Continuous Solvent Extraction of Soybeans and Cottonseed

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ABSTRACT

The current trend in soybean processing in the United States is toward ever larger capacities handled through single extractors and desolventizer-toasters. There are 20 such plants which average over 2,000 tons per day, with the largest handling over 3,000 tons per day. Slight differences in extraction efficiency, in heat economy, in solvent loss, and in plant reliability make or lose thousands of dollars each day for such plants. The operating characteristics of these 20 plants which now crush over half of all the U.S. soybean production are detailed.

Cottonseed is the most complex and variable of all the oilseeds. A review of the corresponding variation in the processing conditions required to obtain quality products is made.

INTRODUCTION

This manuscript is a review of current practice of solvent extracting soybeans and cottonseed in the United States. The most striking new development in soybean processing in the U.S. is the trend toward very large capacity plants handled by single units for extraction and desolventizing. This paper will be slanted toward describing the particular problems and operations involved in the development of these plants handling 2,000–3,000 tons per day (TPD) of soybeans, with only passing reference to the differences between these large operations and the smaller scale ones, since the latter have been well covered in previous technical manuscripts (1-3). There are 20 of these large plants now operating in the United States, and they are processing more than half of the total of 800 million bushels or 24 million tons of soybeans currently being processed in the United States each year.

Soybeans are the easiest oilseed to extract, but cottonseed meats are one of the most difficult. Processors who handle both seeds must train their operators to make sharp changes in operating techniques to obtain efficient results. These differences will be detailed below. Where no difference is specifically mentioned, processing conditions can be assumed to be the same for both materials.

SOYBEAN PREPARATION

Figure 1 shows a simplified chart for preparation of soybean meats. Since a previous paper in this Conference has described seed cleaning, decorticating, and hull separation, only the steps of cracking, conditioning, and flaking of soybeans are shown. The most striking characteristic of this simplified flow chart is that it looks exactly like a flow chart of 40 years ago—but the machinery is vastly different.

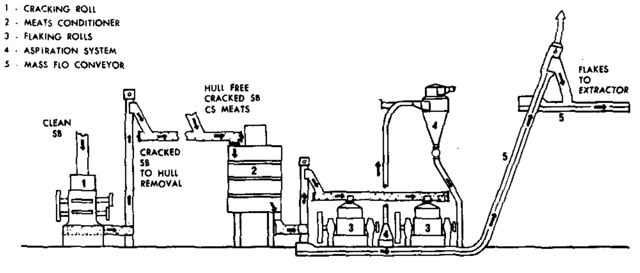

FIG. 1. Soybean (SB) and cottonseed (CS) meats preparation for direct extraction.

The cracking roll (Item 1), representing a line of six to eight machines, has two pairs of rolls with two to four sawtooth shaped corrugations per cm. The rolls are ca. 30 cm in diameter by 130 cm long and driven by a 50-75 HP motor. Each machine will crack up to 500 TPD, reducing the soybeans to quarters and eighths.

The cracked beans are sent to the hull removal equipment described in the previous paper. All the high capacity soybeans plants have front end hull removal equipment for which they dry the beans in storage to 9-11% to facilitate complete hull removal for the production of high protein products.

The hull-free cracked beans are then conditioned in a vertical cooker-dryer (Item 2). Large horizontal steam tube dryers are also used as conditioners. The cracked beans are heated to 70-75 C, with 20-30 min required for good conditioning. The discharge moisture is adjusted to ca. 11%. Some processors favor the vertical cookers as providing a moist stewing action that produces superior nutritional properties in the finished meal, but the cost of equivalent heating capacity favors the horizontal units.

