



 **AEA Energy & Environment**
From the AEA group

Guidance on VOC Substitution and Reduction for Activities Covered by the VOC Solvents Emissions Directive (Directive 1999/13/EC)

Guidance 19:

Vegetable oil and animal fat extraction and
vegetable oil refining activities

European Commission

2008

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1 Introduction

This guidance addresses vegetable oil and animal fat extraction and vegetable oil refining, presenting options to substitute or reduce the use of VOC and its resulting emissions.

Table 1: Scope definition of the VOC Solvent Emission Directive (SE Directive)

SE Directive – Scope definitions (Annex I)
The activity "vegetable oil and animal fat extraction and vegetable oil refining activities" is defined as 'any activity to extract vegetable oil from seeds and other vegetable matter, the processing of dry residues to produce animal feed, the purification of fats and vegetable oils derived from seeds, vegetable matter and/or animal matter. The SE Directive covers installations in which this activity is taking place with an annual organic solvent consumption greater than 10 tonnes.

The SE Directive lays down the following activity specific emission limit values for vegetable oil and animal fat extraction and vegetable oil refining activities:

Table 2: Emission limit values of the SE Directive

SE Directive - Emission limit values (ELVs) (Annex II A – activity No. 19)				
Activity	Solvent consumption threshold [tonnes/year]	ELVs in waste gases [mg C/Nm ³]	Fugitive emission values [% of solvent input]	Total ELVs [kg/tonne]
Vegetable oil and animal fat extraction and vegetable oil refining activities	> 10			Animal fat: 1.5
				Castor: 3
				Rape seed: 1
				Soya beans (normal crush): 0.8
				Soya beans (white flakes): 1.2
				Other seeds and other vegetable matter: 3 ⁽¹⁾ 1.5 ⁽²⁾ 4 ⁽³⁾
Special provisions:				
⁽¹⁾ Total emission values for installations processing individual batches of seeds and other vegetable matter should be set by the competent authority on a case-by-case basis, applying the best available techniques.				
⁽²⁾ Applies to all fractionation processes excluding de-gumming (the removing of gums from the oil)				
⁽³⁾ Applies to de-gumming				

THE SE DIRECTIVE APPLIES TO OIL & FAT EXTRACTION OR REFINING IF A SOLVENT CONSUMPTION OF 10 TONNES PER YEAR IS EXCEEDED

Instead of complying with the above ELVs, operators may choose to use a reduction scheme, following the specifications of Annex II (B) of the SE Directive.

Specific requirements apply for VOCs classified as CMR substances¹ as well as for halogenated VOCs which are assigned the risk phrases R40 or R68². There is a general obligation to replace CMR substances – as far as possible – by less harmful substances or preparations within the shortest possible time. In the case of a mass flow ≥ 10 g/h for VOC classified as CMR substances or ≥ 100 g/h for halogenated³ VOC with R40/R68 the ELVs in waste gases are 2 and 20 mg/Nm³ respectively, and these also apply when a reduction scheme is being used.

National legislation may define lower thresholds for solvent consumption, stricter ELVs or additional requirements.

2 Summary of VOC substitution/reduction

Animal fat extraction is typically carried out by using solvent-free processes like expeller, pusher or a basket centrifuge. Animal fat extraction using solvents is almost phased out in Europe.

In case of vegetable oil solvent based extraction is widely applied since none of the substituting technologies is currently competitive (see section 10). Therefore the application of effective emission prevention and reduction measures (like mineral oil scrubber, condenser, separator and re-boiler) is of great importance for the vegetable oil extraction industry. It is state of the art that the solvent used is in a closed loop process and 99.9 % of the input is reused.

With regard to refining, solvents are only used if a fractionation process is included. This can lead to additional VOC emissions from refining, which are not related to the extraction process.

