Solvent Extraction of Soybeans

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ABSTRACT

The removal of edible oils from oilseeds was practiced by the Egyptians many centuries ago. Some of the developments leading to today's worldwide extraction industry are discussed, and a brief history of the industry in the United States from 1940 to the present is included. The theory of solvent extraction is outlined in practical terms. Several types of solvent extraction and desolventizing systems are explained. Also, typical preparation and extraction processes for presscake, soybeans, and some high oil content seeds are illustrated. Some reasons for taking extra precautions in the preparation process and the desolventizing process when producing human edible soy protein products are explained. Energy conservation suggestions are included.

INTRODUCTION

During the past one-third of this century, solvent extraction of oilseeds in the United States became the main process for the separation and recovery of oil and meal products from soybeans, sunflower, cottonseed, and corn germ. Solvent extraction of these and various other oilseeds such as rapeseed, peanuts, seasame and copra is now widespread throughout the rest of North America, Europe, Asia, Africa and South America. Why was solvent extraction developed and perfected? It removes more oil, typically requires less energy, and normally yields greater profits than does mechanical pressing. Nevertheless, mechanical pressing – both for pre-pressing and finish pressing – is still a growth business in the oilseed and other industries.

The processing of oilseeds is one of the world's oldest industries. Several thousand years ago the Chinese and the Egyptians crushed sesame and other oilseeds by oxen or human slave driven edgestones and then recovered the oil by manually (mostly slave labor) driven presses. During the 19th century, draft horses were mostly used to furnish the power necessary to squeeze oil from the oilseeds in a manner similar to that used in former cider mills. Both the French Oil Mill Machinery Company and Anderson IBEC developed mechanical screw presses during the early part of the 20th century. Many of these early presses and later models are still used in the cottonseed, corn germ, peanut, sunflower, copra and rapeseed industries.

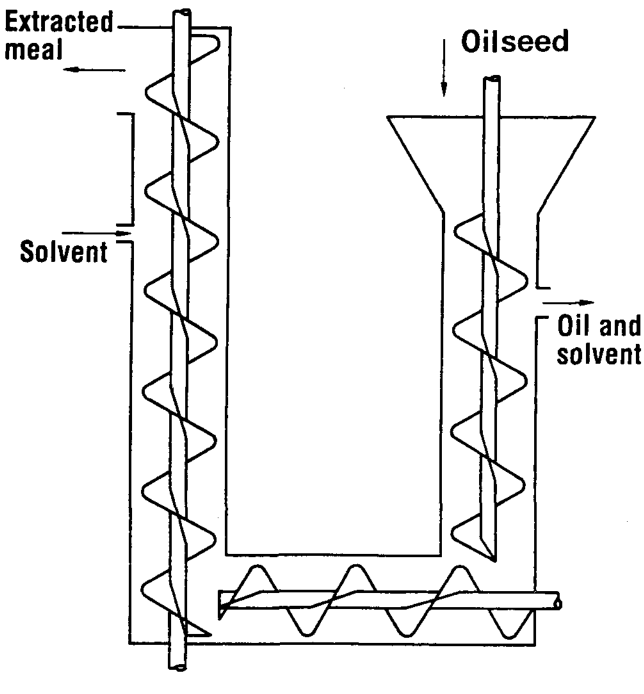

FIG. 1. Hildebrand extractor.

Solvent extraction was developed by the Germans shortly after World War I. Just prior to World War II, the Germans introduced several oilseed solvent extraction systems into the United States. The two basic principles utilized were immersion extraction and percolation extraction. Immersion extraction is accomplished, as illustrated by the German Hildebrant extractor in Figure 1, by conveying and immersing the solvent and miscella through a U-tube system. Percolation extraction, as carried out in the Bollman extractor (Figure 2), allowed the solvent and miscella (oil in solvent solution) to flow by gravity through a bed of solids. (1,2). Modified and improved versions of these two basic concepts of solvent extraction are used for today's extraction systems.

The early immersion extractors were replaced by basket extractors during the late 1940s and early 1950s. Several American companies developed various of the basket extractors during that period. It was found, in general, that basket extractors are bulky, complicated machines in which flakes enter the extractor through a cam-operated double-gate hopper which serves both as a volumetric feeder and as a vapor seal. The baskets move around an enclosed circuit and are inverted as they pass over the head sprocket to dump the extracted flakes. Fresh solvent is used to extract the flakes during the ascending portion of the circuit. Half miscella is used to extract the flakes during the descending portion of the circuit. Basket extractors typically require large buildings to house them, sometimes "drop baskets" when their chains break, and are difficult to adjust rapidly to offset flooding or channeling during periods of misoperation.

American companies that developed and sold solvent extraction plants during the late 1940s and early 1950s were Allis Chalmers, Anderson IBEC, Blaw Knox (now Dravo) and French Oil Mill Machinery Company. Of these original suppliers of extraction equipment systems, only Dravo and French Oil Mill Machinery Company have survived. More recently, however, Crown Iron Works, EMI, and Wurster & Sanger also offer solvent extraction equipment.

Figure 3 illustrates an abbreviated flow chart of a soybean solvent extraction plant. In Figure 4, the unit operations of a typical soybean solvent extraction process are illustrated. The general functions of oilseed solvent extraction are: oilseed preparation, solvent extraction, solvent and oil recovery, meal desolventizing and finishing.

