PRODUCING QUALITY FEEDSTOCK FOR BIODIESEL

by

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Presented at the

1st Brazil-U.S. Short Course in Biofuels Technology

Institute of Advanced Studies of the University of São Paulo

July 27 to August 7, 2009.

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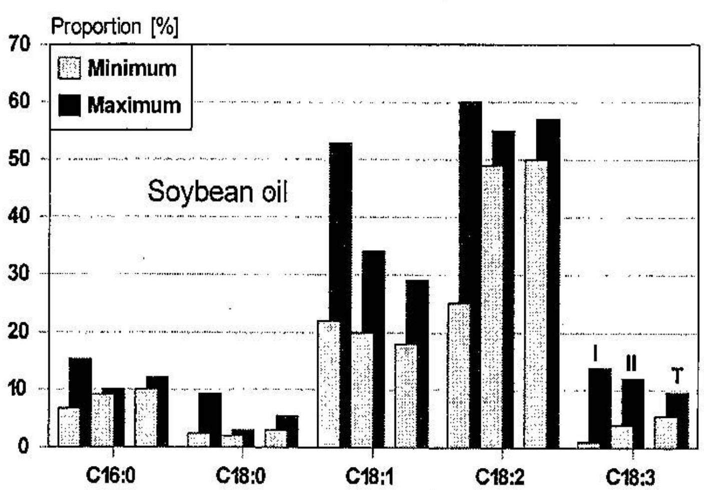
INTRODUCTION

The Feedstock used for biodiesel production is “fat” derived from vegetable or animal sources. Natural oils and fats are triglycerides. Triglycerides are esters of fatty acids with Glycerol (glycerin). Several different fatty acids can be attached to one glycerol backbone. A triglyceride consists of three fatty acids, which are substituted in the hydroxyl site of a glycerin backbone. From triglycerides, biodiesel or fatty acid alcohol esters are produced in a process called Transesterification.

Fatty Acids

The building blocks of fats and oils are the atoms of Carbon (C), Hydrogen (H) and Oxygen (O). Oil is a mixture of 96% to 98% tri-acylglycerols also known as triglycerides. Fatty Acids and glycerin are the building blocks of tri-glycerides. They generally contain 4 to 22 carbon atoms long. For the purposes of discussing Biodiesel, the fatty acids are usually 16 and 18 carbons long with between 0 to 3 double bonds.
The study of lipids (fats and oils) is really the study of Carbon Chemistry, but is usually referred to as Organic Chemistry. The following **Graph 01** shows the fatty acid makeup of Soybean Oil



GRAPH 01—Composition of Soybean Oil

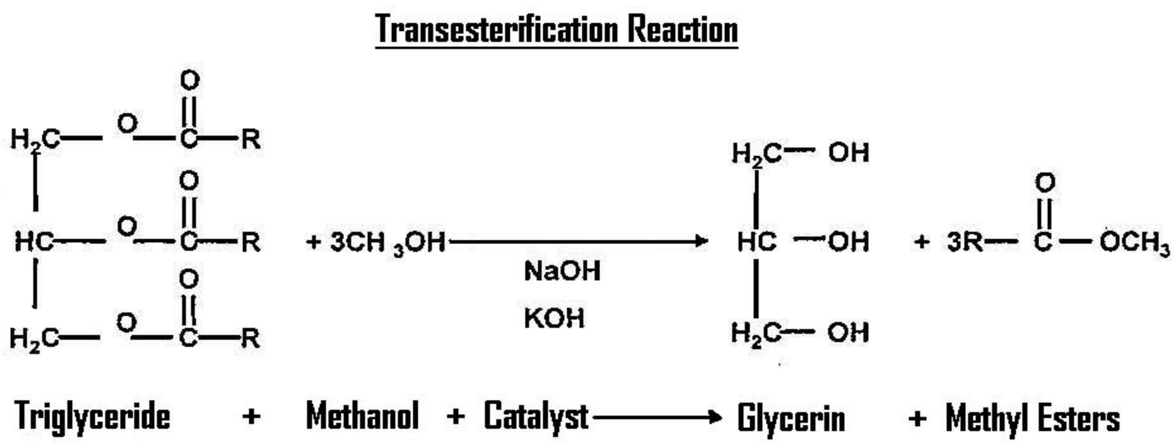
As shown above the primary fatty acids are:

1. **C16:0—Palmitic Acid**
2. **C18:0—Stearic Acid**
3. **C18.1—Oleic Acid**
4. **C18.2---Linoleic Acid**
5. **C18:---Linolenic Acid**

The Palmitic and Stearic Acids are saturated fatty acids and have no double bonds. In biodiesel, they would influence a higher pour point temperature compared to the mono-unsaturated and poly-unsaturated fatty acids.

Transesterification

This paper will concentrate on the obtaining soybean oil from a solvent extraction plant for conversion into a fatty acid methyl ester (FAME). FAME is fuel grade Biodiesel. The conversion of a triglyceride (in this case soybean oil) into a fatty acid methyl ester is accomplished in a process is known as **Base-Catalyzed Transesterification.** This is done by the reaction of the soybean oil with methanol in the presence of a base catalyst, normally a form of sodium hydroxide mixed with methanol sold as sodium methoxide. Other minor chemicals are also involved in the reaction.



Ethanol vs. Methanol

- Ethanol is more expensive in the U.S. compared to Brazil.
- 143% more ethanol required for Transesterification
- Methanol is rated as one of the 168 high-toxic Substances by the USEPA

FEEDSTOCKS FOR TRANSESTERIFICATION

Feedstock Requirements

TABLE 1 - MASS BALANCE for BIODIESEL TRANESTERIFICATION

INPUTS / OUTPUTS	Kilograms
INPUTS	
Refined, Bleached Oil	1,002.0
Methanol*	110.0*
Sodium Methoxide @ 100%	5.5
Citric Acid @ 50%	1.4
Hydrochloric Acid @ 36%	8.0
Caustic Soda @ 50%	0.75
Water	20.0
Input Total	1,147.0
OUTPUTS	
Biodiesel	1,000.0
Glycerin, water and MONG**	135.0
Fatty Acids	12.3
Output Total	1,147.0

*Includes methanol diluted in Sodium Methoxide solution

** Matter Organic Non-Glycerol

Oilseed Crushing

Oilseed Crushing is also referred to as Oilseed Extraction. In the oilseed extraction process there are two common processes used to extract the vegetable oil:

- Mechanical Extraction or Screw Pressing
- Solvent Extraction using a solvent such as hexane to remove the oil.

This paper will concentrate on Solvent Extraction. However many of the sub-processes such as Receiving , Storage, Dehulling and Flaking are similar for Mechanical Extraction Process.

Selection of Mechanical vs. Solvent Extraction Process

- Amount of seed to be crushed per day
- Over 1200 MTPD for soybeans favors Solvent Extraction
- Over 1000 MTPD for canola favors Solvent Extraction
- Residual oil (RO) content in the meal
- Solvent Extraction yields +/- 0.06 RO
- Mechanical Extraction (ME) of soybeans yields +/- 5.0% RO
- ME is easy to expand by adding screw press lines

Feedstock Sources
The common fats and oils used worldwide are:

• Soybean oil	United States & Brazil
• Rapeseed oil (a parent of canola)	Europe & Canada
• Palm oil	Asia
• Babussa Oil	Brazil

Other common vegetable oils, such as corn, cottonseed, canola (rape seed), flax, sunflower and peanut, also could be used. These seed oils generally are more expensive than soybean oil.

New Oilseed Varieties
Many new oilseed varieties and oil sources are being investigated including:

- Camolina
- Jatropha
- Cuphea
- Algae

However, none of these sources are available in the quantity to support the Biodiesel Industry's current supply needs. More important, a high protein meal is not produced when processing these seeds. Algae appears to have a great potential, because of the potential high triglycerides levels that can produced per hectare.

Animal-derived products such as tallow, choice white grease (lard), poultry fat and yellow grease are also triglycerides, and are used as a biodiesel feedstock. These products, when compared to plant-derived oils, often offer an economical advantage as a feedstock. There is also some indication that these sources, which are high in saturated fats, produce less nitrous oxides compared to plant oils.

The third main source of triglycerides is recycled oil and grease, usually from restaurants and food processing plants. Although more pre-treatment is required for this feedstock compared to virgin vegetable oils, economically it can be a very attractive feedstock.

The use of a recycled product such as used cooking oil is an environmentally friendly process since it solves a waste disposal problem.

These alternate feedstock remain important to the Biodiesel Industry. However, the more successful, large operations tend to add them as a subsidiary feedstock stream at levels of 10% to 15 %.

Biodiesel tends to take on a similar physical viscosity as the feedstock it was made from. Therefore, the biodiesel from highly saturated animal fats and greases, which are solid at room temperature, will have cloud points that would make them unsuitable as a fuel in cold weather.

Although alternate feedstocks should always be considered, the production of high protein meal from soybeans and canola to a lesser extent (canola meal is lower in protein than soybean meal) can mean the difference between the success or failure of an integrated Crushing/Biodiesel Operation.

Feedstock Costs

- Feedstock can represent 75% to over 80 % of the cost of Biodiesel
- The dominant feedstock in Brazil and the U.S. is soybean oil.
- The dominant feedstock in Canada is canola oil

Soybeans

- Dominant oilseed crop in both Brazil and the United States
- World Production of Soybeans = **237,797,000 MT**
- Brazil produced **60,149,000 MT** (May 2008)
- United States produced **70,359,000 MT** (Jan. 2008)
- Argentina produced **51,810,000 MT** (July. 2008)
- The “Big Three” produces over **76%** of the world’s soybeans.

Soybeans and canola (rapeseed) currently represent the major sources of biodiesel feedstock in the Western Hemisphere. However, this paper will center on soybeans, Many of the important processing and engineering aspects regarding soybeans also apply to canola.

TABLE 2 Composition of the Soybean

COMPOSITION of the SOYBEAN			
	Range		Typical
Oil	18 to 20%		19%
Moisture	10 to 14%		12%
Protein	35 to 40%		38%
Fiber	6 to 8%		7%
Inert	22 to 26%		24%
After Extraction in Kg's per 100 Kg's of Soybeans			
Oil	0.5 to 1.5 Kg		1.0 Kg
Moisture	10 to 14 Kg		12.0 Kg
Protein	35 to 40 Kg		38 .0 Kg
Fiber	2 to 4 Kg		3.0 Kg
Inert	22 to 26 Kg.		24.0 Kg
Total			78 Kg
38 Kg of Protein / 78 Kg. Total = 48.7% Protein			

Integrated Oilseed Crushing Operation

- A economical effective biodiesel operation should include an integrated crushing operation—this is a must to maintain control of the feedstock
- The high value output of crushing is 48% protein meal for animal feed
- The demand for protein meal drives the soybean crush required

Biodiesel Yield

- A 378.5 mm liter/yr (100.0 mm gal/yr) Biodiesel Process requires a crush of about 5525 metric tons per day(MTPD) received.
- A Solvent Extraction Process at 5525 MTPD produces about 996.4 MTPD of Refined, Bleached and Deodorized (RBD) oil.
- 994.4 MTPD of oil will produce about 994.4 MTPD of Biodiesel or 300,300 gal/day. At 8000 hr/yr. this equates to 100.0 mmgpy or 378.5 mmlpy.

Biodiesel Value vs. 48% Protein Meal Value for 5525 MT Crush

- 300,300 gallons/day of biodiesel @ $2.65 per gallon*** = $795,795
- The biodiesel revenue does not include the glycerin
- Yield of soybean meal = 3858.4 MT @ $385.03/MT*= $1,336,926.
- Yield of soybean hulls = 314.5 MT @ $121.25/MT**= $34,595.
- The value of the Hulls & Meal is $1,523,734 vs. $795,795 for the Biodiesel.

***The values above for soybean products are based on the Cash Market, WSJ, July 17, 2009.**

**** Feedstuffs, June 30, 2009**

***** Price, Chicago July 21, Progressive Fuels**

Perhaps "Oilseed Crushing" is a misnomer! Protein Seed Crushing might be a more accurate term—especially for soybeans. (Stroup 1997)

Production for Success

It is just as important to economically produce quality soybean meal as it is to economically produce quality feedstock for Biodiesel that will meet ASTM and EN standards.

Factors that have contributed to the use of soybean oil as the dominant feedstock

- Soybeans readily available in many regions of the United States and Brazil.
- The composition of soybean oil is a relative constant, compared to by-products of food preparation, particularly recycled restaurant grease.
- Historically, soybean oil is less expensive than other vegetable oils
- There is a high domestic production of soybean oil, compared with other vegetable oils and animal fats. Soybean oil represents almost 60% of the total fats and oils produced in the U.S.
- Many subsidies and grants in the past have been based on vegetable oils, although most of the new governmental programs are feedstock neutral.
- The United Soybean Board has done an effective job in the promotion of its product.

Historically, protein meal has been the driving force for the continued worldwide expansion of soybean crushing capacity. As the standard of living continues to improve throughout the world, and people demand more animal protein in their diet, the production of soybean meal used for animal feed, particularly for poultry, has increased too. One of the important results of the increase of soybean processing is the increase of soybean oil available to the vegetable oil refining industry and now to the biodiesel industry.

Producing Quality Feedstock for Biodiesel

A demand for higher quantities of vegetable protein meal for animal feeds accompanies the higher meat protein demand. Protein meals are vital to the animal feed industry, because protein must be included in any animal feed formulation to maintain health and promote growth.

The formulation of animal feeds with the right ingredients for proper amino acid balance is important. It is also important to select ingredients that have the correct Total Digestible Nutrients (TDN) for **digestible amino acids, energy levels, vitamin levels and mineral levels.** Other factors of importance are **age, carcass quality, palatability, and of course, cost.**

Of all of the available protein meals, 48% protein soybean meal or Hi-Pro-soybean meal is the **protein source of choice**, especially for animal feed that is fed to mono-gastric animals, such as chickens, turkeys, swine and fish. These animals do not benefit from high fiber in the diet as, for example, a poly-gastric animal such as a cow, goat or sheep does.

The **'Magic Formula'** for raising chickens contains:

- Corn (maize)
- **Soybean Meal (48% protein)**
- Fat (animal or vegetable)
- Premix (calcium, vitamins, trace minerals, etc.)

When Chickens are fed this '**Magic Formula'**, the result is:

- Egg hatching to marketable bird in 42 days or less.
- Feed Conversion: 1.9 kg of feed or less required to produce 1 kg of chicken.

As the poultry and swine industry continues to grow globally, so will the demand for soybean meal. One way this demand can be met is to increase imports of soybean meal from the U.S.A., Brazil and Argentina. However, the economies of scale indicate that it is better to import whole beans. The increased importation of whole soybeans for crushing particularly in third world countries will mean not only an increase in local soybean meal production, but more importantly **an increase in the amount of soybean oil available for refining and biodiesel use.** In addition, processing soybeans locally can help stimulate the production of local oilseeds and vegetable oils, which can be blended with soybean oil to make locally—processed Biodiesel. Imported soybeans can also provide a source of locally refined salad and cooking oils.

The quality of soybean oil in terms of nonhydratable phosphatides (NHP), free fatty acids, color, stability, etc. does not begin in the Refinery—it begins in the crushing plant! In fact, soybean oil quality begins in the farmers' fields when the beans are harvested.

Many crushers are not always aware of physical occurrences in the Crushing Operation that can affect the Oil Quality as well as the Cost of Refining.

Some of the major factors affecting the quality of the crude oil coming into your refinery are shown in **Table 3**.

Table 3--CRUDE SOYBEAN OIL QUALITY

Factors Affecting Quality	Resultant Increased Levels					
	Total gums (phosphatid	Non- hydratable phosphatide	Free fatty acids	Oxidation	Iron/meal Content	Pigments
Weed seed				X		X
Immature Beans						X
Field-damaged beans	X	X	X		X	
Splits from Handling	X	X	X			
Storage, time, temp.	X	X	X			
Pre-Flaking Conditioning	X	X		X	X	
Oil Stripper (overheating)		X				
Solv't Stripper (overheating)		X		X		
Oil storage (time/temp)			X	X		

Source: Erickson, Practical Handbook of Soybean Processing and Utilization, 1995

The Crushing Process has a great influence on the Refinery Process and Feedstock Quality. So how do you make sure that the Crushing Process delivers the highest quality crude oil to the Refinery? Just follow the steps:

1. **Acquire good beans. Request U.S. No. 2 or better yellow soybeans.**
2. **Consider the entire crushing process from receiving to degumming**
3. **Engineer for process stability.**
4. **Monitor the process.**

A Plant should be designed not only to produce quality meal, but also quality crude oil for biodiesel feedstock.

What you do and how you do it during the crushing process affects not only meal protein content and amino acid availability, but also the quality of crude oil produced.

In order to produce Quality Crude, the Crushing Process should be surveyed for potential trouble points that affect crude oil quality as outlined in **Table 3.**

CRUSHING PROCESS

The major parts of the Crushing Process that affects crude oil quality include:

1. Grain Unloading	2. Receiving and Cleaning
3. Storing	4. Drying
5. Tempering	6. Primary Ddehulling
7. Secondary Dehulling	8. Flaking
9. Extraction	10. Desolventizing &Distillation
11. Degumming	12. Crude Oil Storage

Unloading and Handling

Ship, Rail and Truck Unloading

The most important preventative action in the unloading of soybeans is to **prevent breakage of the beans.** High breakage means that more fines and splits are produced during handling. Reduction in damage to the beans is important because **excessive splits and fines can cause deterioration during storage.**

Split beans are more conducive to **mold growth**. Crude oils extracted from split beans are higher in **free fatty acids (FFA)** and have higher peroxide values compared to whole beans (Carr 1993). These crude oils also will have a higher level of nonhydratable phosphatides

Splits and Cracks

The ideal level of splits, broken beans and cracked beans is less than **5%.** When this level exceeds **10%**, it is unacceptable from a processing standpoint.

