reliable yields. The most serious factor speaking against the use of vegetable oil as fuel in engines is that the oil can be used in numerous other applications, that can pay a higher price for the oil than if it had been used as fuel in an engine. When rape seed oil is used as fuel in engines there will be a poorer economic return in comparison with diesel fuel oil. Fossil fuels like diesel oil are cheaper than rape seed oil.

The requirement for fuel oil on a farm can be covered with home-grown rape seed oil, if the best technique known today for on-farm oil extraction of rape seed oil is used in a good way in an area with high rape seed yields.

In conventional diesel engines, rape seed oil has been used commercially after transesterification (to rape methyl ester, RME) on a limited scale in Europe. The rape seed oil will probably be used transesterified in conventional diesel engines even in the near future, and not in Elsbett engines. This is because conventional engines are complicated and expensive to convert into Elsbett engines, and Elsbett engines have not yet entered serial production. The rape seed oil is also fairly cheap to transesterify. In developing countries, where transesterification is difficult, Elsbett engines may find a market in the future.

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