THEORY

Solvent extraction processes for oilseeds vary considerably depending upon the raw materials to be processed, the type of meal products to be produced, the local governmental or other specifications for oil products, the solvent used, the cost of utilities and local climatic conditions. To understand why solvent extraction involves so many unit operations, it is desirable to study the theory of solvent extraction. (3,4,5,6). The mechanism for extraction of oil-

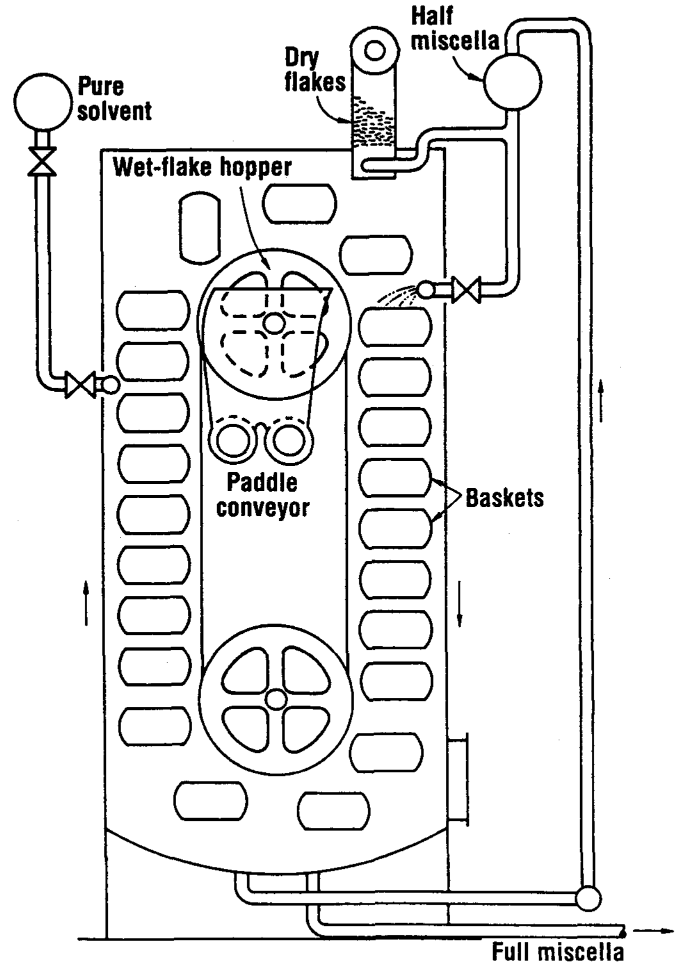

FIG. 2. Bollman extractor.

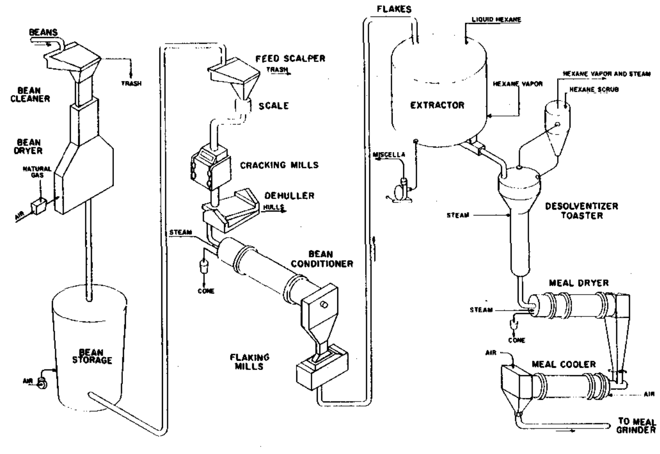

FIG. 3. Flow chart of soybean solvent extraction plant.

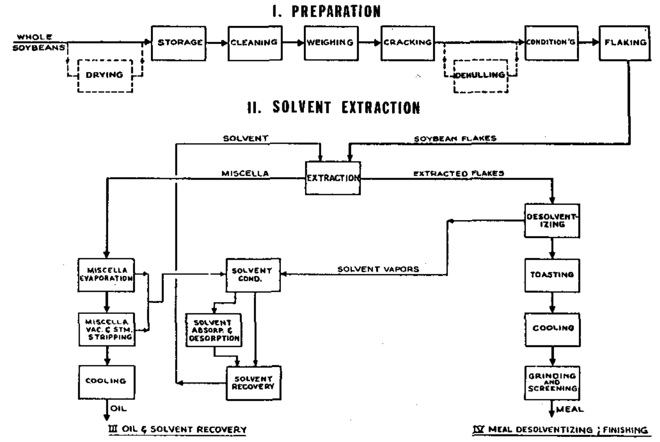

FIG. 4. Typical soybean solvent extraction process.

$$\frac{Y_a}{Y_b} = \left[\frac{X_b}{X_a}\right]^{2.2}$$

ASSUMPTIONS:

0.5 % RESIDUAL OIL (A.O.C.S. TEST) SPECIFIED.

LET X_a = **10 MIL THICK FLAKES**

X_b = **20 MIL THICK FLAKES**

Y_a = **MINUTES EXTRACTION TIME FOR** X_a

Y_b = **MINUTES EXTRACTION TIME FOR** X_b

FIG. 5. Effect of flake thickness on extraction rate.

seeds appears to be a combination of diffusion, dialysis, and the solution of a slowly soluble extractable material. The latter is sufficient to determine the size of commercial percolation extractors.