One area of particular concern is the ship unloading equipment and in-plant pneumatic and mechanical transfer. This equipment can be either pneumatic or mechanical.

Pneumatic Systems

The important design consideration is the pressure (vacuum)/air volume ratio. If a system is designed for high vacuum, low volume, this will result in higher terminal conveying velocities, compared to low vacuum, high volume systems. Higher terminal conveying velocities cause more breakage because of the higher impact energy at elbows and termination points, such as cyclone collectors**.**

Consider Bernoulli's Theorem: $\mathbf{P_1 V_1 = P_2 V_2}$

- Where: $\mathbf{P_1}$ = Pressure at inlet hose (vacuum)
- $\mathbf{V_1}$ = Air Velocity at inlet hose (m/sec)
- $\mathbf{P_2}$ = Pressure at discharge collector (vacuum)
- $\mathbf{V_2}$= Air Velocity at discharge collector (m/sec)

For example: A 25 cm diameter conveying line unloading at 150 tons per hour will achieve a higher terminal velocity than a 30 cm diameter conveying line operating under the same conditions.

Considerations for pneumatic conveying systems

- Minimize the number of elbows.
- Use two 45° elbows rather than one 90° elbow where possible.
- Use long radius elbows of at least 125 cm radius
- Convey at the lowest airflow possible and still achieve desired conveying rates.
- Make transitions long: a 30º included angle is good, less than 30º is better. This helps to cut down turbulence and maintain laminar flow.
- Keep flexible hose as straight as possible. Do not use flexible hose for45°or 90° bends--use rigid pipe.
- Chamfer the inside diameter of pipe at the ends before coupling to eliminate sharp edges.
- Maintain rotary airlock/rotor tip-to-housing clearances. Replace tips frequently**.**
- On spouts, use 'dead boxes' where possible so that beans hit beans instead of metal. A smaller diameter vacuum system may be cheaper, but it will generate more splits and fines.

Pneumatic unloading systems are satisfactory for small capacity systems up to 500 to 600 MTPH. For limited capital budgets and small unloading capacities, sometimes several small portable unloaders are used, particularly where public docks are available at low cost.

However, pneumatic unloaders convey at average speeds of 1370 to 1520 m/min and generate more fines than mechanical unloading systems. Maintenance is higher, and more horsepower is consumed.

Mechanical Unloaders: One of the older type mechanical unloader technologies is the Marine Leg, in which a bucket-elevator-type unloader is lowered into the hold. This unit does not pivot and cannot move up and down easily. When the ship is unloaded, it needs sufficient height (20 - 25 meters above the ship) to accommodate the 'rise' in the water of the now empty ship.

An en masse conveyor-type unloader is a better way for unloading, but it is limited to 300 to 400 MTPH.

As soybean shipments become larger, higher capacity unloaders are needed. At the same time, however, the design must minimize damage to the beans. One very popular design is a Mechanical Screw Unloader (such as the Siwertel). These units are available for capacities of 1100 to 1200 MTPH and even higher. The unit includes a large vertical screw section of about 50 cm in diameter, feeding into a horizontal screw feeding a takeaway belt conveyor.

These units operate on a true Archimedes Screw principle, fill almost 100%, and generate at least 25% less fines than pneumatic unloaders (Elzey 1999).

In all designs of mechanical unloaders, design speeds must be carefully considered. For en masse conveyors and drag conveyors, chain speeds of 15m/min to 18 m/min should be used. Twenty-two m/min would be the maximum. For screw type unloaders, a maximum screw speed of 70 rpm or less is desirable.

One problem affecting oil quality that is common in the U.S.A., primarily at harvest time, is **"Green Beans".** These are immature beans with a high level of chlorophyll that gives a green color to the oil and results in added bleaching clay costs.

Mike Cheney, a well known American oilseed engineer and plant operator remarked that green beans represents some of the worst processing problems that he encounters, followed by sour beans, wet beans and musty beans. Fortunately, imported beans have a chance to "ripen". The problem of "Green Oil" can be common in the when processing local beans at harvest time.. The problems caused by high bean moisture will be covered under the subsequent discussions on Storage and Drying.

RECEIVING AND CLEANING

Once the beans have arrived at the crushing plant, the materials handling systems are usually drag conveyors and bucket elevators. To minimize breakage in these systems, conveyor speeds are important. Drag conveyor maximum speed depends on the size, but as a general rule, 15 - 18 mpm is suggested, with 20 mpm a maximum.

Bucket elevator design should be looked at carefully in order to minimize downtime and breakage. Oil-resistant rubber belts, rather than PVC belts, should be used for soybeans and soybean meal. Bucket selection should be made to provide for clean discharge and minimum maintenance. A CC-style polyurethane bucket (Tapco HD Series) is recommended. Polyurethane buckets are more expensive than other materials, but lasts longer.

One of the problems associated with soybean breakage in bucket elevators is ‘down-legging’. Down legging, or the leakage of the beans down the return leg, usually is caused by poor bucket design, worn buckets, excessive head pulley speed, or poor head design. (Hagemeier, 1999)

Bean Breakage

Another significant cause of bean breakage is the **force of gravity**. The following table shows the breakage of soybeans when dropped from different heights:

Table 4
Breakage of Soybeans

Drop height (ft)	Onto concrete (%)	Onto soybeans (%)
100 FT (30.5 m)	4.5	3.2
70 ft (21.3 m)	2.1	1.4
40 ft (12.2m)	1.1	0.7

Source: USDA Marketing Research Report No. 968 (1973).

Flat storage built simply on grade requires front-end loaders or bobcats to move the soybeans into the grade-level discharge conveyor. Front-end loaders damage beans! A better solution is to:

1. Excavate a pit, line it with concrete, build sloping sides to a flat bottom (reverse trapezoidal shape), then place the discharge conveyor in the middle of the bottom. The reverse trapezoidal shape is required for aeration ducts in the flat bottom.

OR

2. If excavation is not practical or possible, build up the side walls of a reverse trapezoidal shape with earth to counter the significant side pressures that will be exerted by the beans.

OR

3. Consider the use of vertical steel or concrete silos. This is the most popular type of storage in the USA.

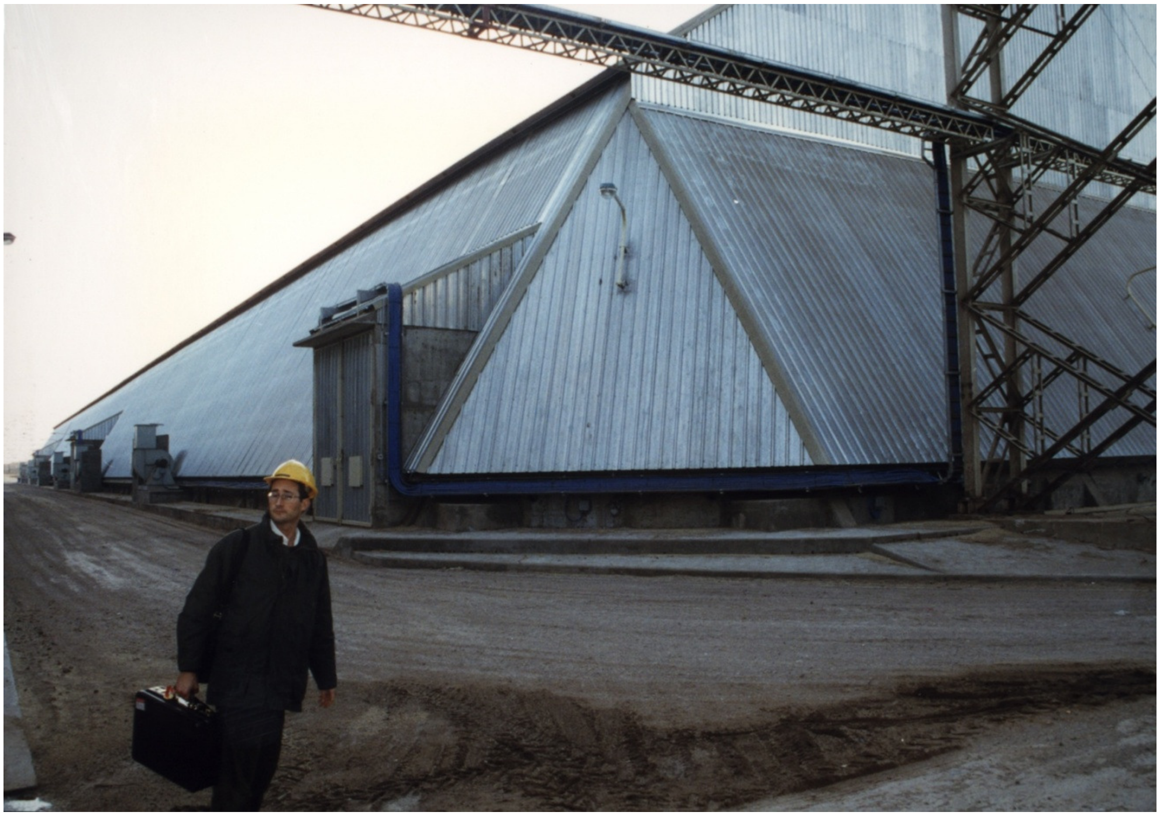
While round storage is sometimes more expensive than flat storage, depending on the total storage required, it offers great flexibility in separating different lots of beans, and generally is easier to unload and aerate. Flat storage, on the other hand, often is preferred, due to a lower drop height when filling.

Aeration

Aeration is important in order to maintain bean quality. Soybeans require drying to 12 - 13% moisture before storage or shipment. The **maximum safe storage is 13%,** although this can vary with climatic conditions. **Soybeans that are stored too wet, particularly in warm climates, are subject to heating, due to the natural growth of microorganisms and the resultant rise in temperature. Severe heating increases the free fatty acid content and damages the oil color and quality (Carr 1992). This can cause formation of a high level of nonhydratable phosphatides (Farr 2000).**

SOYBEAN STORAGE-AERATION FANS

Aeration Fans shown above for Underground Soybean Storage



Top Section of Underground Soybean Storage Structure

Soybeans damaged by heat also have **oil with a lower phosphorous content**. For example, soybeans stored at high moisture levels (16 - 20%) for up to 28 days yielded oils with phosphorus content that decreased in direct relationship to the number of days in storage, according to studies by Mounts and Nash (Carr 1992). The fact that a lower level of phosphatides are produced is of no consequence, or of no value to the refiner. The critical point is that the level of nonhydratable phosphatides is increased, causing a major problem for the refiner (Farr 2000).

The above factors usually affect only the oil that is extracted, and do not generally affect the quality of the soybean meal as an animal feed ingredient.

Soybeans in storage can develop ‘hot spots’ in various areas of the storage unit. To prevent this and subsequent damage to the beans, storage bins, silos and/or flat storage must have provision for adequate aeration. If beans are aerated properly and kept below 13% moisture, storage of the beans for up to one year or more is possible.

Soybeans will seek to be in equilibrium with the moisture content of the ambient air when aerated. **Table 5** shows the equilibrium values for soybeans at 25°C.

TABLE 5

Equilibrium Values for Soybeans at 25°C

Relative Humidity (%)	Moisture in Soybeans (%)
35	6.5
50	8.0
60	9.6
70	12.4
85	18.4

Source: Barger, W.M. J. Amer. Oil Chem. Soc. 58:154 (1981).

From this table one can see that soybeans should not be aerated over 70% RH. To do so will increase the moisture of the soybeans. Thus, the seed storage bin must be continuously monitored for 'hot spots', and aeration must be provided only to the 'hot spot' area, particularly if the relative humidity is high (Farr 2000).

CLEANING

The installation of a well-designed cleaning system before storage is important for these reasons:

1. Removal of foreign material enhances air flow in storage.
2. Removal of weed seeds which increase oxidation products and can add pigments to the oil causing undesirable discoloration.
3. Removal and classification of foreign material (up to 2.0% is allowed under U.S. Standard Grading for Grades 1 and 2).
4. Removal of abrasive sand and dirt reduces maintenance of downstream equipment.
5. Removal of lightweight material such as pods, straw, and hulls aids the downstream drying operation and helps to prevent dryer fires. In addition, these products can be added to the hull stream, helping to decrease production shrinkage.

When specifying screeners for the cleaning operation, it is important to remember that the operations required are:

- Overs Removal
- Fines Removal
- Size Classification

Of particular importance for Oil Quality is the **removal of weed seeds**. With the introduction of products like ***Round-Up Ready® Soybeans***, the amount of weed seeds in soybeans has decreased—but there are still some to remove. The oil portion of weed seeds is different from soybean oil, and has increased fatty acid levels (Mitchell 2000).

The best screener principle for these operations is a Gyratory Screener with a relatively long stroke (up to 9.0 cm) and a low frequency motion of approximately 200 rpm. For example, a high speed, high frequency machine such as a vibratory scalper would not be an ideal selection. Also, a gyratory screener with a relatively low pitch or incline of about 15° is preferred.

The following **Figure 01** shows a typical a Gyratory Screener.

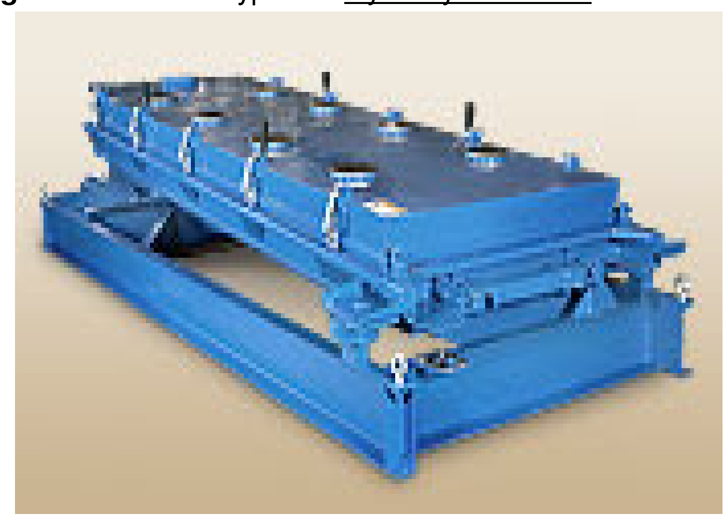


FIG. 01—Gyratory Screener

Some of the factors affecting screener capacity are:

- Screen area
- Screen open area
- Circle of gyration
- RPM
- Slope
- Allowable fines - screener
- Allowable overs - scalpers

The next important factors in efficient dry materials separation are:

- Screen exposure time
- Stratification
- Effective open screen area

Screen exposure time is determined by the stroke of the unit and the angle of screen incline. If the material does not remain in the screen long enough, efficient separation will not occur.

Stratification or how the material arranges itself on the screen is critical in order to separate sizes. Stratification can best be explained by the vertical arrangement of particle sizes in the following **Table 5**:

Table 6

STRATIFICATION

COARSEST
COARSER
COARSE
FINE
FINER
FINEST

The screen area required is important, but this is influenced by the "Effective Screen Opening", which is determined by wire size of the clothing and the slope of the screener. The slope determines the actual projected hole opening in a horizontal plane.

The Goal --- Match particle size to screen opening.

DRYING

Probably the most important sub-process in producing 48% or higher protein soybean meal is **DeHulling**. The beans, in order to be properly and efficiently dehulled, must be at the optimum moisture for hull removal, which is 9.9 to 10.4% moisture, with **10.2% (+ or – 0.2%)** being a good target moisture level. Therefore, beans coming out of storage at 12 to 13% must be dried to this level.

Ideally, beans should be stored at 12 to 13% moisture, and then dried to 10.2 (+ or – 0.2%) prior to flaking. This will improve dramatically the Dehulling efficiency. If seeds are received at the oil mil at 10.0% moisture or less, difficulty in Dehulling will be experienced (Farr 2000).

Grain dryers should be sized at least two times larger than required, because of possible need to dry beans to 13% before storage. The receipt of beans at moistures higher than 13% is possible, even though they would be out of specification. Beans unloaded during storms can pick up moisture and arrive at storage higher than the expected 13%.

Most soybean dryers use natural gas, LNG or propane for fuel. There is the rare occurrence where a drying operation will attempt to use No. 2 fuel oil. Dryers operate with an open flame and fuel oil residue can collect on the beans. Of course, any petroleum residue in the crude soybean oil ruins the quality.

Most grain dryers are designed to bring the beans up to 60°C (140°F) before discharging to the dryer-cooler section. It is important not to exceed 76°C (169°F), because above this temperature, discoloration and protein digestibility will occur. (Bussell 1996). The preferred dryer is a column grain dryer that is equipped with internal louvers or deflector plates to 'reverse' the flow in the dryer so that the beans in the top part of the dryer, which are near the center air column, can be directed to flow near the outer part of the column when flowing down the bottom part of the dryer. In this way the beans are more uniformly dried. Even so, as discussed under "*Tempering*", bean discharge moisture is not uniform.