**NEARLY ALL
THE VOC EMIS-
SIONS IN THIS
INDUSTRY SEC-
TOR ARISE FROM
THE VEGETABLE
OIL EXTRACTION**

3 Description of the activity and related industry sectors

Animal fat extraction

Animal fat extraction (using hexane) is very effective as only 2-8 % of fat remain in the raw material. Other processes using expeller, pusher or a basket centrifuge leave higher percentages (10 to 17 %) of fat behind. As a result of stricter environmental regulations the solvent-based method has, however, largely been ceased in Europe over the past 20 years, with the exception of two companies. [Baert 2008]. The products from the process

¹ CMR substances – carcinogenic (R45, R49), mutagenic (R46), or toxic to reproduction (R60, R61)

² After the implementation of the SE Directive a revision of the R-phrase R40 took place. The original wording of R40 was: 'Possible risk of irreversible effects'. The new wording is: 'Limited evidence of a carcinogenic effect'. In the 'old' version mutagenicity (cat 3) was included. This mutagenic effect is now covered separately under R68: 'Possible risk of irreversible effects'. This new risk phrase does not include carcinogenicity. The 'new' version of R40 is obviously less restrictive than the old version. Until the SE Directive is adapted to this change, a final decision on which version applies can only be given by the European Court

³ Halogenated organic solvents are hydrocarbons with one or more of the following halogens: fluorine, chlorine (e.g. trichloroethylene), bromine (e.g. n-propyl bromide) or iodine.

are meal and fat. As long as the price of meal and fat are similar, there is no benefit in extracting higher levels of fat from the raw material and therefore solvent extraction is not advantageous. Because the prices have been similar for many years nearly every company switched voluntarily away from hexane extraction to less efficient melting processes to obtain fat.

In the following this guidance document only deals with the extraction or fractionation of vegetable oil as the share of solvents which is used in animal fat is negligible compared to the use for vegetable oil.

Vegetable oil extraction

Worldwide approximately 22 different vegetable oils are produced on a commercial scale. Since the fruits from tropical plants (e.g. coconut, palm, palm kernel) perish rapidly, they are directly processed into oils in the countries of origin. Most large scale vegetable oil extractions from the three main oilseeds (soybean, rapeseed and sunflower seed) are performed globally by solvent extraction. In Europe (EU 27) the following annual quantities of seeds are processed: soybeans (~13.7 MnT/year), rapeseed (~14.9 MnT/year) and sunflower seeds (~5.2 MnT /year). [FEDIOL 2006]

The structure of the industry has changed significantly in the European Union over the past ten years. Many independent companies have disappeared and large multinational groups have formed. The crushing industry is now rather stable with respect to applied technology, size of operations and seeds. About 75 % of the European capacity now belongs to four major international groups. [FEDIOL 2008]

Across Europe there are about 150 production units employing about 20.000 people. Some concentrate on one type of seed while others process several kinds of seeds, of which some are imported (mainly soybeans, sunflower) and some are produced locally (mainly rapeseed and sunflower seed). [FEDIOL 2008]

Table 3 lists the production of crude vegetable oils and fats from each of the EU-27 (except Luxembourg) in 2006.

Table 3: Production of crude vegetable oils and fats in the EU-27 [weight %]

AT	1,1%	UK	6,8%
DE	28,5%	CY	0,0%
BE	4,6%	CZ	3,0%
DK	2,1%	EE	0,2%
ES	7,3%	HU	2,8%
FI	0,8%	LV	0,2%
FR	12,6%	LT	0,1%
EL	1,0%	MT	0,0%
IE	0,0%	PL	4,9%
IT	4,7%	SI	0,0%
NL	7,4%	SK	1,1%
PT	4,5%	BG	1,7%
SE	0,8%	RO	3,6%

Solvent fractionation

During the fractionation the starting material (oil) is separated into a low melting fraction (olein) and a high melting fraction (stearin). Fractionation with solvents delivers high separation efficiencies and high stearin yield and is therefore chosen if high stearin yields are required or stearin oil ratios need to be adjusted.