A prepared oilseed has a characteristic rate of extraction that can be measured rather simply by extraction of a weighed sample in a Butt tube under reflux as in the AOCS analytical method. (7). The total extractables can change as much as 1% depending upon the solvent, temperature of extraction, moisture content of flakes, thickness of flakes, preparation technique (cracking, conditioning, flaking), and the heat treatment history of the flakes. Much of this 1% potential additional extractable is not glycerides but is phosphatides, nonsaponifiables and pigments which contribute to refining loss. Heating increases the total extractables from soybeans. For example, an increase of approximately 0.3% in extractables after extraction occurs in a desolventizer-toaster caused by the further heat treatment of the meal. When oil prices are high as compared to meal prices, it is normal to extract to quite low residual oil levels (0.3 - 0.4%) and then degum the crude oil and put the gums back into the meal. This permits the soybean processing company to improve oil quality to a premium price level and meanwhile permits the gums added back to the meal to be sold at the meal price.

Hexane has become the accepted solvent for soybeans and other oilseeds throughout the world. It has the advantages of being relatively volatile (permitting easy desolventizing of oil and meal), being available at a low cost, and being immiscible with water. However, hexane is dangerous to handle, making it essential to take prudent precautions during design and operation of an oilseed extraction plant.

As mentioned previously, flake thickness is one of the major factors affecting extraction rate. Actually, the term "flake distortion" is more appropriate because large cracked bean pieces when flaked to a specific thickness have more distortion and greater porosity and therefore have a higher extraction rate. Consequently, it is important to adjust bean cracking and flaking properly to obtain optimum extraction. As illustrated in Figure 5, extraction time to a specified residual oil level varies inversely as flake thickness is raised to the 2.2 power. On an approximate basis, it will take 4 times longer to extract 20 mil thick flakes than 10 mil flakes to the same specified residual oil level.

$$\frac{Y_b}{Y_a} = \left[\frac{T_a}{T_b}\right]^2$$

ASSUMPTIONS:

0.5 % RESIDUAL OIL (A.O.C.S. TEST) SPECIFIED.

LET T_a = TEMPERATURE AT 120° F

T_b = TEMPERATURE AT 145° F

Y_a = MINUTES EXTRACTION TIME AT 120° F

Y_b = MINUTES EXTRACTION TIME AT 145° F

FIG. 6. Effect of temperature on extraction rate.

Based on laboratory and plant operational studies, an empirical equation was developed to predict the relationship between extraction temperature and extraction rate when extraction is carried out to a specified residual oil level. As shown in Figure 6, the extraction time varies inversely with the square of extraction temperature in degrees Fahrenheit. For most of the world's soybean plants, an extraction temperature of about 145 F is normally used. However, in some European plants, the extraction temperature employed is about 120 F. Figure 6 illustrates that a much longer time and hence a larger extractor is required to obtain the same specified residual oil content with "cold" vs. "hot" extraction temperature. For this particular case, the extraction time at 145 F is only 68% of that for 120 F.

EQUIPMENT SYSTEMS AND CONDITIONS FOR PREPARATION

For soybean preparation the various equipment items such as bean cleaners, scales, conveyors and elevators, cracking rolls, dehulling systems, conditions and flaking rolls are noramlly purchased by the engineering contractor from a variety of vendors. The vendor is expected to guarantee output performance at a specified throughput rate based upon defined input conditions. For example, flaking rolls may be guaranteed to flake 300 tons per day of cracked and conditioned soybeans to 10 mil thickness; however, the conditions for cracking and conditioning must be precisely defined.

The selection of preparation equipment items is dictated by: (a) past history of performance; (b) rapid availability of spare parts; (c) capital cost; (d) anticipated maintenance expenses; and (e) energy consumption. At present, French Oil Mill Machinery Company is the only American supplier of solvent extraction systems that also offers a wide variety of its own preparation equipment such as flaking rolls, cookers, and pre-presses for high oil-bearing seeds.

Soybean Selection and Cleaning (8)

Soybeans should be selected which can be processed to meet the specifications for protein and products. Obviously, soybeans containing toxic materials or difficult-to-remove foreign matter are not acceptable. Likewise, sprouted, immature, heat-damaged or physically damaged seeds or beans generally will be unsatisfactory because these materials deteriorate rapidly. Most of the dust, chaff, rocks, scrap iron, wood, etc., should be removed by aeration and screening before drying and storage.

It is desirable to clean soybeans and remove plant stems, foliage and other trash before the beans are stored because this material decomposes rapidly, heats and deteriorates. Consequently, it has been suggested that trading rules be revised so that penalties start above trace levels of foreign material rather than at 1%. With present trading rules, farmers and country elevators have an incentive to add enough dirt and trash to bring up the allowable foreign material to the maximum. It would become very expensive, and in some cases would be impractical, to remove every type of foreign matter prior to processing soybeans for certain protein products.

For raw materials used to produce soybean isolates and concentrates, it is essential to remove foreign matter very carefully so that the protein products will not be contaminated by color bodies.

Drying and Storage

Moisture is generally believed to be the most important factor in promoting the deterioration of stored grains. Acceptable maximum storage moisture level is about 13% for soybeans. During the past 20 years, drying of beans before storage has become standard practice in most plants, thereby minimizing difficulties in processing the new fall, high moisture crop. Various soybean dryers are available to handle either high throughput and small moisture reduction or low throughput and high moisture reduction.