It is important to note that the inlet air temperature to the dryer should not exceed 93°C (200°F) in order to avoid heat damage to the beans (Farmer 2000).

TEMPERING

Because of the slightly uneven bean moisture discharging from the dryer, tempering the beans in tempering silos for 48 hours to 72 hours is recommended. While there are some engineers who might dispute the need for two to three days of tempering, this Engineer advocates tempering. The reason:

All soybeans are not created equal!

The amount of drying each individual bean undergoes is size-related. Beans vary in size, fiber, oil and moisture content. These factors also effect drying time and, therefore, final discharge moisture.

When moisture tests are made on beans coming from the bean dryer, a sample of at least 125 gm is taken. The average moisture of the sample of beans might be 10.2%. If each individual bean is measured, however, the moisture might easily vary from 9.5% to 11.5%. Dry beans produce fines during cracking. Wet beans can produce a 'mushy' product, and will not properly release the hull.

When corn is dried and the sample tests are satisfactory, the individual kernel moisture percent is not important, because the corn is going to be ground, and no attempt is made to 'dehull' the corn   But when soybeans are dehulled**, each individual bean is dehulled, and individual bean moisture becomes important**.

The measurement of individual grain kernel moisture in the past has been difficult. But recently, I.C.Baianu, Professor of Food , Physical Chemistry and Nuclear Engineering at the University of Illinois-Urbanna, has been directing some exciting grain moisture research using Perten Instrument Near Infra Red Spectrometers. Preliminary data shows that there is variation between soybeans (outside experimental errors) of 0.25 to 0.36% of total by dry weight of single soybean seeds, in terms of moisture, protein, oil and sugars (Baianu 1999).

The successful practical experience of oilseed crushers in improving dehulling by tempering beans suggests that individual bean moisture does vary coming out of the dryer, due at least to differences in bean size, position in the dryer, and individual bean moisture coming to the dryer. Baianu's preliminary work shows that individual beans vary in moisture before processing and drying.

Since nature does not like imbalances, tempering silos or bins offer a low-energy and low- maintenance method to achieve the best moisture levels in individual beans prior to cracking and dehulling.

PRIMARY DEHULLING

Magnetic Protection

There can never be enough magnets in a processing plant in the author's opinion. One of the most critical spots is before Primary Dehulling, especially to protect the Cracking Mills.

The following **Figure 02** shows a **Rotary Drum Magnet**. The main advantage of this type of unit is that it drops out ferrous metal automatically.

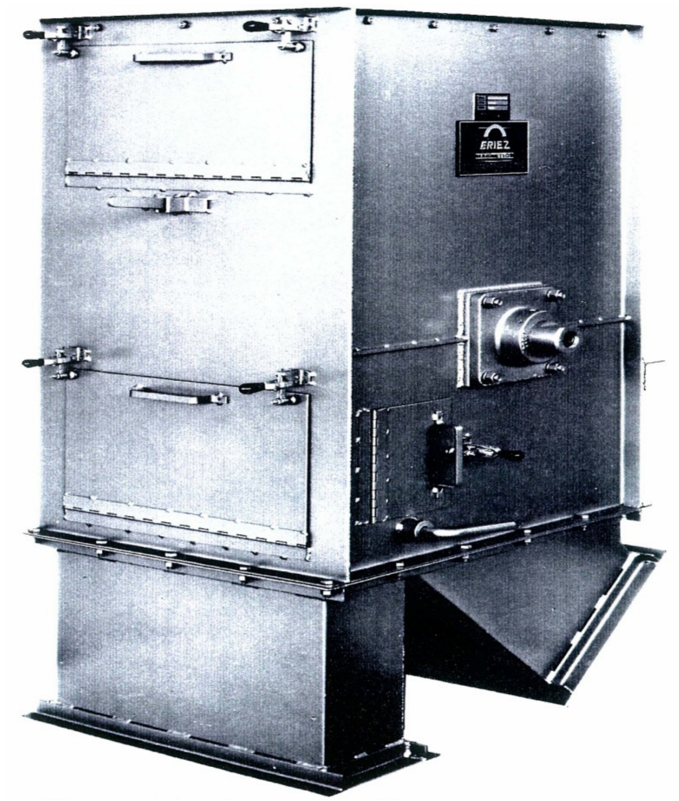


FIG. 02—Rotary Drum Magnet

How it works is shown on the following **Figure 03**.

PRODUCT STREAM IN

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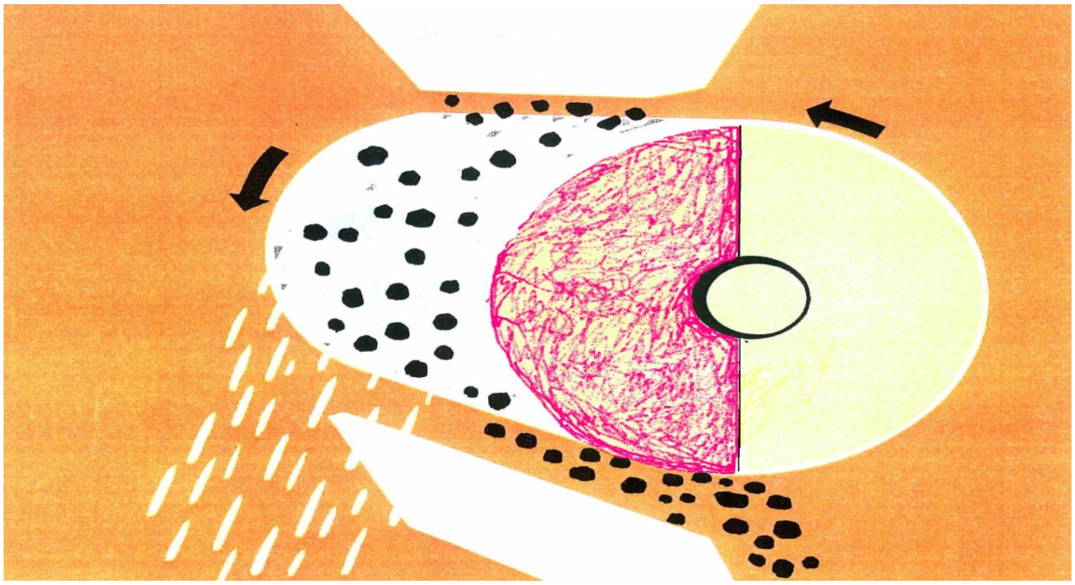


Good Product **Tramp Iron or Steel**

FIG. 03—Rotary Drum Magnet Operation

The product stream flows over a stainless steel cylinder. Inside the cylinder is a half-magnet, shown in **red** along the left side of the cylinder. The stationery half-magnet is located inside the rotating cylinder. Ferrous material is attached my magnetic force to the cylinder(inside of which is the half-magnet). The half magnet does not rotate.

At bottom dead center, the tramp metal is no longer attracted the cylinder since the stainless material is non-magnetic and the ferrous tramp metal simply falls off into a waste container.

<u>Weighing</u>

A <u>weighing device</u> should be installed to measure input to the preparation system after tempering. It should be located to weigh the beans as they enter the preparation building. After weighing, a screener should be installed with aspiration to remove hulls and fines. When the soybeans are subjected to the heated air in the dryer and the temperature quickly rises to 60°C (140°F), the hull begins to separate from the protein material due to stresses set up by the heating. In fact, by the time the beans arrive at the cracking operation, many hulls have separated. These hulls should be removed by aspiration, since they will cause downstream wear to the equipment, particularly to the cracking rolls.

<u>Cracking</u>

The cracking operation uses corrugated rolls to produce cracks, or particles of the proper crack profile, to cause the hull (skin) to split away from the bean.

<u>Cracking Mill</u>

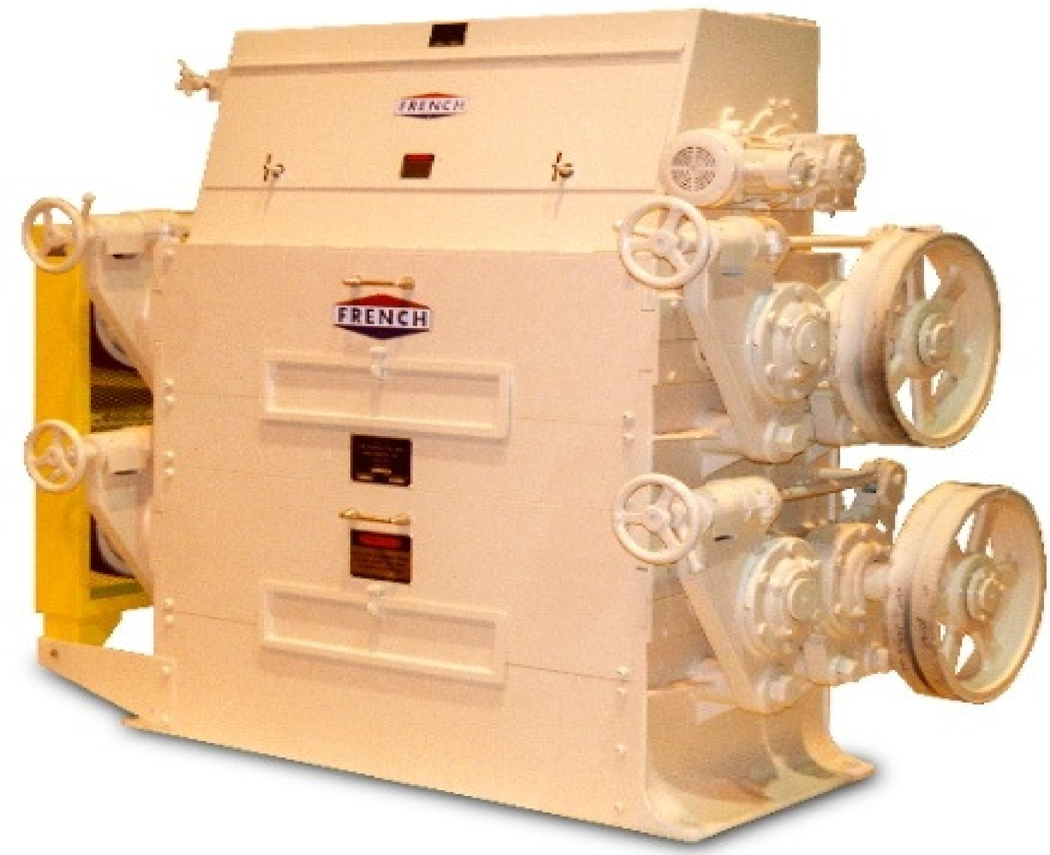
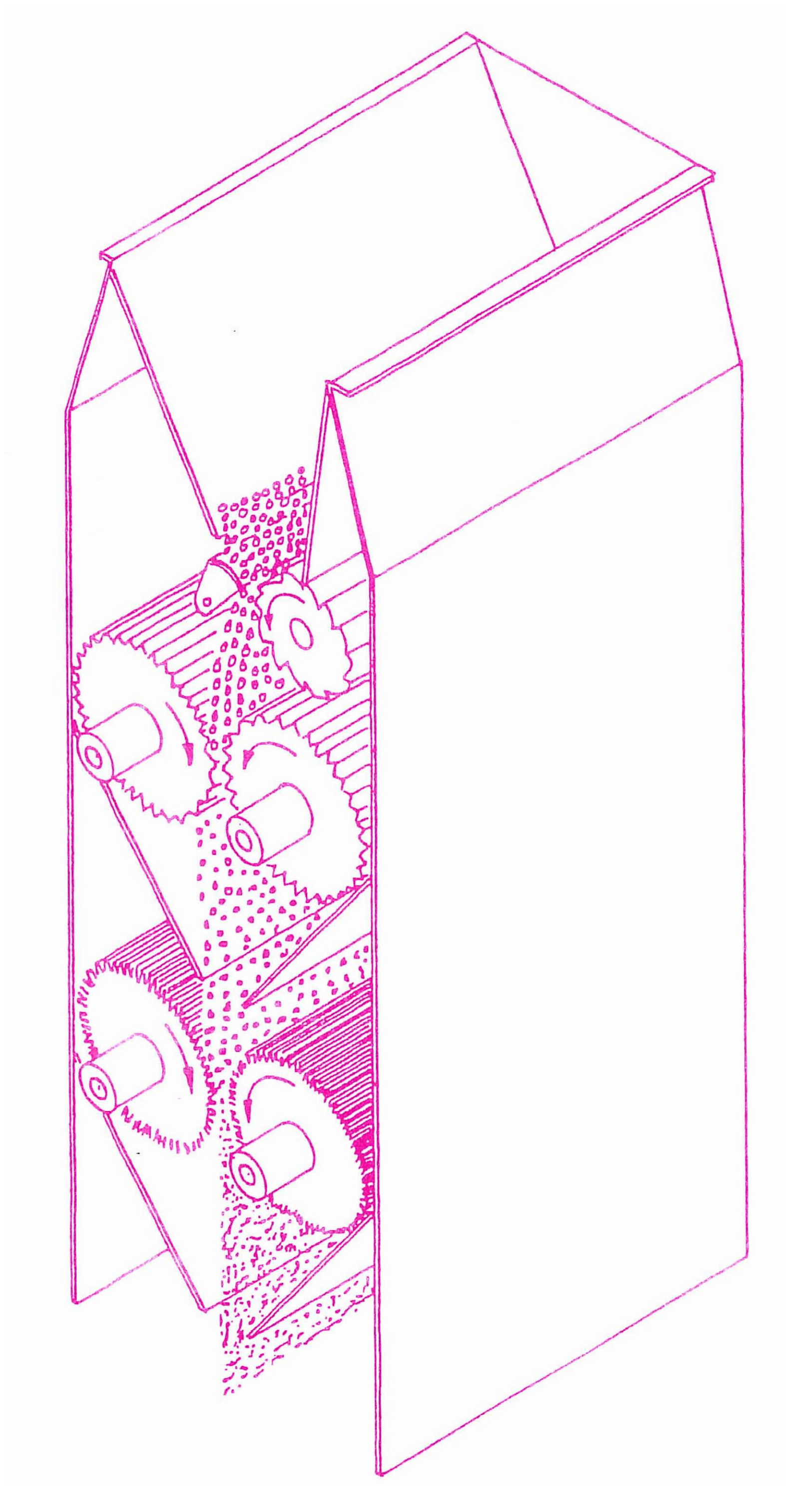


Figure 04—Two Pair High Cracking Mill

The cracks should be of an optimum size for flaking. To achieve the best results, the soybeans should be delivered to the Cracking Mills at approximately 10.2% moisture. In this way the following crack profile can be achieved:

- **+** 6 mesh—10 to 15 %
- **+** 10 mesh—60 to 70 %
- **+** 20 mesh—5 to 10 %
- **-** 20 mesh—0 to 3%

Figure 05—Operation of a Two Pair High Cracking Mill



The proper **Crack Profile** will result in:

1. Maximum hull removal with minimum amount of “meat” in the hulls.
2. Uniform cracks with minimum fines.
3. By delivering the above crack profile to the flaking mills, flaker efficiency is maximized throughout while minimizing flaker wear.
4. Ability to produce good quality flakes. Thicker flakes, averaging 0.36 mm, will produce fewer flaker fines.
5. **Maintaining a good crack profile and minimizing fines will help produce better downstream process stability, thereby producing higher quality meal and oil.**

Occasionally, the cracking mill is the ‘forgotten machine’ in the process. It usually works well and is easy to maintain, but the rolls will wear in time. When the corrugations become worn and dull, the cracking mill will begin to act like a flaking mill, and will begin to produce excess fines and agglomerated pieces, which will **affect the stability of the downstream process.**

Remember, the cracking mill operates on a cutting or cracking principle. When the corrugations become dull, it begins to ‘crush’. Crushed seeds leaving the cracking mill can cause rapid formation of nonhydratable phosphatides (NHP), particularly if there is a large holdup of cracks prior to flaking. This is due to the beginning of the enzymatic action that creates NHP (Farr 2000).

Following the cracking process, the cracks and hulls are directed to a Primary Dehuller Screen. This unit should be a gyratory screener using a long stroke/low frequency horizontal screening motion. This screener usually is clothed with:

3.5 - 5.0 mm (4 - 6 mesh) on top screen
2.5 - 1.5 mm (8 - 12 mesh) on bottom screen

The <u>overs</u> of the <u>top screen</u> will be 1/2 beans (+4 mesh) and large hulls. The 1/2 beans (and occasional whole ‘small’ beans) can be returned to the cracking mill for re-cracking. The large hulls will be stratified on top as they travel down the top screen, and will be picked up by an aspirating hood at the end discharge of the screener.

The <u>overs</u> of the <u>bottom screen</u> will consist of:

a. +12 mesh cracks
b. +12 mesh hulls with pieces of ‘meat’ attached
c. +12 mesh hulls

This entire stream (a,b,c) is fed evenly (sometimes with a stream splitter) into an Aspirator. The <u>fines</u> (minus 8 - 12 mesh) usually are fine dehulled cracks, and will be directed to the conveyor serving the <u>Seed Conditioner</u> prior to flaking.

SECONDARY DEHULLING

The minus 4 mesh hulls, cracks, and hulls with protein pieces (meats) attached discharge from the primary screener and are then directed to a Multi-Aspirator. The multi-aspirator utilizes the terminal lifting velocity of the particles, or TV. Because particles have different TV's due to size, density and shape, the air velocity in the unit can be 'tuned' (increased and decreased) to air-classify the cascading material.