The hull-free cracked beans are then flaked in heavy duty flaking machines (Item 3). The two units shown represent a line of 10 or 12, each containing a pair of smooth chilled iron rolls 50-75 cm in diameter and 100-130 cm long. The larger machines are driven by 150 HP motors and flake 300 TPD. Electrical vibrating feeders with instant cut-off and reset have replaced the older roll type feeders. For efficient operation in the deep bed extractors—such as the French stationary basket extractor and the Rotocel extractor—that are predominantly used in the very high capacity operations, it is necessary to flake only to 0.4 mm. These are relatively thick and dense flakes which pack into the extractor, permitting a longer extraction time which compensates for the thicker flakes. For smaller capacity plants it is usually necessary to flake thinner, in the range of 0.25-0.35 mm, to obtain efficient extraction (4).

CONVEYING AND ASPIRATION

The flakes are conveyed to the extraction area in mass flow type enclosed conveyors in order to maintain the flake structure without excessive breakage. Aspiration to obtain surface drying of the flakes, or at least to prevent excessive sweating in the conveyors, is an essential part of efficient solvent extraction which is too often overlooked in the design of extraction plants. On this flow chart, an aspiration point is shown as Item 4, in which the air is drawn in at the flaking roll feeders, down past the hot rolls, and discharges from the collecting conveyor. This maintains a surface drying on the flakes as they are produced in the flaking roll. Aspiration air should be applied at a rate of 25-30 m^3/min to each flaking roll machine to maintain the proper surface dryness on the flakes. A second aspiration point is shown at the discharge section of the mass flow conveyor, which has two functions in that it will assist in removing any free moisture in the flakes but also will assist in preventing any solvent vapors from getting back to the preparation area.

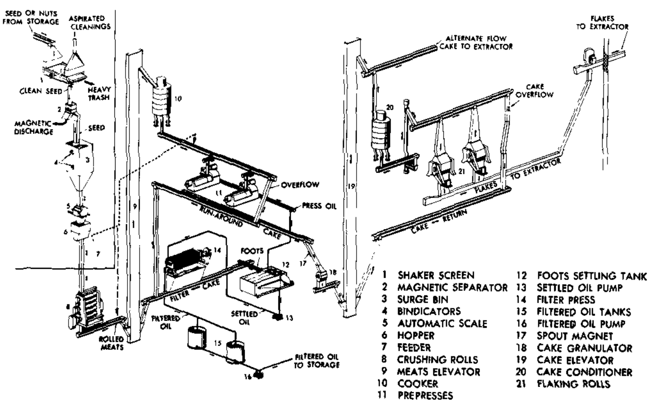

FIG. 2. Pre-press: cottonseed, flaxseed, peanuts, sunflower, sesame, rapeseed, corn germ (wet process), copra.

COTTONSEED PREPARATION

Ca. 65% of the wt of white cottonseed processed will be discharged from the separation room as meats containing 10-15% hulls and ca. 33% oil. The hull content is essential for efficient direct extraction of conditioned cottonseed meats.

From the moment the meats are dehulled, special considerations must be given to preserve oil quality, and the most important one is to send the meats through as quickly as possible and to maintain a minimum time in process. A common practice in oil mills of providing surge bins in the preparation area should be eliminated because it causes deterioration in oil quality. If the seed are over 11-13% moisture, or somewhat damaged, the deterioration in oil quality is even more rapid. A conditioning time of 10-12 min is desirable, and a *maximum* temperature of 65 C should be observed. There is very little possibility of adjusting moisture of wet meats, so every effort should be made to maintain and store cottonseed at not over 12% moisture. On the other hand, moisture below 8% causes problems in the separation room, so such seed should be humidified with the use of live steam after it is delinted. If the seed are of prime quality and 6-10% moisture, it is sometimes necessary to condition somewhat longer and obtain a discharge temperature from the conditioner of 85-95 C. Cottonseed meats must be flaked to ca. 0.2 mm in thickness to obtain the best extraction. The conveying to the extraction area is a critical operation in that the flakes are much more fragile than soybean flakes and must be carefully handled in mass flow type conveyors.