4 Technical process description

4.1 Process flow and relevant associated VOC emissions

In the solvent extraction process VOC emissions occur during cooling, storage and transportation of meal and crude oil. The flow chart in Figure 1 does not describe the oil refining process in detail but concentrates on the extraction process, since the amount of residual solvent in the crude oil is much lower than in the extraction step:

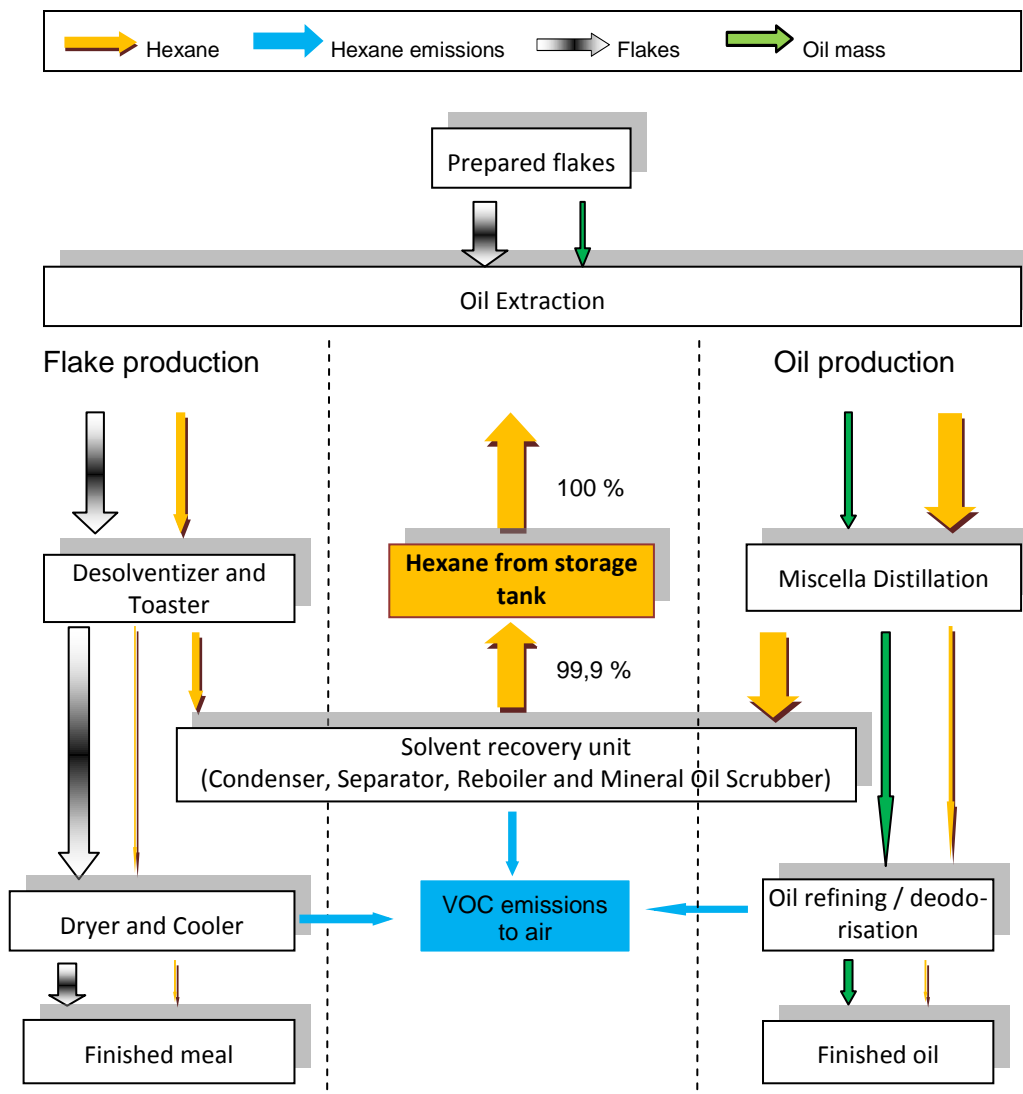


Figure 1: Flow diagram from vegetable oil extraction process [EPA 1995] [NPI 1999]. [VDI 2000]

Guidance 19 Vegetable oil & animal fat extraction and vegetable oil refining

There are no legal requirements for the amount of residual hexane in meal or oil but general provision are set in Council [Directive 88/344/EEC](#) of 13 June 1988 on the approximation of the laws of the Member States on extraction solvents used in the production of foodstuffs and food ingredients⁴ and levels generally need to be kept as low as technically possible.