In soybean Dehulling, the heavier cracks with no hulls attached drop through the aspirator and discharge into the dehulled cracks conveyor, feeding the flaking system. At the same time, the lighter hulls and the hulls with meat attached are 'lifted' out of the aspirator and delivered to a cyclone collector discharging into a Gravity Separator.

The Gravity Separator, or Gravity Table, is a device that has been used for many years very successfully in separating various seeds, including seeds in the seed industry. The Gravity Separator separates particles by their specific density. The discharges of this unit are directed as follows:

a) Hulls to the Hull Conveyor
b) Dehulled cracks to the Dehulled Cracks Conveyor to Flaking
c) Hulls with meat attached back to the Primary Dehulling Screener

The conveying of the material in (c) through bucket elevators, drag conveyors and across the secondary screener will continue to loosen and separate the remaining meats from the hulls. (Shockley-1999)

FLAKING

Pre-Conditioning

Prior to the flaking operation, the dehulled cracks must be heated to approximately 70°C to 72°C (160°F) to make the cracks pliable or 'plastic' enough to be formed into flakes. If the crack temperature is too low, excessive fines will be generated by the flakers. If the crack temperature is too high, smearing in the rolls will occur. But more importantly **for the Refiner, excess temperature at this point will increase non-hydratable phosphatides, total gums, oxidation products and iron/meal content.**
When a **shutdown** occurs in the flaking operation, it is **critical to oil quality to immediately stop the steam** flow to the Conditioner in order not to reach the high temperature level in the unit.

There are two processors used to pre-condition soybean cracks before flaking:

1. Vertical stacked deck conditioners using indirect steam at 10 bar (150 psig) to heat the sealed decks. These units control material temperature very well. However , the HP used to turn the vertical shaft is high.

2. Horizontal Steam Tube Conditioners. These units use comparatively low horsepower (HP). They are not as efficient as the vertical units and do not have the same sensitive temperature control as the vertical units.

Fig. 06-- Vertical Steam Deck Pre-Conditioner

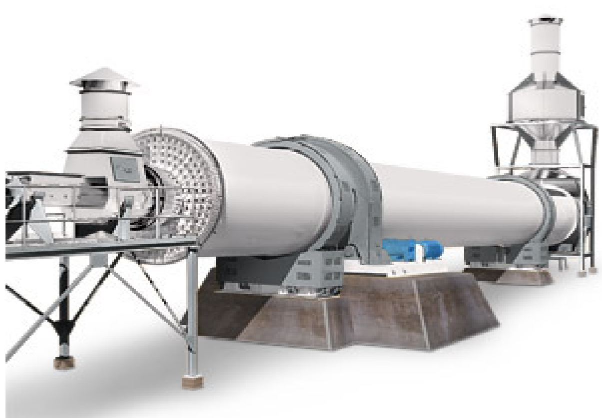


Fig. 7--Horizontal Steam Tube Pre-Conditioner

Some people erroneously believe that one of the main purposes of the flaking mill is to ‘rupture’ oil cells. This is untrue because oil cells are too small to be crushed in the 0.25 mm to 0.40 mm gap between flaking rolls! The purpose of flaking is to expose surface area for efficient extraction. If expanders are used as part of preparation, flake thickness becomes much less important because oil cells will be ruptured in the expander.

Flake Thickness

The ideal flake thickness depends on the type of extractor used. Manufacturers usually make the following recommendations for flake thickness:

- **Deep Bed Extractors: 0.38 mm (0.015 inches)**
- **Shallow Bed Extractors: 0.30 mm (0.012 inches)**

Thicker flakes require less KWH/ton to produce and result in fewer fines during flaking (Stroup-1998)

Regardless of the degree of thickness of the flake being produced, the key to good flaking is to produce flakes of even thickness over the entire length of the flaking rolls. Uneven flakes usually are caused by:

- Uneven roll wear Rolls tend to wear more in the center. Rolls should be dressed (ground) on the ends at least every week to 10 days. It usually is not necessary to grind the center of the rolls.

- Uneven Feed to Flaker This often is caused by plugging in the roll feeder (it is dirty!), or in the case of vibratory feeds, material buildup in the vibrating trays, or simply by out of 'tune' vibrators. Another common cause of uneven vibratory feed is an insufficient number of vibratory feeders for the length of the roll. For example, for 62" wide flakers, four vibratory feeders are recommended.

- Roll Deflection Roll deflection will cause uneven wear, vibration and, eventually, uneven flakes. It is recommended that rolls with a maximum length of two times the diameter be used. If rolls are too long relative to diameter, then chattering, spalling and general uneven roll wear will occur. Roll deflection varies by the third power of the length, so too much length relative to the diameter can be a concern.

Uneven flakes creates negative process stability in the downstream extractor and DTDC. Ultimately, lowered process stability affects the quality of the meal and oil.

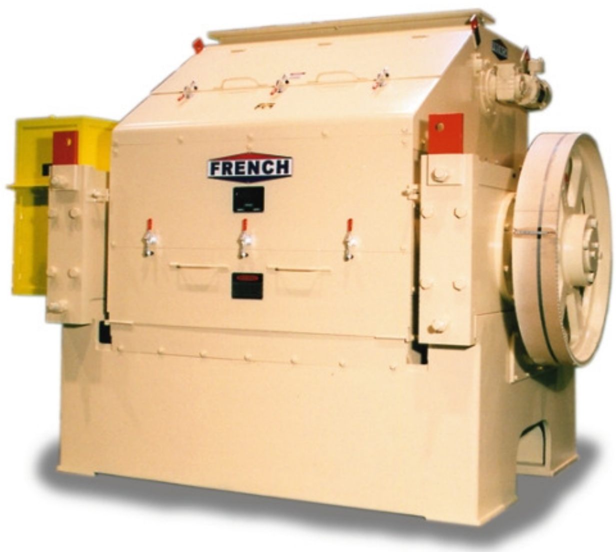


Fig. 8 790 X 158 mm (31 in. X 62 in.) Flaking Mill

The flaking operation is the largest consumer of electricity in preparation and where potential energy savings exist. In the 1200 MTD soybean plant, flakers represent 32% of the total connected HP. The principal variable affecting flaker HP is flake thickness.

FLAKER HORSEPOWER IS INVERSELY PROPORTIONAL TO FLAKE THICKNESS. Figure 8 (flaking cost) shows this relationship. (Stroup 2000)

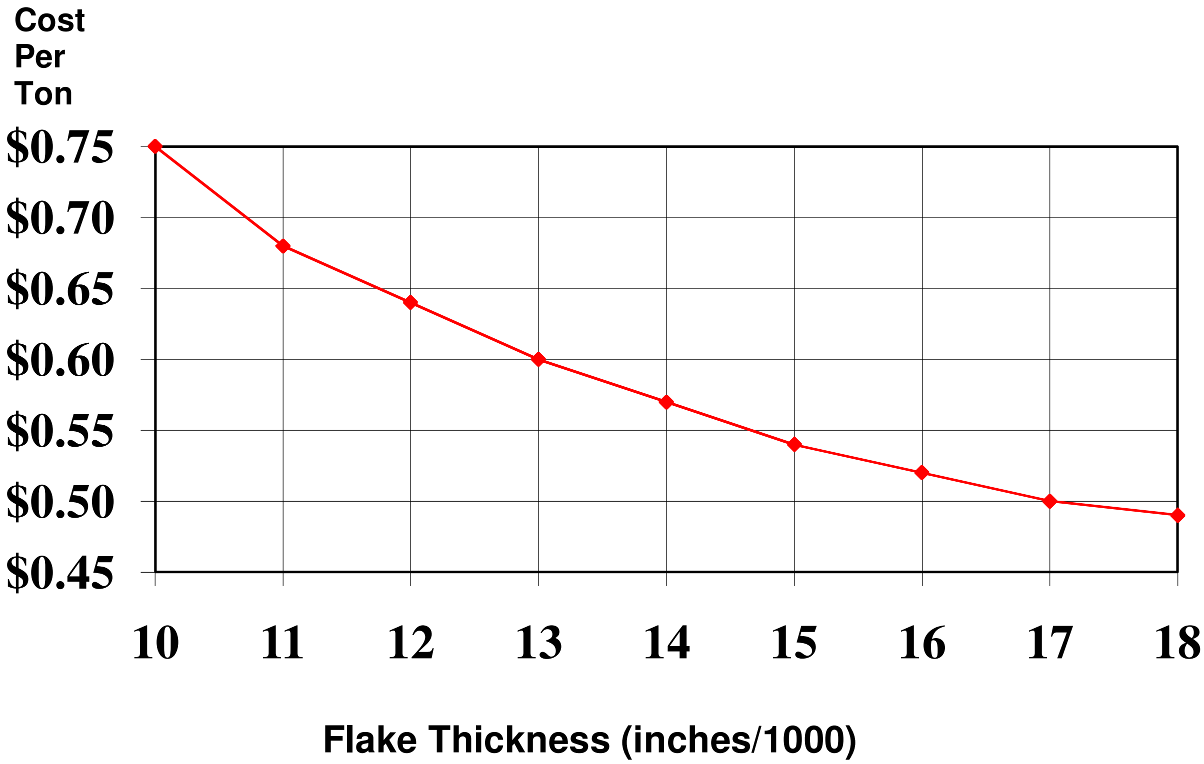
Flake thickness for soybean processing varies from 0.010 to 0.016 inches (0.25 to 0.41 mm). Typically, shallow bed **extractors** require thinner flakes while deep bed **extractors** can utilize thicker flakes. When planning a new plant or the expansion of an existing one, consideration of producing thicker flakes can result in significant energy savings. Consider the cost savings of producing 0.012 inch (0.30 mm) flakes vs. 0.015 (0.38 mm) flakes for the 1200 MTPD plant:

Cost for 0.012" (0.30 mm) Flakes	$0.54 /ton
Cost for 0.015" Flakes - (0.38mm)	$0.40 /ton
DIFFERENCE:	$0.14 /ton

SAVINGS/YR = $0.14 x 1200 MTPD x 350 d/yr.
= $58,800 / yr.

In addition, producing thicker flakes will lower flaker maintenance costs.

FIG. 09-- Flake Thickness vs. Electrical Cost per Ton



FLAKING ELECTRICAL COST

Electricity is an important manageable energy cost, but **steam** remains the largest energy cost for oilseed processing. Most of the steam consumption occurs in the **DTDC**

Keeping the rolls in a Flaking Mill in **Tram** and **Parallel** is very important for producing good flakes. See **Figure 9** (next page) for an illustration of Tram and Parallelism of Flaking Mill Rolls.

Expanders

Expanders (extruders, Enhansers™, etc.) are not required in a well-designed plant. The most recommended use of an expander is to obtain a 'quick **increase' in capacity** of a plant that has demand exceeding capacity. When the electrical power, maintenance costs, steam costs and increased capital costs are considered, the advantages of expanders (increased product density and increased gums in the oil) usually **are difficult to justify** in a new plant (Kemper-1995).

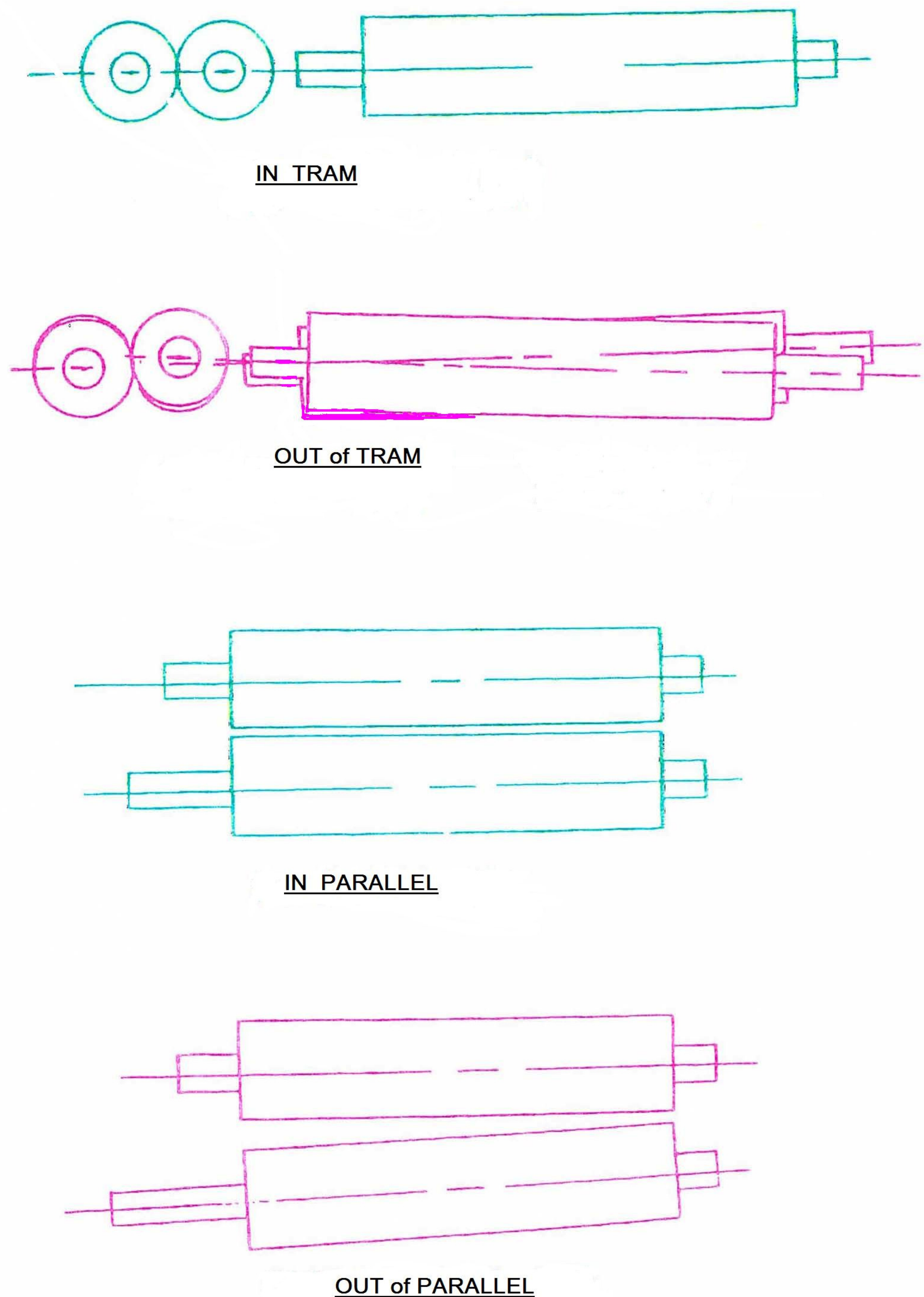


FIG. 10-- Roll Tram and Parallelism

SOLVENT EXTRACTION PROCESS

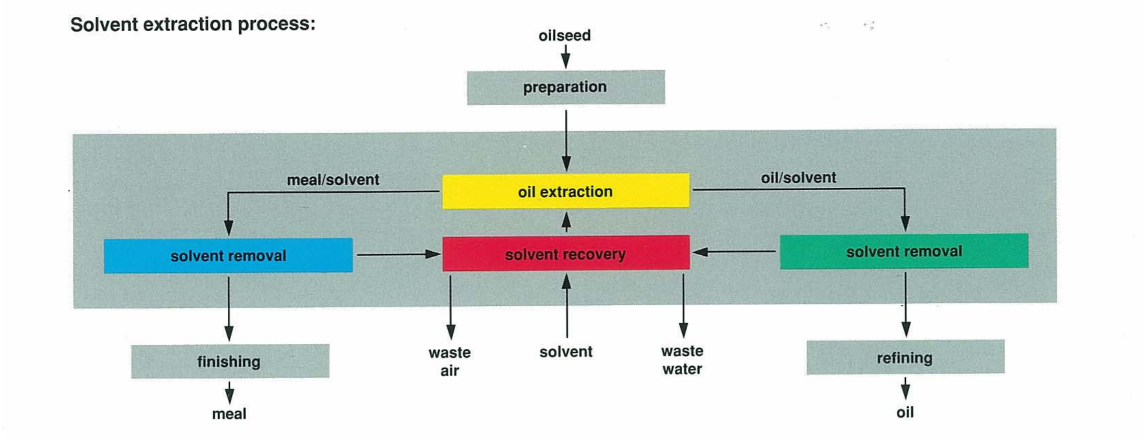


Diagram 01--The Solvent Extraction Process

The purpose of solvent extraction is to remove most of the oil contained in a seed. Extraction is conducted on prepared seeds or, generally in the case of high oil content seeds, the cakes yielded by the pre-presses. The Solvent Extraction Process consists of five major operations:

1. Physical removal of oil from the seed in the Extractor
2. Desolventizing-toasting of the de-oiled seed (meal)
3. Drying and Cooling of the meal.
4. Removal of Solvent in a Distillation System
5. Solvent Recovery for reuse in the Extractor

Extractor Principles

There are two principle types of extraction process:

- **Percolation**, where the solvent is sprayed on the bed of oilseed material and drains or percolates down through the bed of material. This principle is found in shallow bed and medium bed extractors.

- **Immersion,** where the oilseed material is completely immersed in the solvent, which drains down through the bed of material. The solvent is continuously sprayed on the top of the column of the main quantity sufficient to maintain a layer of solvent on top of the column of oilseed material. This principle is used by the deep bed designs.