PRE-PRESSING COTTONSEED MEATS

The alternate method of processing cottonseed meats through an extraction plant is to pre-press the meats and extract the pre-pressed cake as shown in Figure 2. In this process the meats from the separation room, containing 10-15% hulls, are crushed in crushing rolls, which are vertically stacked rolls (Item 8) in which no controlled thickness is obtained or necessary. In recent years, particularly for plants that process both soybeans and cottonseed, it has become common for processors to use their soybean flaking rolls for crushing cottonseed, and there is apparently very little processing difference. The crushed meats are cooked, which is entirely different from the conditioning process for the direct extraction of flakes in that the moisture level is usually raised in the top kettle of the vertical stack cooker (Item 10) to 13-15% and the cooked meats are discharged at ca. 100-110 C, with the moisture content reduced at the discharge to the presses to ca. 8%. The mechanical screw presses (Item 11) may be conventional screw presses such as are used for straight pressing of oilseeds, with the shafts speeded up and the worms provided for less severe pressing action, but modern high capacity pre-presses with 200 HP motors have been developed to process 200 TPD of seed, and, more recently, still larger presses have up to 600 HP and process up to 400 TPD of cottonseed. The end is not necessarily in sight since dewatering presses in the sugar and rubber industries, which have many common design features with oilseed presses, are operating with horsepowers as high as 2,000. Consequently, should a market be developed for such horsepowers with increased capacities there would be no technical problem in making the machine. Screw press oil is sent to a settling tank or foots screen (Item 12), and then the oil is filtered in a filter press or leaf type filter (Item 14) sometimes with filter aid, with the foots and filter press cake being recycled to the screw presses or mixed with the pre-press cake, which runs 10-14% oil, and sent to the extraction plant.

Press cake from modern French Oil Mill pre-presses may be granulated (Item 18) and sent directly to the extraction plant, but heavier and thicker cake must be granulated, conditioned, and flaked (Items 20 and 21) to obtain good extraction.

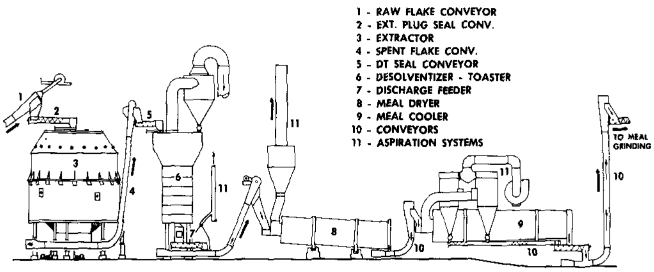

FIG. 3. Extraction solids flow typical for large capacity soybean operations.

EXTRACTION–SOLIDS FLOW

A simplified flow chart of the solids flow through a large capacity soybean extraction plant is shown in Figure 3. Raw flakes are brought in through a mass flow crossyard conveyor (Item 1) to the extraction area. This conveyor should be provided with either natural stack or forced draft ventilation on the discharge section in order to assist in the surface drying of the flakes as well as help prevent any backflow of hexane toward the preparation area. The flakes drop into a filling screw feeder (Item 2) which is designed to provide a plug seal of material. The flakes are slurried into the basket compartments of the extractor (Item 3) through a rotating filling spout. The flakes are extracted with the application of miscella in diminishing strengths and finally with a wash of clear solvent to reduce the residual oil to <1%. It is not within the scope of this paper to describe the mechanics of any specific type of extractor. There are differences in detail, but the process of countercurrent application of solvent and miscella is common to all the popular types of extractors whose details are covered in other papers at this conference. A drainage period is provided for the flakes to reduce the solvent retention to 35-40%, and the flakes are then dumped into a vapor tight mass flow type conveyor (Item 4) which discharges to an enclosed seal conveyor with a plug seal (Item 5) feeding the desolventizer-toaster. The deep bed type of extractor will contain over 200 m^3 of basket volume, which will provide 35-40 min extraction time for the hull-free flakes from 3,000 TPD of soybeans. Such an extractor will be 10-11 m in diameter and stand 12-15 m high.

