Chapter 4

RECOVERY OF OIL FROM SOYBEANS.

C.C. Mustakas
Northern Regional Research Center
Agricultural Research
Science and Education Administration
U.S. Department of Agriculture
Peoria, Illinois 61604

The recovery of oil from oilseeds has been a vital industry for thousands of years. During this time, both the equipment and the methods employed have undergone continuous evolution from primitive toward modern machinery and practices. The present discussion is limited, however, to developments within the past 40 years or so and deals chiefly with the current trend toward the use of solvent extraction almost exclusively for processing soybeans, which in the past have been treated by other means.

COMPETITIVE COMMERCIAL OIL EXTRACTION METHODS

Historically, many processes were used to recover oil from seeds, but the three most common procedures can be listed as hydraulic pressing, expeller pressing, and solvent extraction.

Hydraulic pressing, the earliest of the processes, is said to have originated in Europe in 1795. The hydraulic press, so named because it works on the principle of the hydraulic ram, operates like an ordinary machine shop press. It was first used in the United States for processing flaxseed and cottonseed and later for soybeans. Because it is a batch-type method that requires much hand labor, its use has declined and it is no longer used for soybeans.

In modern times, continuous presses such as the Anderson expeller and the French screw presses have replaced the hydraulic equipment originally utilized. Expellers are still used throughout the world on a wide variety of oleaginous materials, but their use for soybeans, particularly in the United States, has greatly diminished.

For oleaginous materials having high oil contents, a two-step process is carried out extensively throughout the world and consists of a continuous fore- or prepress followed by
Early work indicated that the theory roughly bears out this and design were to the flow of solvent, and the ease with which mass ties of solvent are used relative to the amount of oil extraction in its simplest form. Although effective in the laboratory, it is highly inefficient, since very large quantities of solvent are used relative to the amount of oil extracted. A prime objective in commercial extraction practice is, therefore, to reduce the solvent content of the final miscella or oil-solvent mixture to the lowest possible figure. In the best continuous soybean extraction plants, the solvent-to-bean ratio is 1.0 or less, or an oil-to-solvent ratio of about 0.2.

The design of large-scale solvent extraction equipment is determined by the rate at which equilibrium is attained between a lean miscella outside the seed particles and oil and solvent within the particles. Equilibrium may be attained slowly, particularly as the oil content of the seed falls toward the low level (usually below 1%) demanded by efficient commercial operation. The rate at which equilibrium is approached and, hence, in effect, the extraction rates are influenced by a number of factors. These include the intrinsic capacity for diffusion of solvent and oil; the size and shape of the seed particles; their internal structure; and, at low seed oil levels, the rate at which the solvent dissolves non-glyceride substances, which are oil-soluble but dissolve less readily than the glyceride portion of the oil (Norris, 1964).

The extraction of oil from oilseeds, either by mechanical expression or by means of solvents, is facilitated by reduction of the seed to small particles or thin flakes. Flaking cracked soybeans will facilitate solvent extraction both from the disruptive effect of rolling and also by reducing the distances that solvent and oil must diffuse in and out of the seed particle during the extraction process. Early work indicated that the rate-controlling factor in the solvent extraction of seed flakes was probably the internal resistance of the flakes to the molecular diffusion of solvent and oil (Boucher et al., 1942). Thus, the extraction rate should theoretically be roughly in indirect proportion to the square of the flake thickness. The data of Karnofsky (1948) on the extraction of soybean flakes by percolation with hexane roughly bear out this expectation. Later work by Othmer and Agarwal (1955) showed that extraction rate is proportional to the -3.97 power of the flake thickness and to the 3.5 power of the residual oil in the cake. Other factors should be considered, however, such as the mechanical strength of the flakes, the resistance offered by the flake mass to the flow of solvent, and the ease with which miscella may be washed from flakes. Consequently, for solvent extraction, seeds are not usually rolled to the least possible thickness. Other data on extraction theory and design were presented recently by Myers (1977).

EXTRACTION PRINCIPLES

The ordinary Butt extraction tube is an example of solvent extraction in its simplest form. Although effective in the laboratory, it is highly inefficient, since very large quantities of solvent are used relative to the amount of oil extraction. This process is not generally used for soybeans, since they have a relatively low oil content (18-20%), but rather on high-oil sources such as flaxseed, safflower, sunflower, copra, tung nuts, cottonseed, and corn germ. The chief advantage of prepressing is that it allows solvent extraction to be applied to oleaginous materials that would be quite difficult to process by direct extraction methods. Also, solvent requirements are lowered considerably.