A third type of design to produce methyl esters without solvent or mechanical extraction that is currently under development is the ***in-situ*** **Transesterification** System developed by Dr. Michael Haas of the USDA. (Haas 2002). In this system, flakes are reacted directly with an alcohol and a base catalyst in a reactor. The oil extraction process is not required. A fatty acid methyl ester is formed along with glycerin. A high ratio of alcohol to flakes is required, which makes the alcohol recovery a high energy consumer. Current work contains to reduce the molar ratio of alcohol required.

The Immersion System, based on work by Texas A & M and the University of Rio Cuarto in Cordoba, Argentina showed that the Immersion System removes a greater amount of oil expressed by Oil Concentration in the miscella, particularly during initial stages of extraction. The following graph shows the results of this work.

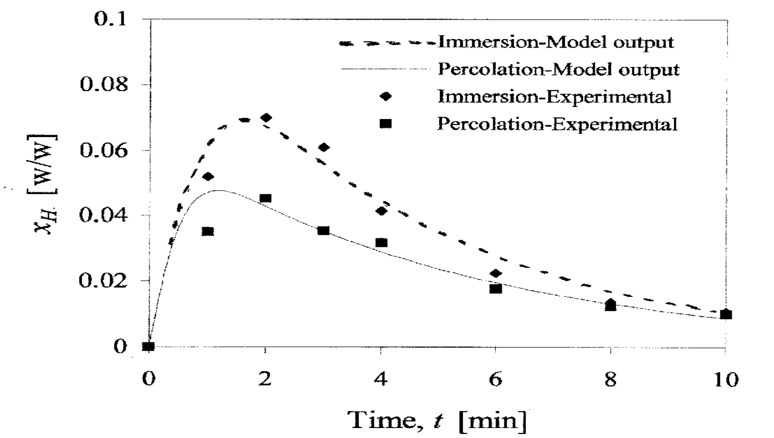


FIG. 1. Oil concentration at bed outlet in a deep-bed arrangement. Solvent flow: 0.59 L/min; model parameters: ε_p = particle porosity = 0.3; ε_l bed porosity = 0.5; D_p = molecular diffusion coefficient = $9.33 \cdot 10^{-10}$ m^2/s; D_z = axial dispersion coefficient = $9.86 \cdot 10^{-6}$ m^2/s; k_x = mass transfer coefficient = $1.42 \cdot 10^{-5}$ m/s; K = equilibrium constant = 0.6; x_H = oil concentration in the miscella leaving the bed.

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FIG. 11--Oil Concentration vs. Time for Immersion & Percolation Extraction

Types of Extractors

The heart of the Solvent Extraction Process is the Extractor. Three types of Solvent Extractors are commonly used:

- **Shallow Bed Extractor.** This unit depends on solvent percolating through a bed of flakes normally less than three feet deep. This type of Extractor uses a chain type belt to convey the flakes from the beginning stage to the ending drainage stage.

- **Medium Bed Extractor.** This unit depends on solvent percolation through a bed of flakes usually =/> 8.0 feet. This type of Extractor uses a conveyor to move the flakes from the beginning stage to the ending drainage stage.

- **Deep Bed Extractor.** This unit maximizes the **immersion principle** and allows the solvent to percolate through a 10 foot deep bed of flakes. The Deep Bed Extractor is round and contains a series of “pie-shaped”, sealed, basket dividers. The internal dividers rotate over a fixed wedge wire bottom.

Shallow Bed Extractors

Here is how the shallow Bed Works:
Material is fed into the extractor an inlet hopper, which incorporates a level sensor device to automatically match the extractor speed with material input.The unit has an automatic level control system which is especially effective when used with computer systems as an accurate "feed-forward" capacity signal.

The material forms a uniform shallow bed and is sprayed with miscella (solvent and oil) supplied by recycle pumps stage pumps as the oilseed material is conveyed across the upper, horizontal section of the extractor, counter current to the concentration of miscella.The concentrated miscella discharges from the extractor through a liquid cyclone. The cyclone separates the material fines from the miscella before being pumped further to the distillation system. There are seven miscella stage pumps in a typical shallow bed extractor system.

The material bed continues along to the curved tail "Loop" section where it is completely turned over with each particle washed from all sides to maximize extraction efficiency. As the material moves horizontally, the bed is washed by miscella of reducing concentration until near the discharge section, fresh solvent washes the lower horizontal section of the extractor.

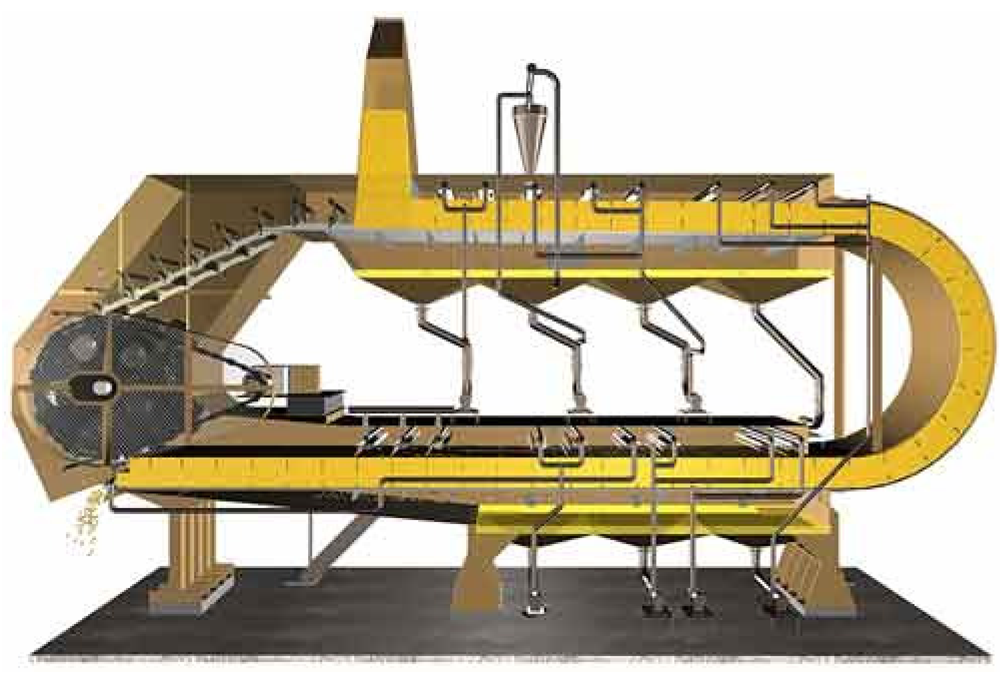


Figure 12—Shallow Bed Extractor

Medium Bed Extractors

How the Medium Bed Extractor works:
Material enters through an inlet hopper and is soon saturated with miscella - extraction starts immediately after entry. After the initial saturation, the bed of material is continuously washed with counter-current stages of miscella.
Rakes at the surface of the material bed, along with an upward belt slope, maintain percolation and prevent miscella contamination.
Since the miscella has more contact time to penetrate the flake than in shallow bed designs, thicker flakes can be used to achieve desired residual oil.

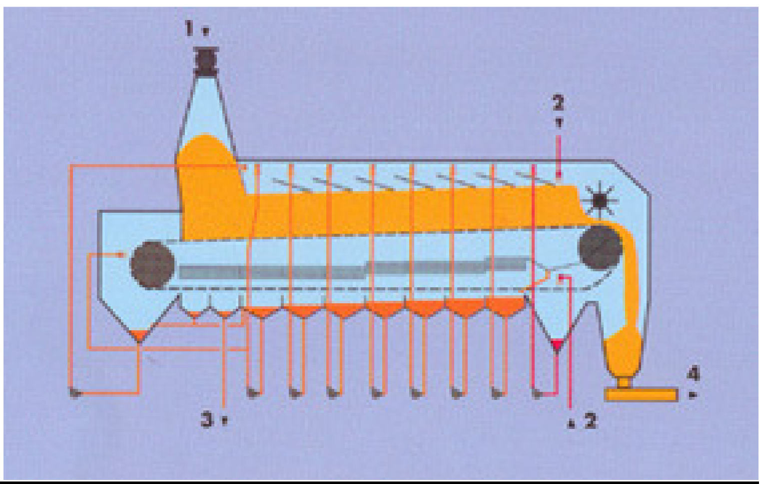


Fig. 13-- Medium Bed Extractor

<u>Maximum Material - Miscella Contact</u>

Contact time is the single most important factor for the efficient solvent extraction of vegetable oils. To maximize contact time, the Extractor's initial immersion sequence enables the oilseed material to be completely surrounded with miscella.

A long percolation sequence follows to keep the miscella stages separated and extract the remaining oil.

Deep Bed Extractors

How the Deep Bed (3.0 meter bed) works:

Material mixed with miscella is slurry-fed into the rotating baskets - Extraction starts immediately.

After the initial slurry feed, the bed of material is continuously washed with countercurrent stages of miscella. Totally sealed basket dividers ensure each miscella stage flows through the proper basket of material.

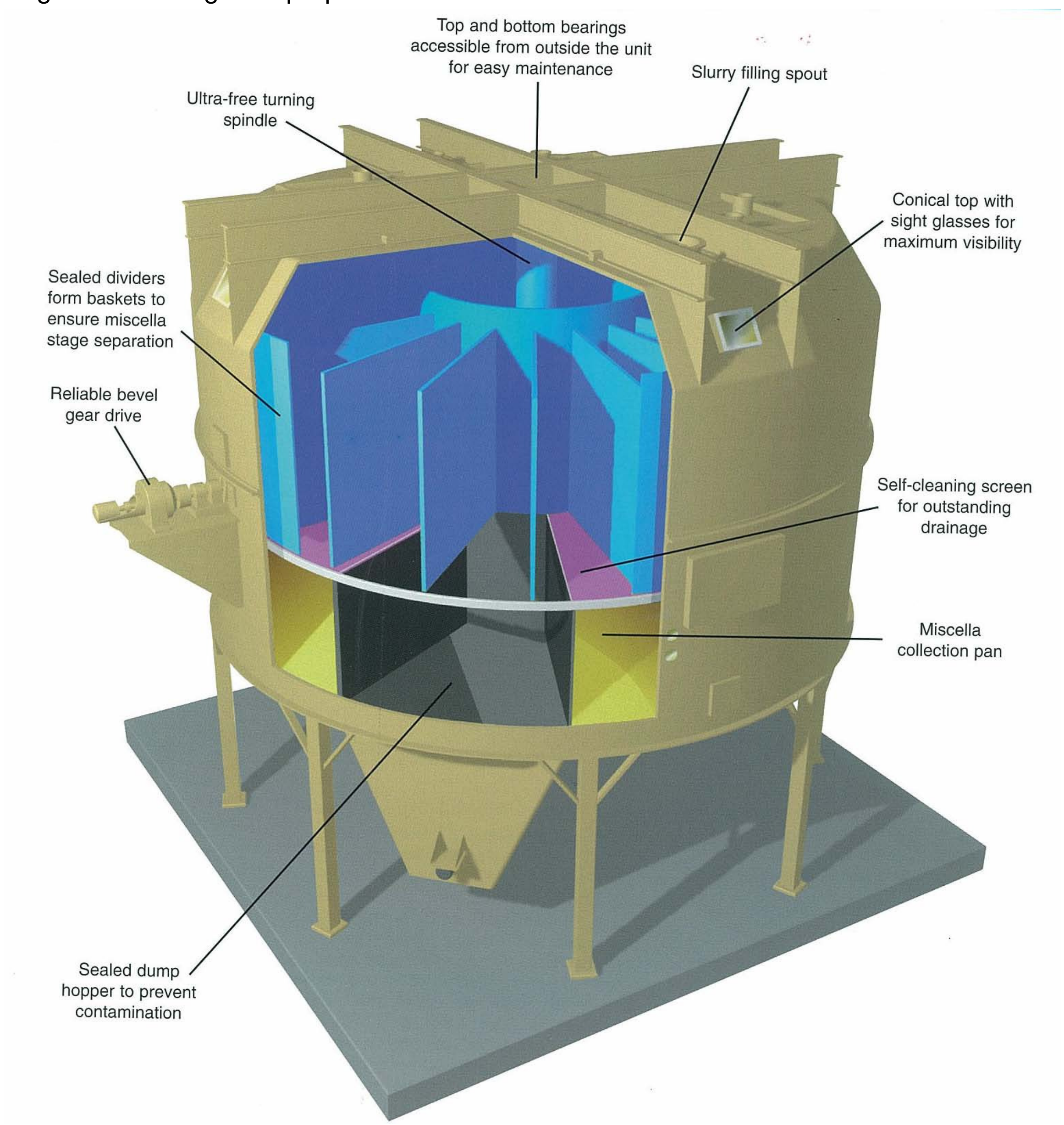


Figure 14—INTERNAL VIEW OF A DEEP BED SOLVENT EXTRACTOR

The following **Figure 15** shows a horizontal or “un-wrapped view of the Deep Bed Extractor.

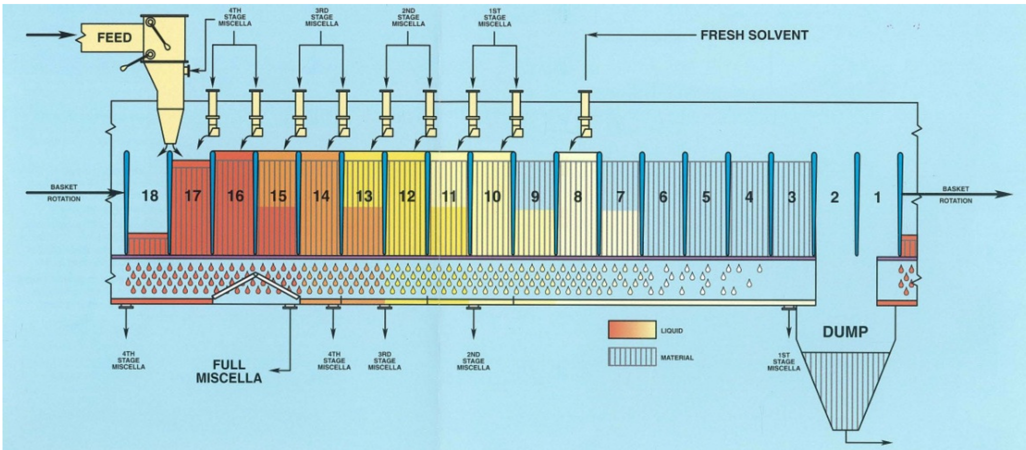


Fig. 15 Deep Bed Extractor—“Un-Wrapped” View

Totally sealed basket dividers allow the entire bed of material in the extraction zone to be thoroughly soaked in miscella. This minimizes inactive time between miscella stages and maximizes contact time. Since the miscella has more contact time to penetrate the flake than in shallow bed designs, thicker flakes can be used to achieve desired residual oil.

Maximum Material- Miscella Contact

Contact time is the single most important factor for the efficient solvent extraction of vegetable oils. To maximize contact time, the Deep Bed’s sealed divider design enables the oilseed material to be completely surrounded with miscella from the time it enters the extractor until the extraction cycle is complete. Only a sealed divider design can do this.

Savings on Seed Preparation

The Deep Bed Extractor, with sealed divider design, accepts thicker flakes than shallow bed or conveyor designs when processing soybeans. Flakes at least 25% thicker can be processed.
This results in lower power and maintenance costs in seed preparation. The savings in seed preparation alone could easily pay for the cost of a Deep Bed Extractor over its life cycle.

Self-Cleaning Screen

One variety of Deep Bed Extractor uses a patented screen technology at the base of the material bed to allow miscella to freely pass through while supporting the material above. The proprietary screen profile allows the screen to wear for many years with no change in slot width. The slot width allows optimum drainage without fine material plugging the slots. Solvent drainage remains constant over time because the baskets continuously move over the screen to keep it clean.

This design allows consistently low solvent carryover in spent material going to the Desolventizer, thus saving steam energy. This design is a dramatic improvement over hinged bottom-type extractors where the material does not move with respect to the screen surface, causing frequent blinded screens and drainage problems.