Properly dried and stored raw materials will process considerably better through a solvent extraction plant than materials which have been allowed to deteriorate. For example, improperly dried soybeans are difficult to dehull and solvent extract. Many processors frequently lose considerable efficiency because drying facilities are inadequate.

Raw material storage represents one of the largest capital investments in an oil mill. Storage should be designed to permit segregation of grain by good and poor quality, control of moisture level, and control of temperature. Ample use of cooling fans, temperature recorders for grain in bins, and conveying facilities for "turning over" the grain should be made to prevent deterioration due to local overheating and high moisture.

It should be remembered that there is seasonal movement of moisture within a storage unit even where the average moisture content is low enough for safe storage. For example, during the fall and winter, soybeans near the walls and upper surfaces cool more rapidly than those near the center of the bin. As a result of convection air currents created by the temperature differential within the bin, condensation occurs as the warm moist air reaches the cool upper layers of beans. Tests reveal that beans with a uniform moisture content of 12% when stored in early autumn have reached moisture contents of 16 to 19% in the upper layers during mid-winter.

Cracking and Dehulling

Soybeans are normally cracked into 6 or 8 parts prior to dehulling. Good cracking at uniform conditions facilitates good dehulling, flaking and extraction, and contributes to the conditions which permit production of meal suitable for subsequent processing into protein products.

Soybeans are approximately 93% kernel and 7% hulls. The whole seed contains about 18% oil and the hulls contain about 0.6% oil. Many United States plants have already installed dehulling equipment for the purpose of producing high protein, low fiber meal which is commonly known as 49% protein meal. The fiber content of such meal should be less than 3%, and the oil content in separated hulls will be about 1.5%. The hulls will be blended back to 44% protein meal or sold as low grade meal for blending. Some soybeans, under favorable growing conditions, have tended to average about 38% protein. Since the extracted and desolventized meal from such soybeans will then contain 46% protein even without dehulling, the oil mill processor can blend back purchased low cost hulls to produce additional 44% protein meal for animals.

Conditioning and Flaking

Soybeans are conditioned prior to flaking so that moisture and temperature are at optimum conditions. Normally, moisture is adjusted to 10-11%, and temperature is raised to about 160 F during conditioning. Proper conditioning yields bean pieces which are sufficiently plastic so that good flakes can be formed.

Properly prepared flakes are essential for consistently good extraction. Normally, soybeans are flaked to 0.010 to 0.012 in. thickness before extraction. However, for certain Oriental foods or for improperly tempered and dried beans, it is necessary to prepare much thicker flakes. These thicker flakes extract more slowly and take longer to desolventize.

One important point to remember is that deterioration takes place more rapidly after flaking because a relatively large surface is then presented to the air for possible oxidation and hydrolysis after the cells have been ruptured. Consequently, interruptions in operation are more likely to yield poor quality meal.

SOLVENT EXTRACTION EQUIPMENT SYSTEMS

There are now three major solvent extractor equipment suppliers in the United States. In addition, at least two of these American extractor suppliers license their knowhow to Europen suppliers. There are also several other types of extractors manufactured in Europe, but these will not be discussed in this paper because of the many other topics to be covered.

Crown Solvent Extractor

As illustrated in Figure 7, the Crown Solvent Extractor resembles a full loop en masse conveyer in appearance. It utilizes both immersion and percolation extraction technology during the complete loop. Although the first Crown extraction plant was built in 1948, most of their installations have been built during the past decade. This system has been especially popular with American Co-op oilseed processors. According to Crown Iron literature, these extractors have been built up to 1,000 tons per day, and larger extractors are being offered. The claimed advantages are that the bed depth is comparatively shallow as compared to that of other extractors and that the bed is turned over completely during the last part of the extraction cycle.

Dravo Rotocel

The Rotocel was developed by Blaw-Knox in the late 1940s to replace and be competitive with basket extractors. Figure 8 illustrates a conventional Rotocel percolation extractor. As the cells rotate on a circular path inside the shell, these cells are flooded with miscella and finally with fresh hexane for the final wash. The bottom of each cell is a perforated, hinged door which is supported by rollers on a track. The lower part of this extractor is divided by vertical baffles into extraction stages. The liquids draining from the cells collect in the compartments and are pumped by the stage pumps in an opposite direction to the rotation of the cells. At the end of the final drainage, the hinged cell door opens, and the flakes are dumped into a hopper before being conveyed to a desolventizer. These extractors are used for soybean operations at throughput rates of 300 to 2,500 tons per day. In recent years, Rotocel extractors have normally been used at 1,500 to 2,500 tons per day for soybean processing in the United States and at somewhat lesser capacities elsewhere. The claimed advantages of the Rotocel are mechanical simplicity, adjustable wash manifolds, and a self-cleaning miscella fines system.

French Stationary Basket Extractor

The French Oil Mill Machinery Company Stationary Basket extractor was developed in the late 1950s to early

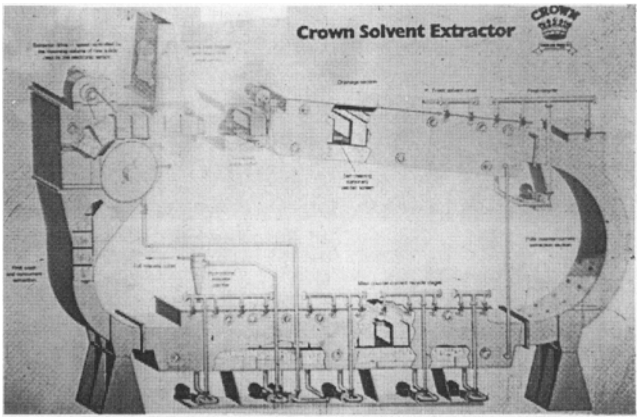

FIG. 7. Crown solvent extractor.