Fugitive emissions can occur during the storage of the meal or the deodorisation of the crude oil. On average, about half of the hexane which is contained in the finished meal is usually emitted during the storage period.

During the process the system is kept under slight vacuum to prevent hexane escaping from process equipment. These vent gases are passed through the condenser and the mineral oil absorption system.

In addition to the hexane used as a solvent in oilseed extraction, solvents can be used in the fractionation process during oil refining.

The hexane emissions from the deodorisation process in the refining process are not treated due to their low concentration and small amount.

Typical process values for hexane based extraction of vegetable oil are summarized in Table 4.

Table 4: Typical hexane value ranges [TC 2008], [VDI 2000] [IU 2008]

Component	Value
Oil content in prepared flakes	6 – 11%
Miscella	10 – 30 % oil, 70 - 90 % hexane
Hexane in crude oil	~ 0.02 -0.05 kg per tonne used seed
Finished oil	~ 1 ppm
Mineral oil scrubber hexane emissions	0.05 – 0.15 kg per tonne used seed
Hexane concentration in exhaust air after mineral oil system	10 – 25 g/m ³
Hexane emission into exhaust air from Meal dryer/cooler	0.01 – 0.05 kg per tonne used seed
Hexane in finished meal	300 – 500 ppm
Hexane emission during storage of meal	~ 200 ppm
Tank breathing and fugitive emission	~0.01 kg per tonne used seed
Hexane in waste water	< 0.0001 kg per tonne used seed
Total hexane emissions	0.5 – 1.2 kg per tonne used seed*

* for more details see **Fehler! Verweisquelle konnte nicht gefunden werden.**

⁴ OJ L 157, 24.6.1988, p. 28

4.2 Process description

Preparation

Oilseeds are prepared for oil extraction by cleaning, dehulling, flaking, conditioning and in many cases pressing.

Extraction

The oil from the rough ground raw materials (oil seeds with a low oil content or expeller pulp produced by previous cold or hot pressing) is extracted using a solvent, such as hexane. The residues, then known as extraction meal, have a residual oil content of only 0.5 – 1.5 % solvent.

Hexane based solvent extraction can be used alone or together with an oil expeller/press. With the expeller 70 to 75 % of the oil can be extracted - depending on the seed. The pulp is then mixed with hexane to extract up to 95 % of the total oil content. The oil dissolved in hexane is then separated by distillation.

Desolventizer & Toaster

The hexane must be removed from the flakes after the solvent extraction. Two removal technologies are established, the 'conventional desolventizing' for animal feed and the 'flash' desolventizing for human feed. Flakes that enter the desolventizer contain about 35 to 40 % of solvent.

Conventional desolventizing for animal feed

Hexane can be stripped from the flakes using either contact ("toasting") or non-contact processes. After heat-assisted drying the flakes are cooled with ambient air. The defatted and grounded meal can be used for animal feed.

Flash desolventizing for human food products

In the flash desolventizing process the solvent is removed from the flakes, under vacuum, using non-contact steam or superheated hexane. After the desolventizer a steam stripper step is applied, the gases of the desolventizer and the stripper are collected and passed to the solvent recovery system.

Less than 5 % of the produced flakes are used for human food (white flakes). They are produced separately and are not combined with flakes for animal feed.

Dryer and Cooler

After the desolventizer the meal is dried and cooled before storage. The removed hexane is reused with little fugitive emissions (10-50 g per tonne used seed) to air.