The wedge wire screen bottom is shown in the following photo:

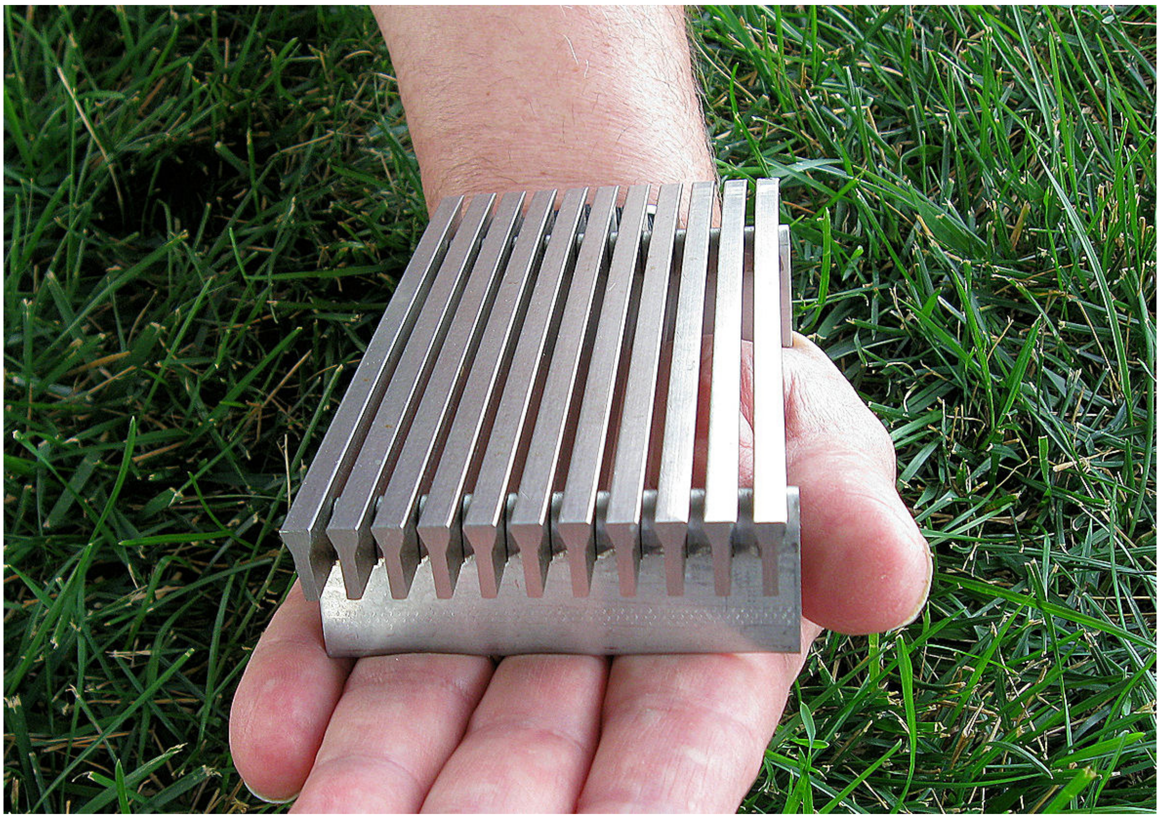


Fig. 16--Wedge Wire Extractor Bottom

Extractor Pumps

The Deep Bed Extractor (=/> 3.0 meters) uses fewer miscella stage pumps than a Shallow Bed Extractor.

Since the Deep Bed Design has a very high volume to surface area ratio, the miscella flow required to soak the material during the long contact time is minimized.

Extractor Drive

The Deep Bed Design uses 25-50% less horsepower than other designs, lowering electric costs. This is possible because most of the material weight is picked up by the divider side walls which in turn transfer the load to the vertical rotating spindle. The spindle is supported directly by a bottom thrust bearing so even the largest model units use very little installed power.

The following **Figure 17** shows the installation of a “Deep Bed Extractor (shown in the bottom right corner).

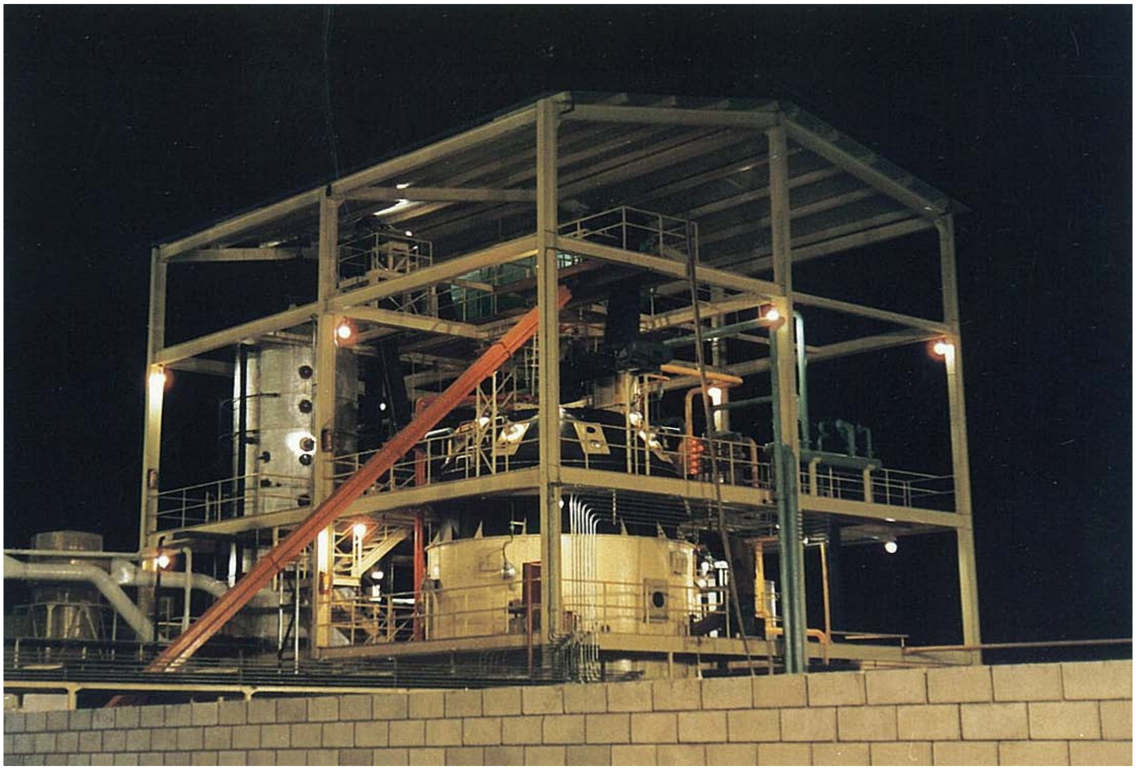


Figure 17—Typical Solvent Extraction Operation with a Deep Bed Extractor

The following **Table 6** shows the effect of Flake Thickness on Residual Oil in the Spent Meal comparing Flake thickness, Time of Extraction and Extractor Type.

FLAKE THICKNESS	EXTRACTION TIME	
	45 Minutes	35 Minutes
0.012 inches (0.30 mm)	Deep Bed--0.57% Shallow Bed--0.50%	Deep Bed--0.57% Shallow Bed--0.50%
0.015 inches (0.38 mm	Deep Bed-- 0.57% Shallow Bed-- 0.50%	Deep Bed 0.57% Shallow Bed-0.50%

TABLE 6—Effect of Flake Thickness vs. Residual Oil

THE DESOVENTIZER TOASTER DRYER COOLER (DTDC)

Principle

The de-oiled meal from the solvent extractor contains from 20 to 45 % solvent by weight depending on the material. The meal must be desolventized, then dried and cooled. Desolventizer-Toaster (DT) is a vertical vessel containing stages capable of pre-desolventizing, desolventizing, toasting and stripping the meal. It is often combined with the meal Dryer-Cooler in one vessel known as DTDC.

Pre-desolventising

In the pre-desolventizing section, hexane is evaporated by indirect heating via heated trays. In the desolventizing section, most of the hexane is evaporated while condensing live steam.

Toasting and Solvent Stripping

In the toasting and stripping section a combination of indirect and live steam is used to strip the remaining hexane while at the same time toasting the meal.

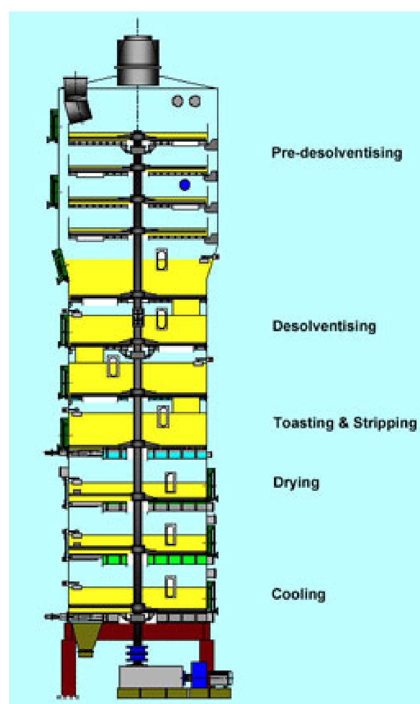
Drying and Cooling

In the drying section, hot air, steam heated in an air-heater, is blown through the meal, whereas ambient air is blown or pulled through the meal for cooling. Direct steam is introduced into the spent meal via a sparging tray at the bottom of the DT. The steam rises upward through several layers of meal supported by trays in a counter-current manner as the meal flows downward from tray to tray.

Operation of the DTDC

The Desolventizer-Toaster (DT) serves the purpose of removing the solvent from the meal, which can be directly used as an ingredient in animal feed compounds.
A DT consists of a vertical stack of several cylindrical gas-tight pans, each having a steam-heated bottom. In the top trays, solvent is evaporated by simple heating in dry atmosphere. Live steam injection is used in the lower compartments and removes most of the residual solvent from the meal. The meal is generally dried and cooled in additional pans located below those used for desolventizing.

A photo of a DTDC is shown to the right →



Producing Quality Feedstock for Biodiesel

Principle

The de-oiled meal from the solvent extractor contains from 20 to 45 % solvent by weight. The meal must be desolventized, then dried and cooled.

A DT is a vertical vessel containing stages capable of pre-desolventizing, desolventizing, toasting and stripping the meal. It is often combined with the meal

A Desolventizer-Toaster plus a Dryer-Cooler contained in one vessel known as **DTDC.**

Pre-desolventising

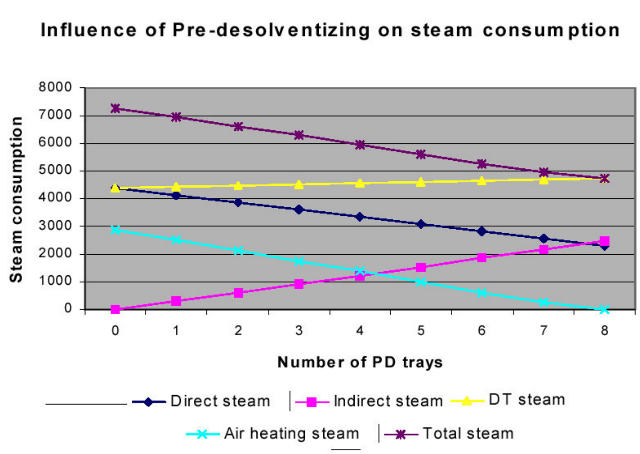
In the pre-desolventizing section, hexane is evaporated by indirect heating via heated trays. In the desolventizing section, hexane is evaporated while condensing live steam.

Toasting and stripping

In the toasting and stripping section a combination of indirect and live steam is used to strip the remaining hexane while at the same time toasting the meal.

Optimal use of steam

In the drying section, hot air, steam heated in an air-heater, is blown through the meal, whereas ambient air is blown or pulled through the meal for cooling. Direct steam is introduced into the spent meal via a sparging tray at the bottom of the DT. The steam rises upward through several layers of meal supported by trays in a counter-current manner as the meal flows downward from tray to tray.



As it rises up through the meal, the steam provides specific heat and a carrier gas to strip final traces of solvent from the meal.

In the uppermost counter-current tray, the steam condenses into the meal, providing its latent heat to vaporize a solvent-water azeotrope, and to heat the meal from about 65 ℃ to above 100 ℃, 3 kg of condensing steam heat is used up to </= 100 kg of meal.

The amount of live steam that is condensed is directly proportional to the amount of solvent in the meal, one kg of condensing water vapor evaporating between 6 and 7 kg of hexane.

The purpose of the pre-desolventizing section (PD) is to evaporate a quantity of hexane before the meal enters in contact with live steam so as to reduce the meal moisture. The saving in meal drying requirement induces a saving in steam consumption, and also in fan power.

The DTDC complex consumes about 75% of the steam and electrical power of the total solvent plant.

Oilseed processors are faced today with an increasing pressure to reduce solvent losses, because of environmental, health, and safety concerns.

Simply increasing steam flow in the DT to reduce solvent loss causes elevated vapor temperature and wastes steam.

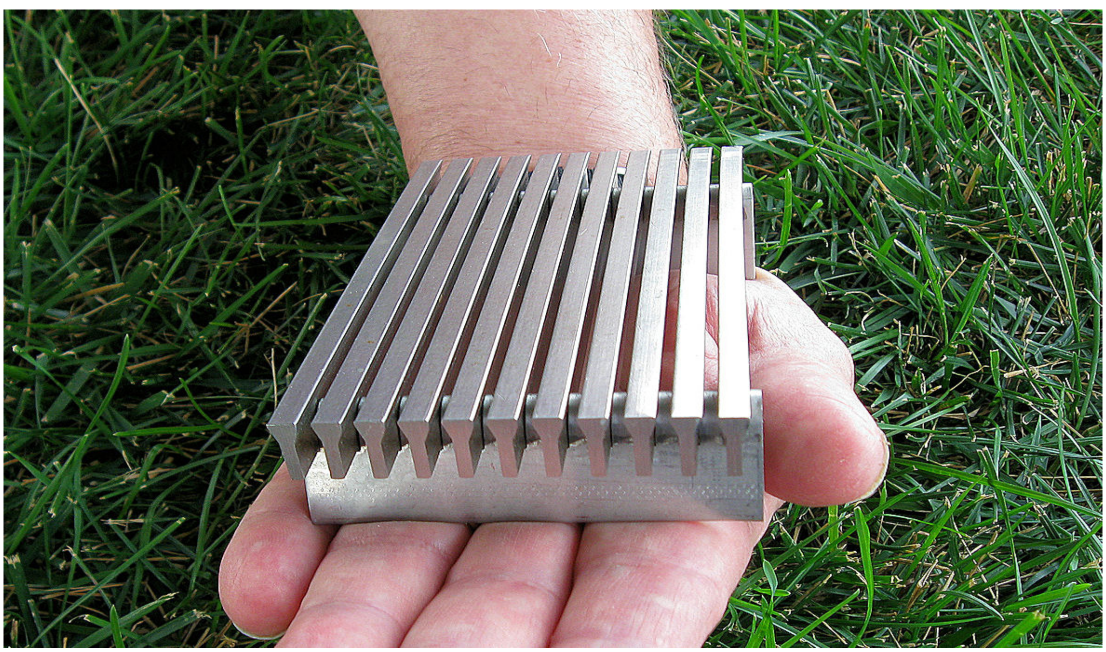
Increasing toasting and stripping time is not a good solution either because of its impact on meal quality.

The challenge is to make better use of the toasting time to improve stripping of the residual solvent from the meal, without increasing energy consumption.

One answer is to replace the traditional counter-current decks with hollow stay-bolts with slotted-screen counter-current trays. This design has been patented since 1999.

The photo following shows the type of slotted wire screen that is used for the counter flow section of the DT.

Slotted Wedge Wire Screen



High quality meal
Many efficient DT's are designed smaller in diameter with more counter-current trays. This permits an increase in the steam density in the lower part of the DT without wasting energy and allows the meal to be more effectively stripped of solvent in the normal toasting time.

By maintaining toasting time, the DT can also continue to provide good quality meal that has not been over-processed. his innovation in desolventizing provides new opportunity for satisfying both environmental and meal quality needs.

Installation of a DT

Meal--Solvent Flow

Refer to ***Diagram 02*** shown below:

The basic flow of flaked oilseeds to the Extractor is shown on ***Diagram 02***. Product from the Flaking Operation is conveyed to the Extractor with a Cross Yard Drag Conveyor. According to ***NFPA-36, Standard for Solvent Extraction Plants***, the Extraction Building (wherein the Solvent Extractor is housed) must be located 100 ft (30.5 m) from the Preparation and other process buildings. The Boiler Room, for example must also be located outside the 30.5 m boundary.

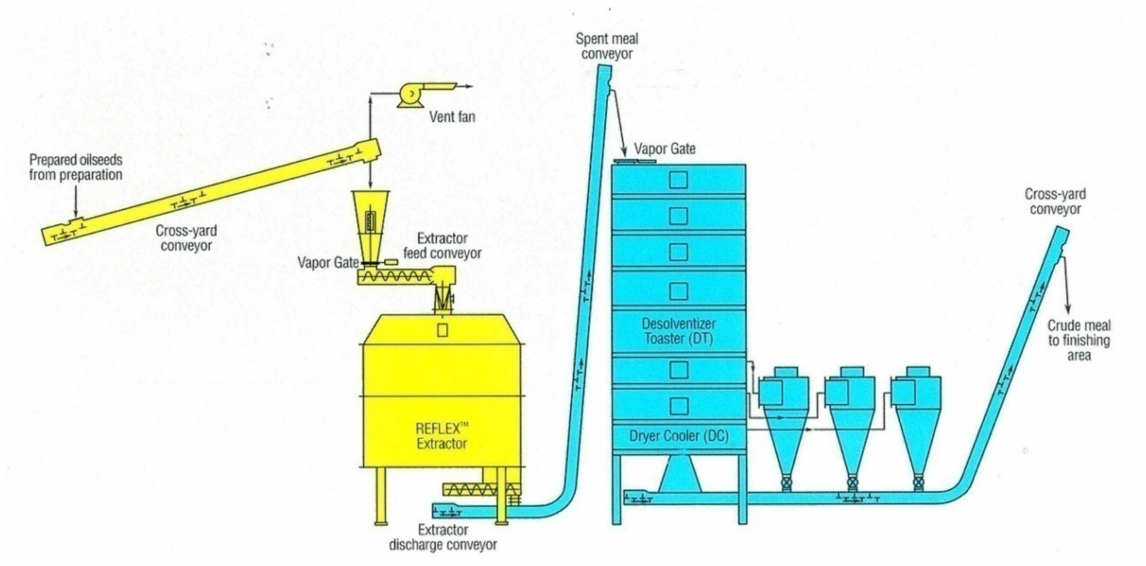


DIAGRAM 02—Meal/Solvent Flow

The flakes (or collets, in the case of the use of an Expander) pass thru a vapor gate and discharge into an extractor feeder, is mixed with miscella (solvent and vegetable oil) which forms a slurry as it enters the Extractor.