Solvent extraction as a "batch process" originated in Europe in 1870, and its use soon spread to the United States where it is still employed for such materials as meat scraps, pine chips, garbage, and botanicals.

Technological advances in Europe shortly after the First World War led to the development of continuous solvent-extraction systems, which proved excellent for processing soybeans to a meal of very low oil content. As a result, the continuous process was introduced in the United States for soybeans in the 1930's. Since then, its use has increased tremendously to keep pace with our expansion in soybean production. The most striking new development in soybean processing in the United States is the trend toward very large capacity plants handled by single units for extraction and desolventizing. In 1976, according to Hutchins (1976) there were 20 of these large plants operating in the United States. These plants processed more than half of the total of 800 million bushels or 24 million tons of soybeans for that year.

One variation of the direct solvent process that is being used commercially on a limited scale, is the Filtration-Extraction Method developed more than 20 years ago by U.S. Department of Agriculture's Southern Regional Research Center at New Orleans, Louisiana (D'Aquin et al., 1954). The process was developed commercially by Wurster and Sanger, Inc., Chicago, Illinois. This process is particularly useful for high oleaginous materials and combines precooking, slurrying, filtering, and washing to obtain a low residual oil in the meal.

A second variation of direct solvent extraction using two stages is now offered commercially by Costruzioni Meccaniche Bernardini, SpA of Rome, Italy (Bernardini, 1976). The process patented under the name "Direx" uses both a percolation-type and an immersion-type extractor operating in series that is claimed to effect a high recovery of oil.

CHOICE OF SOLVENTS

The most common solvent used worldwide and in the United States for soybean oil extraction is n-hexane, a paraffinic

solvent.
petroleum fraction. This product has a fairly narrow boiling range of approximately 146-156°F (63-69°C) and is an excellent oil solvent. Solvent losses in American plants employing hexanes for extraction generally do not exceed 1-2 gallons (3.8-7.6 liters) for each ton of seed processed. The American extraction naphthas are substantially free from nitrogen- or sulfur-containing compounds and unsaturated hydrocarbons and leave a residue upon evaporation of less than 0.0016%.

Studies of work area air concentrations of hexane and other hydrocarbons by OSHA have been recently undertaken and maximum exposure standards of 350 mg per cubic meter of air (8-hr time weighted basis) have been set up. Since pressures are increasing to minimize or eliminate occupational hazards, perhaps the solvent extraction industry should be studying the use of alternate solvents to hexane.

A serious disadvantage to n-hexane is its extreme flammability. Rather elaborate precautions have been developed to avoid fire and explosion hazards, but danger of severe accidents make it desirable for the industry to develop a nonflammable solvent.

Trichlorotrifluoroethane for oilseed extractions has been studied and reported by Temple (1976) and Temple and Sullivan (1978) as a nonflammable low toxicity solvent. Recently, authors from France (Brats, 1978; Despiau, 1978) report that this solvent has much promise but that considerable research needs to be carried out. According to the authors, replacing hexane now being used almost exclusively by the industry will be difficult and financial risks in a changeover will be very large.

Trichloroethylene (TCE) boiling at 188°F (86.7°C) was applied (Sweeney and Arnold, 1949) some years ago as a safe nonflammable solvent for soybeans; however, serious toxicity problems arose from the extracted oil meal when it was fed to cattle (Altschul, 1958). The toxic component produced a refractory, hemorrhagic aplastic anemia in cattle and, consequently, regulatory officials stopped its use for soybean extraction. The toxic factor of TCE-extracted soybean oil meal was identified by McKinney and coworkers (1959) as the S-dichlorovinyl derivatives of L-cysteine.

Some years ago, an alcoholic (ethanol) extraction process was developed for soybeans (Beckel et al., 1948a, 1948b; Beckel, 1949) at the Northern Regional Research Center at Peoria, Illinois. The process had a number of advantages and yielded improved oil and meal products that were light in color. However, some inherent disadvantages prevented its commercialization. For example, solubility of oil in alcohol was less than in hexane unless temperatures near boiling were used. When cooled moderately, the alcohol miscellas separated into multi-phase layers containing phosphatides, carbohydrates, and other nonglyceride extractives, so that oil recovery and purification was difficult.

A number of other laboratory developments were also reported that employed alcohols as solvents for soybeans (Harris and Hayward, 1950; Rao and Arnold, 1956; Rao and Arnold, 1958).