Miscella Distillation

The solvent-oil mixture (Miscella) containing approximately 10 to 30 % oil is undergoing a multi-stage distillation process for solvent recovery. The desolventising of the oil is done by exposing the miscella to steam (contact and non-contact).

FLASH DESOLVENTIZING IS USED FOR THE PRODUCTION OF WHITE FLAKES FOR HUMAN DIET; CONVENTIONAL DESOLVENTIZING IS USED FOR THE PRODUCTION OF MEAL FOR ANIMAL FEED.

Oil refining (deodorisation)

Oil refining is done to prepare the oil for shipment. Unwanted substances as phosphatides, color-producing substances, residual soap or substances with an undesirable smell are removed. During deodorisation volatile compounds are removed by steam injection under a high vacuum.

Solvent recovery system

The solvent recovery system consists of condenser, separator, reboiler and mineral oil scrubber.

Hexane contaminations are either in water or air. The majority of the hexane in the water is removed with a separator. With a reboiler the amount of hexane in the water is further decreased. The majority of the hexane in the air is removed with a condenser, which liquefies the hexane. The final hexane removal from the air is done by a mineral oil scrubber (see also section chapter 7)

5 Solvent use, emissions and environmental impact

5.1 Solvents used

For decades only hexane has been used for solvent-based vegetable oil (and animal fat) extraction in Europe.

5.2 Solvent consumption and emission levels

The overall non methane VOC emissions from vegetable oil extraction were approximately 50 kt in the EU 25 in the year 2000. [Synopsis 2005].

Solvent vegetable oil extraction

Typical hexane emissions from the solvent extraction process are given in Table 5:

Table 5: Typical hexane emissions from the solvent extraction process [VDI 2000] [IU 2008]

Hexane emissions kg hexane per tonne seed	
Soybeans	0.5 – 0.8
Rapeseed	0.5 – 1.0
Sunflower seed	0.5 – 1.0
Linseed	approx. 2
Castor beans	< 3

Solvent fractionation

In case of solvent fractionation emissions only sum up to approximately 3 kg per tonne produced oil due to the use of emission prevention and abatement techniques [Cryo-condensation, membrane systems, good housekeeping, leak detection and repair programme (LDAR-programme)]. Emission might also occur from the vent system, rectification (water removal) or emit as fugitive emissions. [FEDIOL Q 2008]

5.3 Key environmental and health issues

In vegetable oil & animal fat extraction and vegetable oil refining mainly hexane is used for different types of processes e.g. extracting and fractionating.

VOC emissions together with NO_x emissions are precursors of ground level ozone formation in the presence of sunlight. Occupational workplace limits should also be taken into consideration.

Emissions of VOC to air may occur from both the process and the product storage.

Hexane poses a particular health hazard as it may cause peripheral nerve damage following chronic (long-term) exposure [ESIG 2003]. Hexane is flammable, harmful, dangerous to the environment and toxic to reproduction (category 3). As a consequence of its potential environmental and health impact hexane is classified as R48/20 substance with some 'danger of serious damage to health by prolonged exposure'.

Acetone is extremely flammable as liquid or vapour. It causes skin and eye irritation and is harmful if swallowed. Vapour may cause flash fire and is harmful if inhaled. High vapour concentrations may cause dizziness.

Meal which has been in contact with hexane is only used for animal feeding; meal for human food is completely solvent free.

6 VOC Substitution

Various solvent free extraction processes have been tested for vegetable oil extraction (see section 10) but at the moment none of these technologies is considered economically and/or technically feasible in Europe (see section 10 on emerging techniques).