The miscella is fed into one of several rotating baskets. The bottom of the Extractor is a stationary self-cleaning screen, which allows the miscella to drain while supporting the oilseed flakes above.

Each Extractor Basket rotates under several miscella spray nozzles containing various concentrations of oil and solvent.

The Extractor is a Counterflow Device. In the first section, the oilseeds are subjected to a high oil/low solvent miscella concentration to dissolve the easy-to-extract oil. Each subsequent miscella spray concentration has less oil and more solvent. In the final section of the sealed baskets a nozzle spraying pure solvent removes the remaining traces of oil.

The spent meal, fully extracted and soaked with solvent is held in the rotating baskets while the relatively pure solvent drains by gravity. The final basket then discharges through an opening in the screen extractor bottom and the spent meal discharges into the Dump Hopper at the Extractor Base. The spent meal is conveyed to the top of the Desolventizer Toaster (DT) and enters the DT through a vapor gate.

<u>DT Operation</u>

- Indirect, steam- heated stationery "hot plates" (PD Decks) remove about 25% of the solvent. The PD Deck material is discharged to a Counterflow Deck below
- A Counter Current (CC) Plate with a slotted wedge wire bottom allows live steam at approximately 15 bar to pass through the material on the CC Deck. In this section, about 75% of the solvent is removed.

<u>Oil Solvent Flow</u>

Refer to ***Diagram 03--Oil/Solvent Flow.***

Heated solvent is pumped to the Extractor where it is sprayed across prepared oilseed flakes containing the least amount of oil. In this type of Deep Bed Extractor the flakes in the divided sections are completely immersed in the solvent. The solvent dissolves oil as it percolates through the bed of flakes. At the bottom of each divided section, the miscella (oil and solvent) drips through the Extractor bottom formed by a stationery wedge wire bottom screen. This heated and fresh solvent has changed composition and now contains some oil and is known as **first stage miscella.**

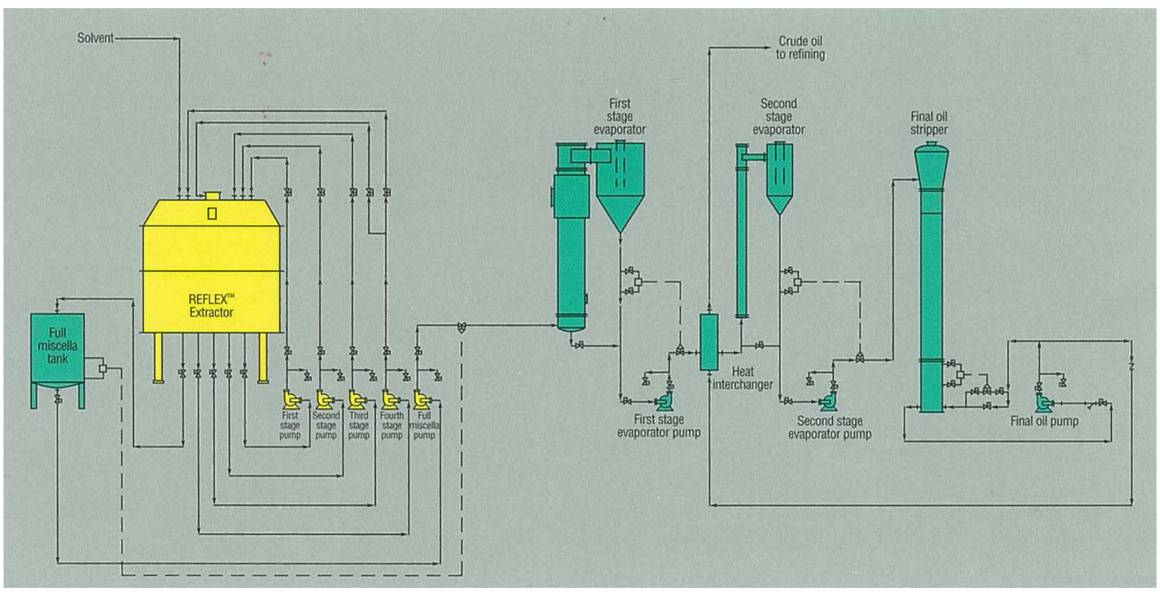


DIAGRAM 03—Oil/Solvent Flow

<u>Vapor /Air Flow</u>
Refer to **DIAGRAM 04—Vapor/Air Flow**. Solvent vapors from the DT exit the tops of the entrainment separators on the First and Second stage evaporators, sometimes referred to as the first effect and second effect evaporators. The combined vapor streams are the condensed into liquid within the primary condenser, which is held under a mild vacuum by a steam ejector. Vapors from the stream ejector are discharged into the First Stage Evaporator.

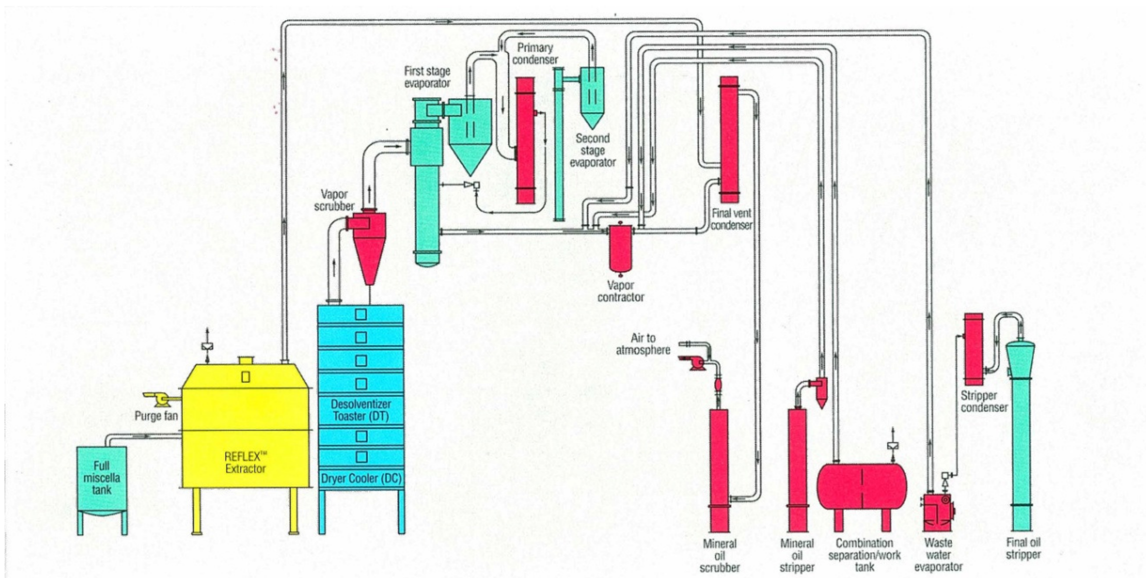


DIAGRAM 04—Vapor/Air Flow

Solvent and water vapors exit the Final Oil Stripper and are condensed into liquid in the Stripper Condenser, which is held under a high vacuum by a steam ejector. Vapors from the steam ejector are discharged into the Waste Water Evaporator.

Solvent and water vapors leaving the DT flow up to the Vapor Scrubber. Here, any particulate fines are centrifugally removed from the vapor stream and returned to the DT. The clean vapor stream flows to the First Stage Evaporator.

Most of the heat energy in the vapor stream is taken out in the First Stage Evaporator, causing most of the vapor to condense. Residual vapor, at its azeotropic temperature (lowest temperature at which vapor composition will exist) travels to the Vapor Contactor, where most of it is condensed into liquid as it is sprayed with cool solvent. The combined condensate and solvent spray exit the bottom of the Vapor Contactor, while the remaining vapor flows to the Final Vent Condenser.

Air, solvent vapor and water vapor from the <u>Vapor Contactor</u>, <u>Extractor</u>, <u>Full Miscella Tank</u>, <u>Waste Water Evaporator</u>, <u>Separation Work Tank</u> and <u>Mineral Oil Stripper</u> all are routed to the Final Vent Condenser, where they are condensed into liquid.

In some areas where the ambient temperatures are high, the first Final Vent Condenser is followed by a chilled-water or a refrigerant Vent Condenser to effectively remove the last remaining solvent and other VOC's.

Since the air does not condense and holds solvent vapor, the Final Vent Condenser is vented to the Mineral Oil Scrubber. The air entering the bottom of the Mineral Oil Scrubber passes up through a packed column while mineral oil flows counter-currently down the column.

The mineral oil extracts solvent from the air stream and clean air is drawn by a Fan through a Flame Arrestor as it exits the Scrubber. To minimize solvent loss, an air control damper on the Vent Fan maintains a slight vacuum on all process equipment.

<u>Mineral Oil Flow</u>
Refer to **<u>Diagram 05—Mineral Oil Flow</u>**

Hot mineral oil, flowing out of the Stripper, passes through a Pre-Cooler to reduce oil temperature, thus minimizing pump wear. This mineral oil is pumped through the Heat Exchanger, followed by a Cooler, to further cool the mineral oil and prepare it for the Mineral Oil Scrubber.

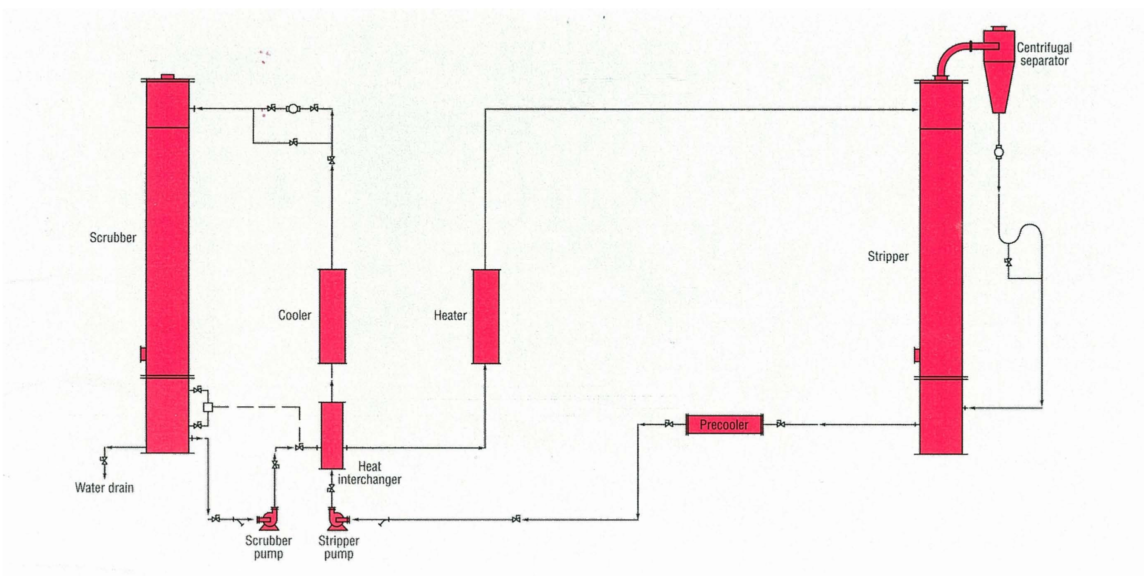


DIAGRAM 05—Mineral Oil Flow

Entering the top of the Scrubber, the mineral oil is distributed across a bed of packing material. As it flows down in a thin film across the packing, the mineral oil **absorbs** solvent from a counterflow air stream. The cool, solvent-rich mineral oil collects in the base of the Scrubber. Water in the mineral oil separates out and is manually drawn off at this point.

The cool, solvent-rich mineral oil is automatically drawn through the Scrubber Pump to the Heat Interchanger. The oil is heated in the Heat Interchanger and then heated further in the Heater before it enters the top of the Stripper.

Entering the top of the Stripper, the hot, solvent-rich mineral oil is distributed across a bed of packing material. As it cascades down in a thin film across the packing, the mineral oil's solvent content is stripped by a counterflowing stream of super-heated steam. The solvent vapor and steam exit the top of the Stripper and pass through a Centrifugal Separator. The hot mineral oil collects in the base of the Stripper, along with any entrained mineral oil draining from the Centrifugal Separator and flows to the Pre-Cooler—continuing the process.

Solvent/Water Flow

Refer to **DIAGRAM 06—Solvent/Water Flow**. Condensed solvent from the Primary Condenser is pumped through the Vapor Contactor, where it is heated by condensing solvent and water vapor. This combined stream drops by gravity into the Separation Tank, which also receives other condensed solvent and water streams from the First Stage Evaporator, Final Vent Condenser, Water Trap and Stripper Condenser.

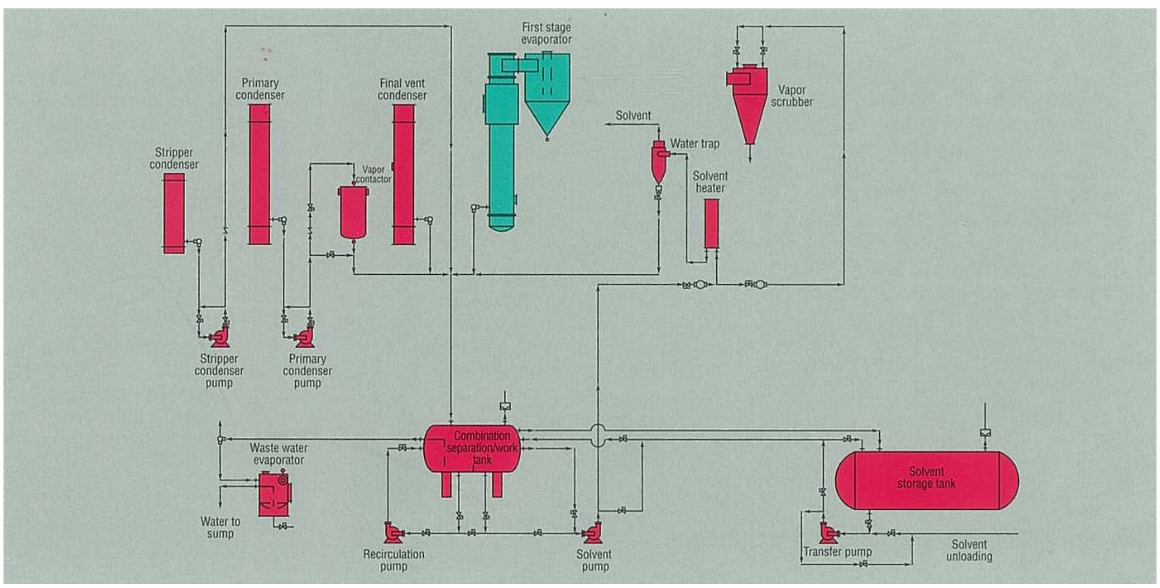


DIAGRAM 06—Solvent/Water Flow

Because of their immiscibility and different specific gravities, the solvent and water quickly separate. The water sinks and the solvent rises. As more solvent-condensate and water enter the Separation Tank, the interface level between the two levels is maintained, allowing the water to drain through an underflow pipe and the solvent to overflow a weir (dam).

The underflow water leaving the Separation Tank carries a small residue of solvent as it drops into a Waste Water Evaporator. Using heat from both a steam injector and an external source, the residual solvent is evaporated. The stripped (solvent-free) water exits the process, via gravity flow to a waste water sump.

At the same time, the solvent stream flowing over the Separation Tank Weir goes to a Work Tank, where it is held prior to being pumped back to the process. Here, “make-up solvent” to compensate for any normal solvent losses is pumped into the Separation/Work Tank from an external Solvent Storage Tank.

To ensure that no water builds up in the Separation/Work Tank, a small flow of solvent is continuously re-circulated back to the Separation/Work Tank. Should it become full, the Work Tank automatically overflows to the Solvent Storage Tank.

Solvent from the Work Tank is pumped through a Indirect-Steam Heater to bring the solvent up to its proper temperature. The solvent then flows through a Water Trap to remove trace water before it enters the Extractor.

A small stream of solvent from the Work Tank is also pumped to the Vapor Scrubber to was fines into the Desolventizer Toaster (DT).

DISTILLATION

There are several areas in the Desolventizing and Distillation Process that must be closely controlled to assure good oil quality. Excessive retention time can occur, which can cause over-processing.

There are often Cost Saving Opportunities that have fast payback in the Solvent Recovery Area.

First Stage Evaporator
One example of a poorly run operation is the misguided attempt to increase the miscella concentration by raising the temperature from 74°C to 120° C (165° F to 248°F) or even 132°C (270°F)! This is **bad for the oil** and will not only cause discoloration, but **will actually set the color (Lay 2000).** Never increase the temperature to compensate for poor vacuum—correct the vacuum problem (Farr 2000).

The **replacement of an undersized** First Stage Evaporator **will decrease steam** consumption and save money. For example, if only 50% concentration is being achieved in a 1200 MTPD plant; by providing the proper-sized First Stage Evaporator, this concentration would rise to 80% and steam consumption would drop to 788 lbs/hr (357 kg/hr) - a savings of 2556 lbs/hr (1159 kg/hr). At a steam cost of $10.00/1000 lbs., this results in a savings of **$214,700/year** based on 8400 hrs/yr uptime.