A mixed solvent-extraction process for cottonseed was reported by the Southern Regional Research Center in 1965 using an azeotropic mixture of hexane, acetone, and water, but its development to commercial practice for either cottonseed or soybeans was never accomplished (Gastrock et al., 1965).

THE SOLVENT EXTRACTION PROCESS

The solvent extraction process may be considered as consisting of three parts: (1) preparation of beans, (2) extraction of oil from the beans, and (3) reclamation of solvent from the oil and meal. A flowsheet of the plant is shown in Figure 1.

STORAGE AND PREPARATION OF BEANS

At bean harvest time in October and November, a large volume of soybeans is received at the plant by truck and rail for storage. However, purchase and receipt of beans continue throughout the year. Storage of beans is in large concrete silos. Before they are ready for processing, the beans are cleaned, dried to about 10% moisture, and preferably conditioned for storage for about 10 days to facilitate dehulling.

Soybeans are brought into the mill by belt conveyors and bucket elevator, collected in storage bins, passed over a magnet to remove stray metal, then fed into the cracking rolls (Fig. 1, P-3). If dehulling is carried out, a shaker screen follows the cracking rolls where fines drop out and hulls rise to the top to be removed by fan aspiration.

The moisture content of the beans coming from the elevator is generally in the range of 9 to 13.5%. For optimum operation of the solvent extraction process, 9.5 to 10% moisture is desirable, and preparatory flaking is accomplished most satisfactorily at 165-175°F (74-79°C). The desired conditioning of the cracked beans is achieved by means of a steam-jacketed cooker, usually a vertical-stack type (Fig. 1, P-4) or rotary steam-tube dryer type.

The beans are then conveyed to flaking rolls (Fig. 1, P-5). The roll stand consists of a pair of smooth-surface rolls regulated to produce flakes about 0.010 in. (0.254 mm) thick in one pass. Large-volume extractors can utilize somewhat thicker flakes; the thicker flakes pack better and require an increase in extraction time. After leaving the rolls, the flakes are conveyed by mass flow-type enclosed conveyors de-
signed to minimize flake breakage (Fig. 1, E-3).

SOLVENT EXTRACTION

Solvent extraction is carried out in a variety of extractor types as discussed later in the report under extraction equipment. In general, however, solvent extraction involves soaking the oil-bearing material in hexane so that the oil is dissolved in the solvent to form a mixture called miscella, which drains from the meal. For safety reasons, an airtight lock needs to be built in the conveyor installation linking bean preparation to extraction. The most efficient form of solvent extraction is by a percolation process; the process is divided into stages to avoid back mixing of weaker and richer miscellas. Division of the streams allows continuous flooding, and a succession of washes permits close control of the extraction time.

RECLAMATION OF SOLVENT FROM MEAL

The wet spent flakes leaving the extractor contain approximately 35% hexane, 7-8% water, and 0.5-1.0% oil. These are carried into the meal desolventizing system (Fig. 1, E-5) commonly referred to as the D-T (desolventizer-toaster) unit. A vertical central shaft fitted with stirrers for each compartment moves and spreads the material which progresses downward through each stage. In the upper stages, open steam is used to strip off hexane; then, as the meal moves downward, the steam condenses and increases the moisture content to about 25%. Toasting with indirect heat is carried out in the middle and lower stages. The bottom stages are used to reduce moisture of the D-T meal to 10-12% moisture with indirect heat. This operation (30-40 min) serves to inactivate trypsin inhibitors (antigrowth factors) and improve the palatability of the meal to animals. In a few units, the exit D-T moisture is higher and a meal dryer is used to reduce moisture to 10-12%.

RECLAMATION OF SOLVENT FROM OIL

Full miscella from the extractor containing approximately 25-30% oil enters the first-stage evaporator (Fig. 1, E-7), which contains steam-heated tubes for vigorous evaporation of solvent. Vapor from the evaporator passes through a condenser and directly to the work tank from which the hexane is recycled to the extractor. Miscella leaves the first stage at about 65-70% oil and enters the second stage evaporator (Fig. 1, E-9) where it is concentrated further to approximately 90-95% oil content. The concentrated miscella is pumped to the top of the oil stripper (Fig. 1, E-11) which is a steel cylindrical vacuum
column usually of disk and doughnut type inner construction or just filled with inert packing material. Live steam introduced into the column at the bottom flows upward countercurrent to the cascading flow of oil. The finished oil product leaves the column at about 99.8% or higher oil content and is pumped to a storage tank.