**THERE IS NO
VOC FREE
COMPETITIVE
SUBSTITUTION
FOR SOLVENT
BASED VEGETA-
BLE OIL EX-
TRACTION YET**

7 Other VOC emission prevention measures and abatement techniques

Preventive measures, process improvements and abatement techniques can be used to prevent and reduce VOC emissions, where VOC substitution is not possible. The following measures are commonly applied for vegetable oil solvent extraction:

7.1 Abatement technologies / End of pipe measures

Condenser, hexane/water separator and reboiler

The collected hexane-laden air from the plant is passed through a water shell-tube condenser. The treated air includes the vented air from the surrounding needed to maintain a small vacuum in the process equipment. This small vacuum prevents fugitive emissions from the equipment. Due to the low boiling point of hexane (69°C) a water shell-tube condenser – with low energy consumption and costs - is sufficient to recover most of the solvent. In a separator, the hexane/water mixture is separated into hexane which is reused, and water, which is further treated in the reboiler. The reboiler heats the water to at least 85°C to evaporate remaining solvent [FEDIOL 2007]. The vapour from the reboiler is directed to the condenser and the waste water containing less than 3 mg/l hexane is fed to the waste water system. The air from the condenser still contains small amounts of hexane and is directed to the mineral oil scrubber.

Mineral oil scrubber

Non condensable components and hexane are removed from the air coming from the condenser in a mineral oil scrubber consisting of an absorption column with cold, food grade mineral oil. The hexane-laden mineral oil is then passed through a steam stripping column to recover the hexane for reuse. After cooling the mineral oil is reused in the mineral oil scrubber.

Cryo-condensation

In comparison to the conventional condensation which often uses water as cooling agents in case of cryogenic condensation coolants like nitrogen are used to achieve very low temperatures (e.g. in case of nitrogen -120 °C).

Cryogenic condensation efficiency typically exceeds 99% and so it offers a very high degree of VOC emission reduction. It is also a very versatile process. Since the condensation process is influenced by the vapour pres-

sure of the compound to be separated, adapting the condenser operating conditions allows handling the wide range of concentrations and compounds present in the pharmaceutical industry.

For cryogenic condensation the flow rate can vary between 10 up to 3000 m³/h. The minimum loading should be above 20 g VOC/Nm³ and the pressure between 20 mbar and 6 bar [BREF LVOC, PanGas, Glatt]. Cryogenic condensation is therefore appropriate for low flows and high concentrations. By varying the cooling temperature different types of solvents can be recovered.

Operational costs depend on the cooling gas used; the cost of liquid nitrogen is around 30-50 €cent/l.

This technology is used for the solvent fractionation.

**CRYOGENIC
CONDENSATION IS
PARTICULARLY
USED FOR CHLO-
RINATED OR
OTHER VALUABLE
SOLVENTS**

7.2 Process improvements

Diffuse emissions occur during storage, transport and processing of meal containing some residual hexane. In addition, fugitive emission may occur through flanges, valves and pumps, but are largely prevented by the vacuum conditions of the system.

Fugitive VOC emissions may also arise from solvent storage, handling and leaks. The most commonly used measures to reduce these emissions involve process improvements to collect escaping vapours from process systems, storage tanks, and handling areas etc. in local exhaust ventilation hoods for subsequent treatment or abatement. The fugitive emissions in this industry are less than 0.1%

A wide range of best practice and process improvements are possible which aim at containing VOC emissions. The following list is not exhaustive:

- Leakage monitoring
- Process parameter optimisation
- Throughput measurement installations
- Increased efficiency from optimised process technologies
- Back venting to the solvent delivery tanks during bulk storage tank filling
- Improved exhaust air collection systems
- Implementing leak prevention systems

**FUGITIVE EMIS-
SIONS CAN BE
REDUCED BY
GOOD HOUSE-
KEEPING, LEA-
KAGE CONTROL
AND THROUGH-
PUT MEASURE-
MENT INSTALLA-
TIONS**

8 Summary of VOC emission reduction measures

The following table summarizes the VOC emission reduction measures discussed in chapters 6 and 7:

Table 6: Measures for VOC substitution and reduction in vegetable oil extraction

Objectives	Description	Applicability
VOC-free systems	Test phase	
VOC-reduced systems	Test phase	
Process improvements	Collecting of exhaust air Proper handling of solvents Solvent recovery/recycling Good housekeeping	Applicable in all cases and state of the art
Abatement technologies	Condenser, water separator, re-boiler Mineral oil scrubber Counter current de-solventizer and toaster	Applicable in all cases and state of the art

9 Good practice examples

All European companies extracting vegetable oil use the same process and therefore solvent reduction resulted so far mainly from company specific improved process parameters.