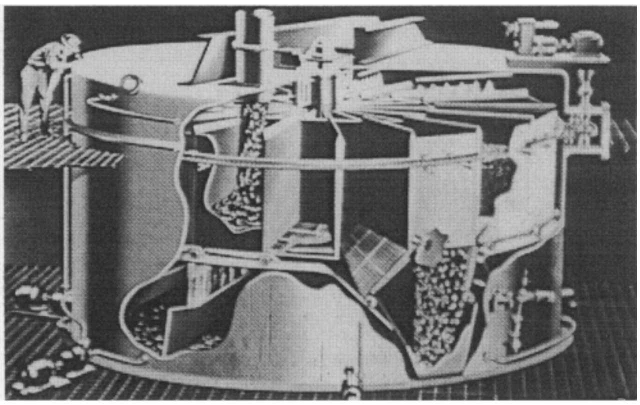

FIG. 8. Dravo "Rotocel" extractor.

1960s. Since then, it has found wide application in the United States and abroad.

Figure 9 illustrates a stationary basket extractor. This extractor is also a percolation extractor. It is designed and operated so that the baskets remain stationary while the feed spout, the miscella and hexane wash, the miscella collection system and the spent flake collecting system rotate. Meanwhile, successive washes of miscella are advanced in counter flow to the stationary bed, and the final wash is accomplished by fresh hexane. Three claimed advantages of this extractor are: no movement of the bed which minimizes compacting of fragile flakes; no heavy weights supported by bearings on loaded cells; and more complete utilization of the space inside the vapor-tight shell. This extractor has been used over a range of 200 to 3,000 tons per day for soybeans.

DESOLVENTIZER EQUIPMENT SYSTEMS

All desolventizing systems must be designed to receive defatted soybean flakes containing about 30 wt % hexane and remove the hexane from the meal down to commercially acceptable levels. To produce a soybean product having both the required protein dispersible index (PDI) and relative protein efficiency, control of processing variables during desolventizing is essential. During desolventizing, the three pertinent variables (time, temperature, and moisture) are near or above their threshold values. Consequently, by carefully controlling these variables, a flake product can be produced, at will, having the desired PDI.

Soybean protein has excellent nutritive value when it is properly processed. Typical commercial defatted soy flours

TABLE I

Type	Protein dispersible index (a)	Relative protein efficiency (b)
Negligible Heat	90 - 95	40 - 50
Light Heat	70 - 80	50 - 60
Moderate Heat	35 - 45	75 - 80
Toasted	8 - 20	85 - 90

(a) PDI as measured by A.O.C.S. Tenative Method Ba 10-65.
(b) Dried skim milk equals 100 per cent.

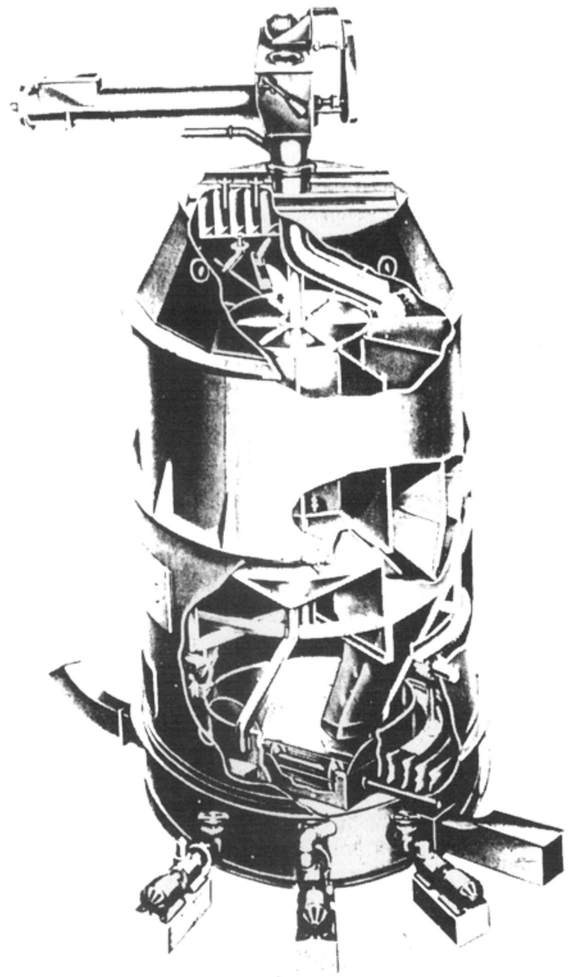

FIG. 9. French stationary basket extractor.