A single desolventizer-toaster, developed and patented by the French Oil Mill Machinery Co., is now the standard of the industry (5) (Item 6) and will handle the volume of extracted flakes from 3,000 TPD. Such a unit is ca. 3 m in diameter and has a dome or expansion chamber in the top 5-6 m in diameter and 5-6 m high. To desolventize this volume of extracted soybean flakes, as much as 20,000-23,000 kg of steam per hour will be blown into

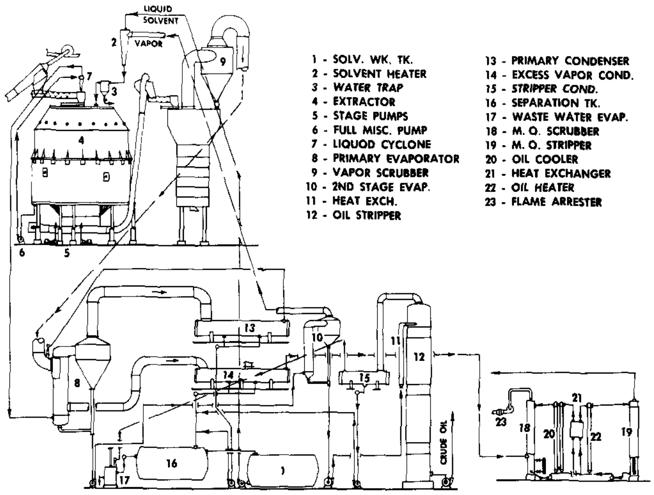

FIG. 4. Solvent extraction, solvent-miscella-vapor flows. MO = mineral oil.

the extracted flakes in the top kettle, followed by smaller amounts of stripping or sparge steam in the lower kettle. A variable speed driven feed screw (Item 7) will be provided in the discharge to regulate the discharge feed and synchronize it with the flakes entering the plug seal conveyor at the top. Various automatic devices are used to control the discharge feeder, based on the levels in the desolventizer-toaster. The best operation usually provides a vapor temperature leaving the desolventizer of ca. 80 C, which is regulated by the amount of blowing steam put in the top kettle. Sufficient steam jacketed surface should be provided in the lower kettles to increase the temperature to above 100 C so that the open steam provided in the lower kettles will strip out the last traces of hexane. A well designed and operated desolventizer-toaster should reduce the residual hexane in flakes to below 500 ppm, and it is possible to obtain efficiencies to half this residual hexane so that the contribution of the hexane lost in the extracted meal should be <0.1% of the material coming to the extraction plant. Overall solvent losses should be held to not over 0.15% of the incoming material, which means that a 3,000 TPD extraction plant should have a solvent loss of not over 6,000 liters per day.

The meal discharging at over 100 C and at a moisture of 18-22% will flash a great deal when brought into the atmosphere, and provision for aspiration should be provided. The hood and natural draft stack (Item 11) should be of stainless steel because of the corrosive nature of the first vapors from soybean meal coming from a desolventizer. A mass flow type conveyor is usually used to convey the desolventized meal to a rotary steam tube dryer (Item 8), which will be 2.5-3 m in diamter and 18 m long with a 75 HP motor drive and will reduce the moisture to 10-13%.

The natural draft stack shown on the rotary dryer has the advantage of continuing in operation in case of a power failure; and in the United States it also has a considerable advantage because the discharge from the natural stack will have a low enough solids content of dust to meet the Environmental Protection Agency (EPA) standards for air pollution, whereas a forced draft system will usually have to have a final filtration through canvas bags to meet the standards. Since 180 m^3/min is required for a 3,000 TPD operation, the natural stack, even though made of stainless steel, is a much cheaper solution than forced draft with dust filters which require great quantities of bleed-in air to prevent condensation in the filters.

The dried meal then goes through a mass flow type conveyor to a meal cooler (Item 9), which is usually a rotary type unit (as shown) 3-3.5 m in diameter and 18 m long and requires aspiration air of 2,000 m^3/min. A fan driven by a 150 HP motor is required. This air must be filtered before being discharged to the atmosphere.