OIL STORAGE

Prolonged storage of any fatty oil is undesirable because of the deterioration that occurs through oxidation. However, crude soybean oil can be stored in large tanks with limited access to air for considerable periods. Before being pumped to storage, the oil should be cooled to near ambient temperature.

In the case of any oil stored in the crude form, it is important for the oil to be clean and, insofar as it is possible, free of moisture because this promotes hydrolysis of the oil. Crude oils high in phosphatides measurably deposit a troublesome layer of gummy material upon long standing in tanks, or even during the course of long shipments in tank cars.

When a storage tank is being filled, the oil should be transferred by means of a dipping pipe (with syphon-breaker) to avoid splashing.

CURRENT SOLVENT EXTRACTION EQUIPMENT

The basic types of commercial extractors in current use today fall into the categories of either percolation type or immersion type. An excellent recent review is presented by Milligan (1976).

PERCOLATION EXTRACTORS

This is the most common design used today worldwide, but in a number of variations. Basically, the liquid solvent or miscella is pumped over a bed of soyflakes, percolates down through the bed, and leaves at the bottom through a perforated plate, mesh screen, or wedge wire screen bar system (Fig. 2) (Milligan, 1976).

A number of percolation-type extractors have been designed for use in large solvent plants. They differ only in mechanical design. This system is more adaptable to larger capacities in limited space and, for this reason, is considered to be more efficient than the immersion type.

Rotary Type. The rotary type is essentially a vertical cylindrical shell within which are baskets or cells, either rotating or stationary, around a central shaft. Figure 3 shows a rotating type with cut-away view. Fresh solvent is pumped onto flakes that are nearing the end of the extraction cycle. These flakes are allowed to drain before being dropped into the discharge hopper. Miscella is pumped countercurrent to the flow of flakes—becoming richer as oil is extracted—and finally is pumped over a bed of fresh flakes for filtration, leaving the extractor as full miscella. The advantage of the rotary extractor is its small size; the disadvantage may be the more complex technical lay-out. Some of these extractor types are produced by Dravo, French Oil Mill Machinery, Simon-Rowlands, and EMI (Engineering Management, Inc.). Of opposite design is the French Stationary Basket extractor (Fig. 4), in which the cells and perforated doors are stationary and the liquid manifolds and solid hopper rotate.

Chain and Basket Type. This type of percolation extractor uses separate baskets having fixed perforated bottoms to transport and extract the flakes. The baskets rotate on trunnions about a horizontal axis and move through the extractor on a pair of endbar chains. In the early extractors, the baskets moved up and down between two sprocket wheels at opposite ends of a tower about five stories high. Miscella flow in the vertical units is a combination of countercurrent and co-current miscella (Fig. 5) (Milligan, 1976).

In this descending column, half miscella is pumped over the bed at the top of the column and descends co-currently with the raw flakes, absorbing oil and becoming full miscella at the bottom. Then the baskets turn and rise, countercurrent to the flow of fresh solvent pumped to the top of the ascending col-
Fig. 4. Stationary basket-type solvent extractor.
(Courtesy of French Oil Mill Machinery Company, Piqua, Ohio.)
Immersion extractors are rarely used and are not commercially significant for soybeans. They are generally used for extraction of small volumes or low capacities of oilseeds. Commonly offered for special and direct extractions today are the Bernardini vertical design, used in combination with their percolation extractor, and the EMI horizontal extractor used for a variety of specialty extractions such as fish protein concentrate and pigment extractions (Milligan, 1976).

**Perforated Belt Type.** The third type of percolation extractor is the perforated belt type. The extraction takes place on a horizontal endless perforated belt. Cells are formed by creating ridges of flakes periodically to act as barriers to backflow of miscella, which otherwise could result in loss of extraction efficiency. This design is illustrated by the De Smet Extractor. Perforated belt extractors are also manufactured by Lurgi and others.

**Chain Conveyor Type.** The fourth type of percolation extractor is the chain conveyor unit in which a double drag chain and flight move inside a stationary casing, conveying the extracting solids over two sections of wedge wire screen. This type is illustrated by the Crown extractor which combines percolation and immersion principles.

**Filter Type.** The fifth type of percolation extractor is the vacuum filter system in which the natural drainage force of gravity is assisted by pulling a vacuum under a filter cloth separation medium. This type is illustrated by the Wurster and Sanger Filtration Extractor which employs a horizontal pan vacuum filter, separate miscella tanks, and a sophisticated vacuum pump system.