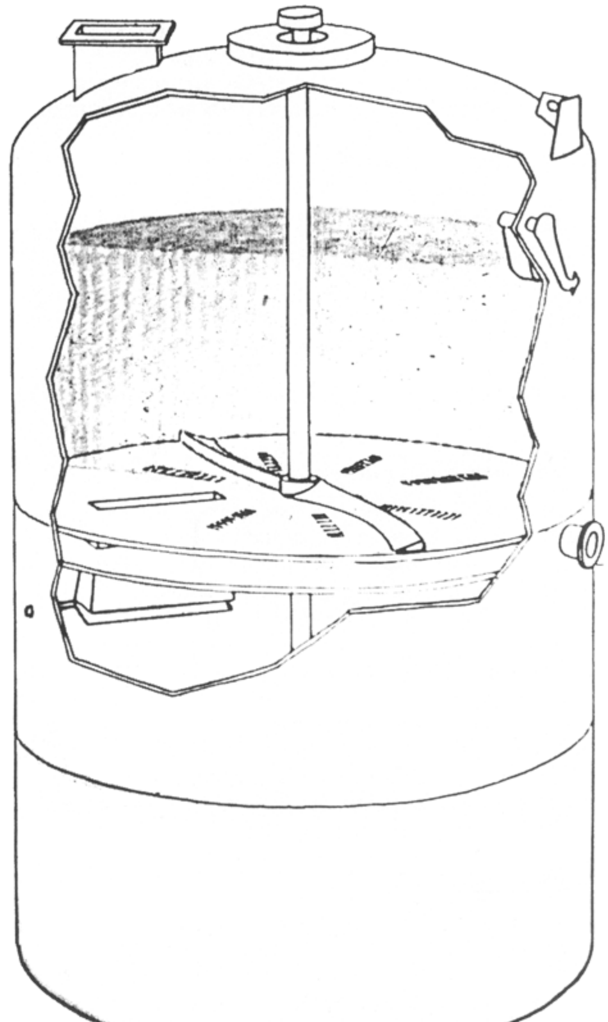

FIG. 10. Crown DTDC.

and their relative nutritional values are summarized in Table I.

Desolventizer-Toasters

Crown Iron Works, Dravo, and French Oil Mill Machinery Company all offer desolventizer-toaster systems. The mechanical and the process features of each of these supplier's D-T systems vary, depending upon the intended application and upon the manufacturer's patents and standards. The method for controlling level in these D-T systems also varies with different suppliers. The comparative advantages of each D-T system and its mechanical features should be evaluated very carefully before final selection is made. Remember, safety is the primary consideration, and rugged, sturdy design is absolutely essential to withstand the harsh conditions imposed in operations. For example, it sometimes happens that giant doughballs form inside the D-T unit following sudden shutdowns. Consideration should be given to how to start-up again, after this condition, without damaging the equipment.

Basically, the processes involved in any of the desolventizing toasting systems are similar. The D-T unit is a vertical shell vessel containing steam heated trays, sparging steam sections, sweep arms and a drive system, and a means for discharging the vapor at the top and the meal at the bottom. Hexane wet flakes enter the top section and are sparged with steam on one of the upper trays. Steam condenses in the flakes vaporizing the hexane so that the moisture content is raised to about 20%. In the lower tray sections, flakes are heated to about 225 F, and the moisture content of the flakes is reduced several %. Desolventizer-toasters are commonly used to produce toasted meal for ruminant and poultry feeds. Typical PDI products range from 10 to 30%.

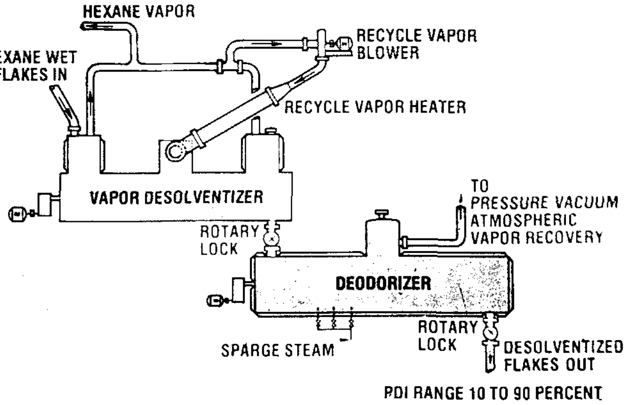

FIG. 11. Vapor desolventizer deodorizer system U.S. patent No. 3,392,455.

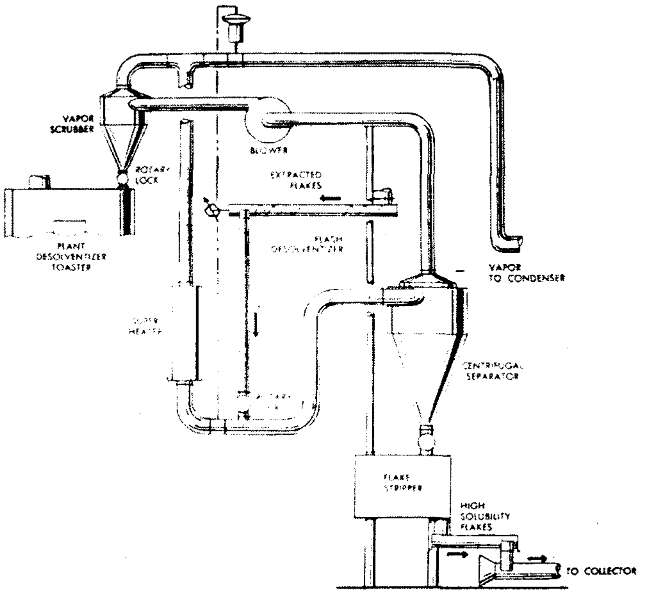

FIG. 12. French flash desolventizer.