For smaller capacity plants the material flow in the extraction area is completed after the material passes through the extractor and the desolventizer-toaster. In this case the desolventizer acts as the meal dryer, and the desolventized meal is often conveyed by air to the meal grinding area in a system that cools as well as conveys.

For cottonseed the desolventizer-toaster is much larger per ton of material processed than for soybeans because commercial preference requires light colored meal, which requires a low moisture level through the desolventizing stage, and this in turn prevents the use of large quantities of sparge steam. Instead, much greater steam jacketed areas per ton of capacity must be provided.

SOLVENT EXTRACTION—SOLVENT MISCELLA AND VAPOR FLOWS

Liquid and vapor flows through a solvent extraction plant are shown in Figure 4. The equipment represents roughly to scale the relative sizes of equipment required by the multithousand ton operations on soybeans. Solvent is pumped from the solvent work tank (Item 1) to a solvent heater (Item 2), which is an induction heater using moisture-free solvent vapor from the second stage evaporator (Item 10). The vapors condense in the liquid hexane, and the heat of condensation serves to heat the hexane to ca. 65 C. A very effective addition to modern plants is a final solvent water separator (Item 3), which must be installed immediately adjacent to the extractor. This auxiliary water separator has been amazingly effective in improving extraction efficiency. Temperatures of ca. 60 C should be maintained in the extractor. Two of the four or five or more stage pumps (Item 5) are used in various solvent extraction systems to recycle miscella of diminishing strengths through the extractor. The full miscella pump (Item 6), pumps the 20-35% oil concentration in hexane through a liquid cyclone (Item 7), which is effective in removing any stray flakes that might fall into the full miscella. Processors who degum their finished oil and produce commercial lecithin sometimes filter either the miscella or the finished oil before they degum the oil.

The clear miscella goes to a first stage preevaporator (Item 8), where the vapors from the desolventizer are used on the shell side of the tube chest to provide the heat to evaporate most of the hexane from the miscella. The evaporation inside the tubes takes place at ca. 45 C at ca. 400 mm Hg vacuum or ca. 1/2 atmosphere of absolute pressure, and produces miscella of 65-70% oil. The vacuum that can be obtained is a function of cooling water temperature. At sea level conditions, cooling water of not over 30 C must be available. The miscella from the first stage evaporator is pumped to a second stage evaporator (Item 10), where steam is applied through the shell side of the tube chest and the miscella is concentrated to ca. 90% oil. It is then pumped, usually, through another steam heated exchanger (Item 11) to a disc and donut oil stripper (Item 12), which is operated at 450-550 mm Hg vacuum or ca. 1/3 atmospheric absolute pressure.

The steam ejectors from the two vacuum condensers (Items 13 and 15) are blown into a vessel where the heat from the steam can be utilized. This chart shows the ejector from the oil stripper condenser discharging into the waste water evaporator (Item 17) and the ejector from the primary condenser (Item 13) discharging into the vapor inlet to the first stage evaporator. In some instances, operators discharge ejectors into the desolventizer, where a great deal of sparging steam is used anyhow, or into the base of the oil stripper. Another steam economy application frequently used is a flash steam heat exchanger to heat the miscella from the first stage evaporator to its boiling point prior to being introduced into the second stage evaporator.

The vapors from all the extraction vessels are vented through condensers to a mineral oil scrubber (Item 18) in which cool mineral oil of not over 40 C trickles down over packing or discs and donuts countercurrent to the flow of the noncondensable gases from the extraction system which discharge to the atmosphere through a flame arrester (Item 23). Sometimes a forced draft fan is applied to the vent system, but bleed-in air must be available in order that the amount of vapors pulled through the system do not exceed the capacity of the scrubber. The mineral oil is pumped from the base of the scrubber to an oil to oil heat exchanger (Item 21) and then to an oil heater (Item 22) into a mineral oil stripper (Item 19) at a temperature of 220 C with sparge steam applied at the bottom. The vapors go back to the excess vapor condenser (Item 14).