Soybeans Actually Processed

*Fig. 6. U.S. Soybean Processing Capacity (U.S. Department of Agriculture, 1979).*

**IMMERSION EXTRACTORS**

Immersion extractors are rarely used and are not commercially significant for soybeans. They are generally used for extraction of small volumes or low capacities of oilseeds. Commonly offered for special and direct extractions today are the Bernardini vertical design, used in combination with their percolation extractor, and the EMI horizontal extractor used for a variety of specialty extractions such as fish protein concentrate and pigment extractions (Milligan, 1976).

**SOYBEAN EXTRACTION INDUSTRY DEVELOPMENT, CAPACITIES, AND OPERATING COSTS**

Solvent extraction is the preferred method for soybeans, with more than 90% of the soybeans crushed in the United States being processed by this method (Milligan, 1976).

In the 1950's, the soybean industry began major changes. Solvent extraction was replacing mechanical extraction. This led to increased efficiency in oil extraction. Processing capacity of solvent plants increased markedly and number of plants declined. Since soybean plants were usually built close to their source of raw material, soybean crushing industry has
Table 1: Soybean Plants and Capacities by Specified Capacity Ranges

<table>
<thead>
<tr>
<th>Specified daily capacity, short tons</th>
<th>Soybean plants, %</th>
<th>Percent of total industry capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 500</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>500-999</td>
<td>35</td>
<td>23</td>
</tr>
<tr>
<td>1000-1499</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>1500-1999</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>2000-2499</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>2500 and over</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>


Table 2: Estimated Yields and Operating Cost Data per Bushel of Soybeans, 1978/79

<table>
<thead>
<tr>
<th>Yield of products per bushel crushed</th>
<th>Oil (lb)</th>
<th>11.2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meal (lb)</td>
<td>46.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>57.2</td>
</tr>
</tbody>
</table>

Manufacturing costs, dollars/bu

<table>
<thead>
<tr>
<th>Wages, payroll taxes</th>
<th>0.08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insurance</td>
<td>0.01</td>
</tr>
<tr>
<td>Property taxes</td>
<td>0.01</td>
</tr>
<tr>
<td>Power</td>
<td>0.05</td>
</tr>
<tr>
<td>Fuel, water</td>
<td>0.10</td>
</tr>
<tr>
<td>Plant supplies</td>
<td>0.01</td>
</tr>
<tr>
<td>Repairs</td>
<td>0.05</td>
</tr>
<tr>
<td>Depreciation</td>
<td>0.05</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0.01</td>
</tr>
<tr>
<td>Total</td>
<td>0.37</td>
</tr>
</tbody>
</table>

General and administrative expenses, dollars/bu

| Total | 0.07 |

Financial expenses, dollars/bu

<table>
<thead>
<tr>
<th>Total</th>
<th>0.06</th>
</tr>
</thead>
</table>

Total costs and expenses, dollars/bu

| Total | 0.50 |


Estimated average yields and operating cost data per bushel of soybeans crushed in U.S. soybean plants for the year 1978/79 are given in Table 2. Average manufacturing costs for the plants were 37¢/bu. When general administrative and financing costs are added, the total costs increase to approximately 50¢/bu.

Equipment costs for soybean plants as estimated (October 1977) by one large manufacturer (French Oil Mill Machinery Company, Piqua, Ohio) of soybean extraction equipment are as follows:

- Plant Capacity: metric tons/day
  - 500: 1.7
  - 800: 2.1
  - 1200: 2.6
  - 1500: 3.0

The above costs are based on equipment only for the processing of soybeans and include all equipment and materials necessary for preparation, extraction, meal processing, and certain miscellaneous items such as a cooling tower, boiler with accessories, and a fire protection system. They do not, however, include the cost of hull-removal systems. The cost of installation may be estimated at roughly 100-130% of the equipment price. The latter is quite variable depending on many factors, one of which is the geographical plant site location which can greatly affect labor costs.

ACKNOWLEDGMENTS

I would also like to thank the following companies and groups for furnishing material: Engineering Management Corporation (EMI); Crown Iron Works Company; Lurgi Apparate-Zecknik; Simons-Rosedowns, Limited; Wurster and Sanger; Construgioni...
REFERENCES

Beckel, A. C. 1949. Soybean Dig. 9(7):20-21 (May).