DTDC (desolventizer, toaster, dryer, cooler)

As illustrated in Figure 10, Crown Iron Works manufactures a machine which performs desolventizing, toasting, drying and cooling continuously. The desolventizing-toasting portion is accomplished in a manner similar to that described previously except fewer trays are used. The drying is done by contacting hot air with the toasted meal. Finally, the cooling is accomplished by blowing ambient air through the meal.

Vapor Desolventizer-Deodorizer

Figure 11 illustrates the Dravo vapor desolventizer-deodorizer system (9), which is designed to provide a broad range of PDI products. This system is designed to allow time, temperature, and moisture to be adjusted at will during operation. All but 1% of the solvent is removed from the meal by the superheated vapor in the desolventizer. The meal then passes through a lock to the deodorizer. The steam pressure within the deodorizer can be regulated between ½ atmosphere and 2 atmospheres. By adjusting this steam pressure and by minor adjustments to the height of the discharge dam, the PDI of the meal can be adjusted over a range of 10 to 90 with the upper limit approaching 1 or 2% below the PDI of the extracted flakes.

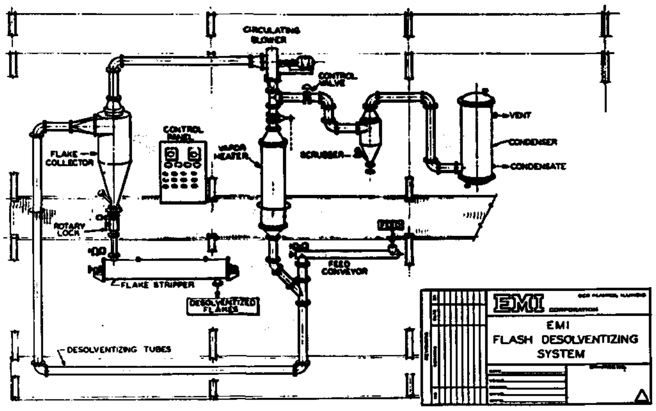

FIG. 13. Flash desolventizing system.

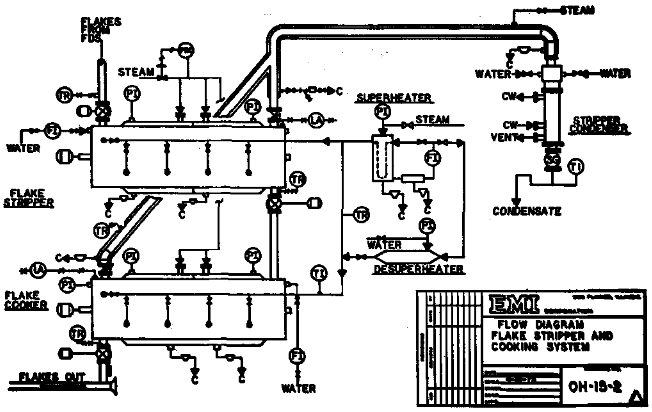

FIG. 14. Flow diagram flake stripper and cooking system.

Flash Desolventizer

Both French Oil Mill Machinery Company and EMI have sold recent flash desolventizing systems. Figure 12 illustrates the French flash desolventizer and Figures 13 and 14 show the EMI system (10). Basically, a flash desolventizer consists of a pneumatic-conveying desolventizing tube, a cyclone flake separator, a hexane blower, and a hexane vapor heater arranged in a closed-loop system in which superheated vapor is constantly circulated. Solvent-wet flakes are fed continuously into the system through a variable-speed feed conveyor to the circulating vapor stream where the solvent is removed down to about 1%. The desolventized flakes are then discharged into a cooking system wherein the variables of time, temperature and moisture can be adjusted to allow flakes to be produced in a closely controlled PDI range as required according to EMI; low range 10-25, medium range, 40-60, and high range 70-85 flakes can be produced at will by adjusting the variables of time, temperature and moisture during cooking.

MEAL DRYING, COOLING, AND STORAGE

From a desolventizer-toaster system, the meal is dried first in a rotary steam tube dryer and is then cooled by air before being sent to storage. Meal from DTDC, flash dryer, and vapor desolventizer-deodorizer systems does not need to be dried. Hence, when calculating capital and operating expenditure for such systems, credit should be taken for the elimination of the conventional meal dryer.

Typically, the desolventized meal will be stored at 12% or less moisture and about 100 F maximum temperature. However, occassional upset operations or equipment malfunctions will cause higher temperature and/or higher mois-

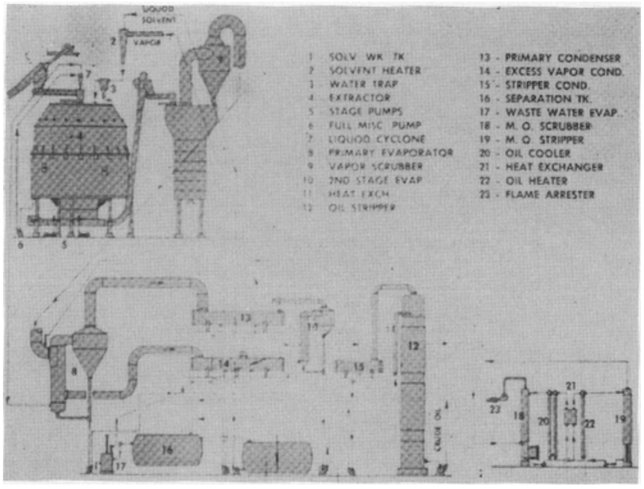

FIG. 15. Flow chart solvent extraction solvent – miscella – vapor flows.