Miscella Oil Interchanger
Removing heat from the process not helps oil quality, but you can save money too! By placing a **Miscella Oil Interchanger** between the **First Stage** and **Second Stage Evaporators,** heat from the final oil stream can be captured. This heat is used to preheat the miscella going to the **Second Stage Evaporator**, thereby saving Second Stage steam. In the 1200 MTPD plant, the steam saved will be 485 lbs/hr (220 kg/hr). The annual savings would be:

Annual Savings = 485 lbs/hr x $10.00/1000 lbs x 8400 hours = $40,740

PAYBACK = 1 year

Mineral Oil Interchanger
The solvent stripping oil (mineral oil) causes problems with increased non-hydratable phosphatides and free fatty acids when it is overheated. While mineral oil can be heated to 127°C to 132°C (260° to 270°F), it begins to degrade at 99°C to 104°C (210° to 220°F) and becomes less effective in absorbing hexane over time. One solution is to use a Mineral Oil System that is designed to operate under a vacuum. Then the mineral oil can be used at 93°C (200°F). This solves the problem of overheating the oil and prevents the mineral oil from degrading, thus giving more consistent removal of hexane from the oil.

<u>Mineral Oil Cooler</u>

One important part of the **Mineral Oil System** is the **Mineral Oil Cooler**. When replacing or upgrading the system the size of the Cooler can be reduced and steam saved by placing a **Heat Interchanger** in the **Mineral Oil System** between the **Mineral Oil Heater** and the **Mineral Oil Cooler**, the temperature rise in the **Mineral Oil Heater** can be reduced by 61° F. (34° C.). This will save 142 lbs/hr (64 kg/hr) of steam.

Annual Savings = 142 x $10.00/1000 x 8400 = $11,998/year

PAYBACK = 2 years

<u>Summary of Energy Savings based on 1200MTPD noted above</u>:

- Thicker Flakes: $ 58,800
- Large First Stage Evaporator: $ 214,700
- Vapor Contactor: $ 33,264
- Miscella Oil Interchanger: $ 40,740
- Mineral Oil Interchanger: <u>$ 11,998</u>

TOTAL POTENTIAL: $ 359,502

These energy savings calculations were based on a production rate of **1200 MTPD.** Translated to a production rate of **5500 MTPD** the savings are projected to over **$1,650,000 per year.**

<u>Pinch Analysis</u>

Some designers us "Pinch Analysis" for determining the approach for achieving utility savings. The following definition of "Pinch Analysis" is furnished courtesy of DeSmet Ballestra (Kemper 2009).

Pinch Analysis

A systematic methodology based on thermodynamic principles to achieve utility savings by better process heat integration, maximizing heat recovery and reducing the external loads (cooling water and heating steam.

One analysis using this approach for a 5000 TPD Soybean Extraction Plant is shown in the following Table:

Steam Savings

Desmet / Hytech

Annual Savings (u$s/year)	Steam Cost 12 u$s/Ton	Steam Cost 25 u$s/Ton
Flash Steam from Meal Steam Dryer to First Evap.	$100.000	$208.333
Air Pre-Heating in Meal Dryer with Strippers' vapours	$200.000	$416.667
Grain Dryer Optimization	$180.000	$375.000
Air Pre-Heating with Flue Gas from Boiler	$320.000	$666.667
Total Savings	**$800.000**	**$1.666.667**

Note: *Based on 5000 TPD & 8000 hrs/year*

Investment Cost:

Payback Period (for all the alternatives)
*between **1 to 2 years***

DEGUMMING

Degumming
Vegetable oils such as soy and canola contain relatively high amounts of gums, or phospholipids. Soybean oil for shipping must be degummed to prevent gums from settling out in trucks and ocean-going vessels Many processors in the US who are not in the degummed oil export market still degum their soybean oil (converting the wet gums into lecithin), because degumming reduces the overall refining loss, and results in improved oil quality. (Farr 1999).

Degumming for Biodiesel
For Biodiesel Processing, the Acid Degumming Process is used rather than the more common Water Degumming Process which typically will leave a phosphorus content in the oil of about 200 ppm. This level is unsuitable for the Biodiesel Process.

The Acid Degumming Process will yield an oil with a phosphorus content of <20 ppm which is within specifications for biodiesel feedstock. The oil from the Solvent Extraction Process is pumped to Surge Tank. The oil from this Tank is metered into a High Shear Mixer where it is mixed with Citric Acid (50%) metered into the Mixer from a Citric Acid Surge Tank The acid and oil mixture is then directed to a Retention Tank which discharges at a controlled feed rate to a Centrifuge. The Centrifuge separates the gums and oil.

The gums are usually pumped back to a Double Agitator Mixer in the Preparation Plant, where the gums are mixed with the soybean meal.

The now degummed oil is pumped to a Feedstock Heat Exchanger followed by a Feedstock Heater. The oil is then pumped from the Heater to an Acid Mixer in the Caustic Refining System.

SOYBEAN MEAL

Soybean meal from the Dryer/Cooler (DC) is conveyed back to the Preparation operation where the meal is ground to particle size specifications in a Hammermill. To prevent over-grinding the meal is usually screen on a Gyratory Sifter (similar the Cleaner discussed previously. Only the overs are ground in the Hammermill. **Figure 18** shows a typical Hammermill. **Figure 19** shows an internal view of the Hammermill.

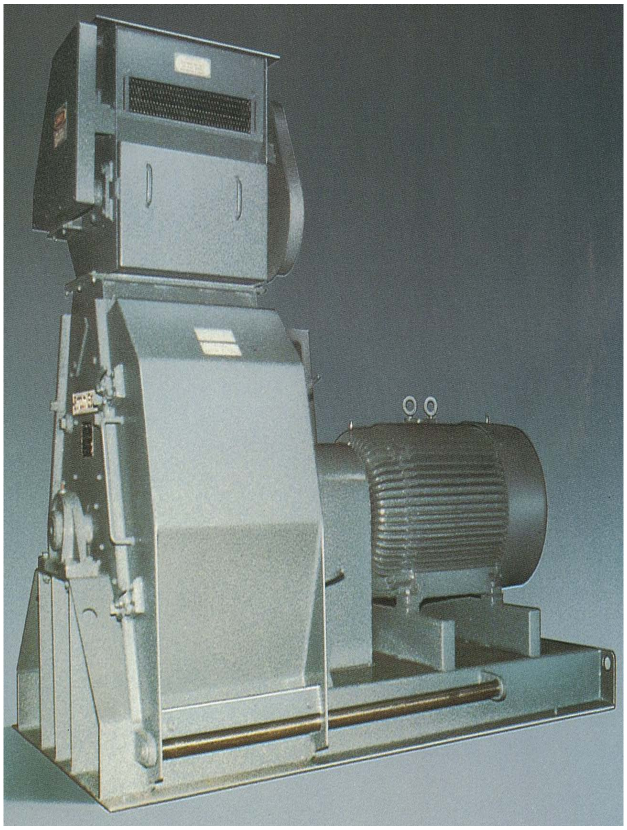


FIG. 18—Hammermill

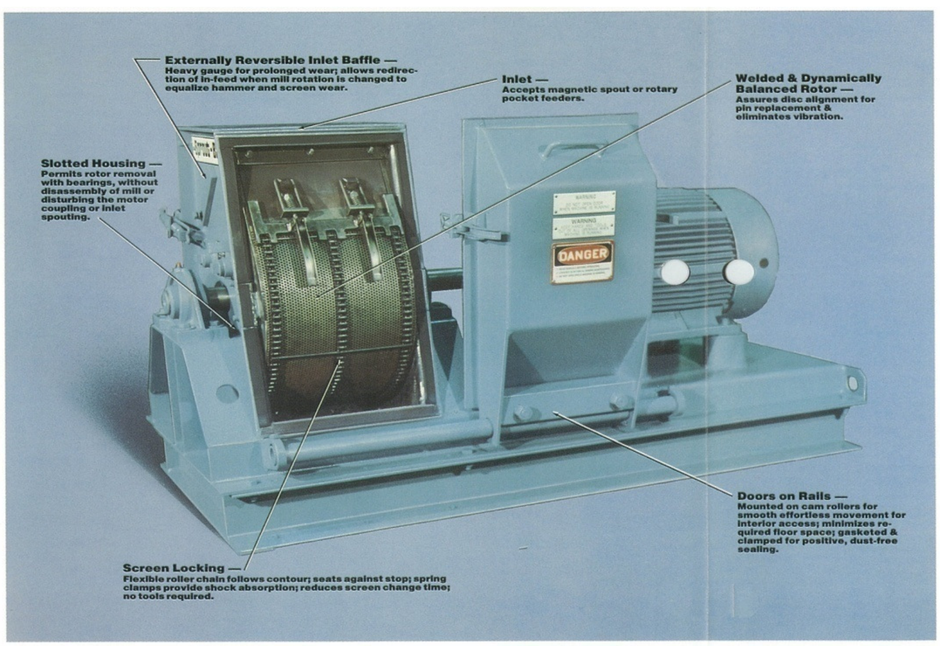


FIG. 19-- Internal View of Hammermill

The meal stream is fed under controlled conditions to a Double Agitator Mixer, sometimes referred to as a “Pug Mill”. This mixer also receives the gums from degumming, which are blended with the meal at the Mixer. Water that may also added at this point to adjust the moisture content if required. It is sometimes better to add water at the Soybean Hammermill Grinding Operation. The hammermill will “blend out” any water balls that may form, particularly if the meal moisture is low.

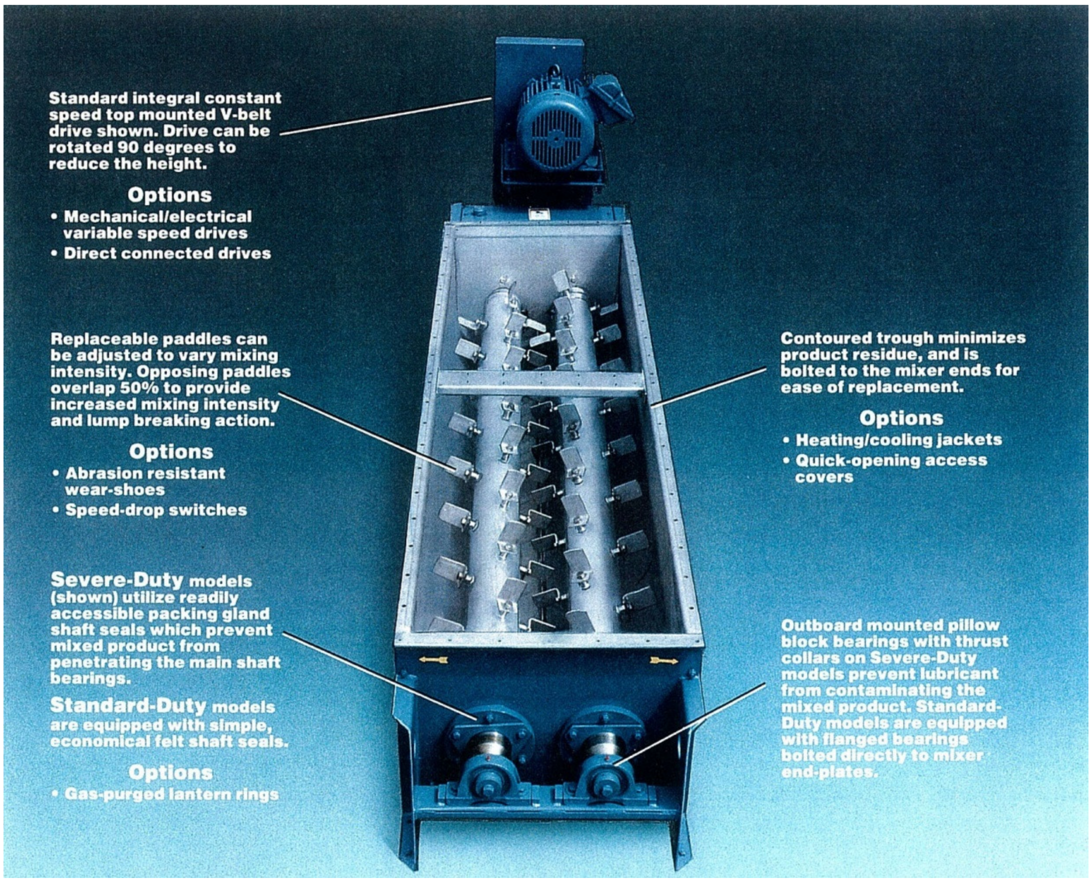


FIG. 20—Double Agitator Mixer

The meal that has been prepared is 48% protein. If 44% protein meal is required, hulls can be blended with the 48% meal in the Double Agitator Mixer; thereby, reducing the protein to 44% or lower. Dairy cows or other poly-gastric animals are usually fed the higher-fiber 44% soybean meal.

<u>Hulls</u>

Hulls conveyed from the Dehulling Operation are ground in a hammermill before being metered into the Double Agitator Mixer.

Meal storage

Soybean meal from the grinding and blending operation is conveyed to on-site storage or loaded directly into trucks, railcars or barges. In many cases the finished soybean meal is packed in 1000 Kg toe bags for container shipment.

CONCLUSION

The various recommendations and process philosophies set forth in this paper are just the beginning of the work to be done to produce quality soybean meal and oil. The next steps are to:

1. Set up a Quality Control System that includes sampling and analytical procedures, process monitoring, quality specifications and a laboratory equipped to follow through on the inputs from the Quality Control System.

2. Set up a Total Quality Process System that encourages people to ‘do it right the first time’, and to do their job in a way that conforms to the customer’s specifications, whether or not that customer is external or internal. Develop a quality policy. Set up a quality improvement program, including a program to reduce the cost of ‘poor’ quality.

Energy Management continues to be one of the most important tools in a successful oilseed and biodiesel operation. To quote Jim Willits VP of DeSmet Ballestra, (Willits 2009):

Thermo Dynamics teaches: ***Energy can neither be created nor destroyed.***
Plant Operations teaches: ***Energy can neither be created nor destroyed.***
Just Lost

Bibliography

Baianu, Dr. I.C., University of Illinois, private communications with R.L. Stroup, August 1999.

Barrows R., Haas M., Stroup R., etal. *Processing Soybean Meal with New Process for Feeding Rainbow Trout*), Aquaculture Journal-283, (2008) pp 141-147

Bockisch, Michael, *Fats And Oils Handbook*, AOCS Press, 1998

Erickson, David, Practical Handbook of Soybean Processing and Utilization, 1995.

Cheney, Mike, Honeymead Corp., private communications with R. L. Stroup, March 2000

Farr, Walter, *Methods of Degumming, Refining, Bleaching, Hydrogenation, Dewaxing, Winterizing and Deodorizing,1999*

Gupta, Monoj K., *Practical Guide to Vegetable Oil Processing*, AOCS Press, 2007

Haas M., Stroup R. Yee W, and McAloon A, A Comparative Analysis of the Predictable Economics of Biodiesel Production from Soybean Oil and from Intact Soybeans, AOCS Conference, 2006.

Haas, Michael, Stroup, Robert, etal. *In-Situ Transesterification for Biodiesel Production*, AOCS Conference, May, 2009.

Heimann, Mark, Roskamp Champion, *Soybean Meal & Hull Grinding*, 1992.

Johnson, Lawrence A., White, Pamela J. Galloway, Richard; *Soybeans-Chemistry, Production, Processing and Utilization,* AOCS Press, 2008

Kemper, Timothy G., *Guidelines for Pellet/Flake Ratios in Soy Crushing AOCS INFORM Magazine, 1995*

Kemper, Timothy G.,PE, *Energy Conservation in Solvent Extraction*, IOMSA Meeting, June, 2009

Knothe, Gerhard; Krahl, Jurgen; Van Gerpen, Jon, *The Biodiesel Handbook*, AOCS Press, 2005

Mitchell, Grant E., PE, Process Plus LLC, private communications with R. L. Stroup, March, 2000.

Shockley, Harold, Perdue Incorporated, private communications with R. L. Stroup, August, 1999

Soya & Oilseed Bluebook, 2009

Stroup, Robert, *Oilseed Meals as Animal Feeds*, AOCS International Symposium on New Approaches to Functional Oils and Cereals, November 1997, Beijing, PRC

Stroup, Robert, *Energy-Efficient Oilseed Extraction: How to Get the Most and Spend the Least*, Vol. 1, pp 43-47, Proceedings of the World Conference (Istanbul) on Oilseed and Edible Oil Processing, 1998

Stroup, Robert, *Maximizing Profits By Minimizing Energy.* AOCS/USDA Oilseed Conference, 1998

Stroup, Robert, *Crushing for Good Oil*, ASA/USB Seminar, April, 2000 Istanbul, Turkey

Stroup, Robert, *Managing Energy to Increase Profits*, ASA Regional Meeting, Tel-Aviv, September, 2000

Stroup, Robert, *Dehulling Soybeans-Making 48% Hi-Pro Soybean Meal*, ASA Conference, September, 2009, Istanbul

Stroup, Robert, *Processing Canola*, Biofuels Seminar, University of Idaho, January, 2006.

Stroup, Robert, *Processing Canola for Biodiesel*, Winter Canola Seminar North Carolina State Univ. September 2006

Willits, James, *Conservation of BTU's Used During Vegetable Oil Refining*, IOMSA Meeting, June, 2009