Best case examples would include company specific know-how and this might lead to competitiveness issues.

Therefore it was not possible to find any of the contacted companies willing to provide detailed data. [Cargill 2008] [Bungee 2008] [ADM 2008] [CROK-LAAN 2008] [Aarhus-Karlshamn 2008] [FEDIOL Sep 2008]

10 Emerging techniques and substitutes under development

Different technologies have been developed to obtain vegetable oil. These include enzymatic, supercritical CO₂, osmotic shock and ultrasonic extraction. None of these emerging techniques are realised on an industrial scale. The main unsolved problems are of economic and/or technically nature. These technologies mostly require significantly more energy than the conventional hexane-based extraction.

Supercritical Fluid extraction

Nearly 100% of the seed oils can be extracted with supercritical fluids, such as CO₂. This method, however, needs special equipment for containment and pressure. In this extraction process CO₂ is liquefied under pressure and then heated to the point that the CO₂ has properties of both a liquid and a gas. This occurs at approximately 80°C and 700 bar. Yields with supercritical fluid extraction are typically much higher than those of extractions performed by traditional techniques. [JACOS 2006] This process is 100 % solvent-free but very energy intensive mainly due to the high pressure which has to be reached. [TC 2008].

Enzymatic extraction

Enzymes are used to degrade the cell walls with water acting as the solvent, which makes fractionation of the oil much easier. Although this process would result in process improvements it is not implemented due to the high operational costs [OILGAE] [TC 2008]

Novo Nordisk calculated a pilot plant for enzymatic oil extraction. Table 7 and Table 8 show a comparison between this plant and an existing solvent extraction plant. Both plants were dimensioned for processing 100,000 tonnes of rapeseed per year.

Table 7: Comparison of output form an enzyme process and conventional process processing 100,000 t/y of rapeseed

Product	Enzyme process production t/y	Conventional process production t/y
Oil	35,000	38,000
Protein meal	32,400	---
Fibres	16,302	---
Syrup	28,303	---
Rape meal	---	62,000

MANY SUBSTITUTIONS FOR THE USE OF SOLVENT FOR VEGETABLE OIL PRODUCTION HAVE BEEN TESTED, BUT ONLY WITH MINOR SUCCESS YET.

Table 8: Comparison costs (mio €/y) for an enzyme process and conventional process processing 100,000 t/y of rapeseed.

	Cost unit	Enzyme Process [mio €/y]	Conventional Process [mio €/y]
Investment costs	Process equipment	3.25	6.07
	Drying equipment	3.59	
	Utilities	1.51	
	Engineering and installations	1.41	1.49
	Buildings (silos....)	3.28	3.17
	Unexpected costs	1.69	3.03
	Total	14.73	13.76
Operational and maintenance costs	Manpower	0.62	0.75
	Energy	1.95	0.66
	Subsidiary material enzyme	4.94	0.00
	Subsidiary material chemicals	0.65	0.13
	Production costs per year	8.16	1.55

The enzyme process provides oil and protein of a higher quality and additional products are manufactured. The enzymatic process is nevertheless uneconomical due to the operational and maintenance costs which are about 5.3 times higher than for a comparable solvent extraction plant. [Novo Nordisk 1998]

Ultrasonic-assisted extraction

Ultrasonic extraction can accelerate the extraction process. The ultrasonic waves are used to create cavitation bubbles. When these bubbles collapse near the cell walls shock waves and liquid jets are created that cause the cell walls to break and release their content into the solvent.

The practical implementation of this technology is very costly and thus it is not yet realised. [OILGAE] [TC 2008]

Osmotic shock

This is a sudden reaction at osmotic pressure which causes cells in a solution to rupture. A realisation of this technology failed so far due to economic reasons. [OILGAE] [TC 2008]

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