TABLE II

Critical Design Criteria for Distillation and Solvent Recovery Systems

Oil Product specifications
Maximum temperature allowed
Moisture and volatile content
Miscella to Evaporator
Throughput rate
Concentration
Quantity of air flowing through system
During normal operation
During start-up operation
Steam at use point
Pressure and Quality
Cost
Cooling water at use point
Temperature
Quantity available
Pressure
Tendency to Foul Heat Exchangers

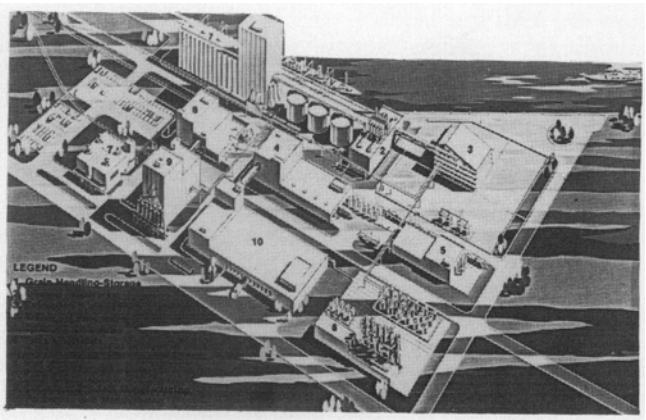

Fig. 16. Panoramic sketch of complete factory (McKee).

ture meal than typical to be produced. In storage these abnormally produced meals are subject to further denaturation, as well as difficulties in removing meal from bins.

DISTILLATION AND SOLVENT RECOVERY SYSTEMS

For this industry, the terms "distillation and solvent recovery" together describe all processes in the solvent handling area other than solvent extraction and meal desolventizing and includes the following: (11)

1. Evaporation of hexane from vegetable oil – single or dual effect – from the miscella to about 90 wt% oil concentration.
2. Flashing and low pressure steam stripping to remove hexane from the oil down to less than 0.15 wt % moisture and volatile content.
3. Heat exchangers and steam economizer systems.
4. The condensers, solvent separator, water stripper and waste water sump to recover hexane in a safe manner.
5. Vent condensers, blowers, and ejectors for final removal of solvent from exit gases.
6. A mineral oil absorption and recovery system for final removal of solvent from exit gases.
7. Pumps, piping, flame arrestors, vent seals, instruments and controls to make the system operational.

Figure 15 briefly illustrates a typical distillation and solvent recovery system for an oilseed solvent extraction plant. All suppliers of solvent extraction equipment also will furnish distillation and solvent recovery systems to match their other systems.

Table II lists the critical design criteria for distillation and solvent recovery systems. Since safety as well as conditions for prolonged operations are involved, it is most important to consider these and any other special design criteria to assure maximum efficiency.

THE COMPLETE FACILITY

As indicated previously, all three American suppliers sell the equipment systems for the entire solvent extraction area. All of us in this industry realize that the technical and economic success of a soybean processing facility usually is dependent upon many factors other than soybean preparation and solvent extraction. In this latter quarter of the 20th century, many of the large American and even the small foreign oilseed processors are taking the overall factory complex approach when designing their new grass roots plants. Many of these plants, especially those in foreign countries, handle and store numerous grains, prepare and extract several different oilseeds, make several grades of flour, operate a feedmill to produce a number of formulations, process vegetable oils into salad oils and other consumer products, design for their future entry into a variety of human edible proteins, and operate warehousing and shipping facilities. Figure 16 illustrates an Arthur G. McKee panoramic sketch of a complete factory for the handling and processing of grains and oilseeds into various animal and human food products. It illustrates the following facilities on a grass roots site:

1. Grain handling and storage
2. Oilseed preparation
3. Solvent extraction
4. Edible oil processing
5. Specialty chemicals and pharmaceutical intermediates
6. Fatty acid and fatty chemical processes
7. Edible proteins and dry milling
8. Wet milling
9. Feed mill
10. Consumer product manufacture, packaging, and warehousing.

THE RIGHT PLAN OF APPROACH

To obtain and maintain a sound long term financial position in this industry, a company should first implement their plan of appraoch by selecting a project management team whose objectives are identical with those of the Owner. These objectives should include:

1. Obtaining the best R.O.I. (return on investment) during the operating life of the facilities.

2. Selecting equipment systems with good performance records and which can be maintained properly in remote areas (if applicable).
3. Compliance with existing and anticipated codes and regulations.
4. Designs for safe operation during start-up, normal processing, and shutdowns.
5. Pollution abatement (air and water) considerations.
6. Energy Audits for Efficient Energy Utilization (12).

Today's inflation and uncertainties compel companies to evaluate capital expenditure programs very carefully. The age of "catalog engineering" and the "once over lightly" approach no longer pays – it might even put a company out of business. Thorough planning during the conceptual or pre-engineering phase will insure higher profits per dollar invested, safer and cleaner plants, and plants more easily adaptable to future expansion. To optimize R.O.I. and insure earliest possible plant completion for a comprehensive project, the owner should select the most experienced technical and construction expertise available to him. Often the best investment that an owner can make is to select and use the vast experience of a skilled engineering-constructor.

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