It is important that care be exercised to make sure that the recycle lines provided for steam economy do not provide a dead end where noncondensable gases can collect and air bind the condensers or other equipment.

All the solvent from the condensers comes back to a water separation tank (Item 16), where any water is settled from the hexane by gravity, with the hexane overflowing back to the work tank and the water overflowing through an automatic level control device to the waste water evaporator (Item 17), where all the waste water is heated to the boiling point before being allowed to go to the sewer.

Crude soybean oil is pumped from the base of the oil stripper (Item 12) to any further treatment such as water washing or refining. If the crude oil is stored it is sometimes desirable to cool the oil first, but for soybean oil this is not considered essential by most processors.

COTTONSEED EXTRACTION

Cottonseed extraction follows the same flow, but the technique is vastly different (2). The amount of slurry must be sharply curtailed in basket filling, and the amount of recycled miscella must be carefully controlled to prevent a buildup of miscella on top of the beds of flakes. If any appreciable buildup of miscella takes place, drainage will stop and efficient extraction will become impossible because of fine particles of meal or flour that are suspended in the miscella in the early stages. These will settle out on top of the beds of flake. With the proper technique a polished miscella can be obtained for the cottonseed full miscella. With less than proper technique the liquid cyclone is frequently called into play to clarify the miscella in the extraction of either cottonseed flakes or of cake.

One of the most essential precautions in cottonseed extraction is to evaporate the miscella quickly, since darkening of the oil takes place very rapidly. When cottonseed extraction plants are shut down, the extractor must be emptied and all miscella evaporated immediately to prevent deterioration. Low temperature evaporation is also very desirable to preserve cottonseed oil color. We find that temperatures below 95 C throughout the entire evaporation cycle are very beneficial to the eventual refined cottonseed oil color. Darkening that takes place in the extraction process is very difficult and expensive and frequently impossible to bleach out of the finished oil. Just as important is the necessity of cooling the crude cottonseed oil very rapidly before it goes to storage. Crude oil cooling is considered a luxury for soybeans but is an absolute necessity for cottonseed processing.

Miscella refining or solvent refining is often employed for cottonseed oil because it is possible to increase the yield of refined oil almost to the theoretical optimum by reducing the amount of glyceride oil that is carried down with the refining foots, and the short time from extractor to refined oil is beneficial to finished oil color. Miscella refining will often produce prime oil from damaged seed (6,7).

OPERATION OF LARGE CAPACITY SOYBEAN SOLVENT EXTRACTION PLANTS

The essential consideration in the location and operation of a multithousand ton soybean processing plant is an adequate local supply of soybeans. When you consider that a farm containing 1,000 acres devoted to soybean production, which is ca. 4 km^2, will produce only enough soybeans in a year to keep one of these plants operating for 6 hr, you can understand that the plant must be located in a large farming area or else on a water system that reaches into a large growing area. In laying out these large plants, traffic is the prime consideration since hundreds of trucks or the equivalent in railroad cars must be moved in and out every day to bring in the beans and ship out the products.

The greatest consideration from a technical standpoint, involving equipment specifications, is to buy the very best quality and most dependable equipment available because a breakdown in any one item of equipment necessitates a complete plant shutdown. It is worth many hundreds of thousands of dollars of extra expense to ensure reliable operation. Many years ago, if a single conveyor broke down, a man with a shovel could keep the material moving temporarily until a repair was made, but in these large plants there is no possibility of operating if the material cannot be moved through to final storage and shipping. Mill managers used to value storage capacity for products to give them flexibility in markets; but most of these large plants have very small product storage facilities compared to their production, since any reasonable size of storage would be filled up so rapidly that it would give no worthwhile relief from the necessity of shipping each day.

The economic justification of these plants is impressive. Operating costs per ton are less as the plant size increases. A very accurate rule of thumb is that a new plant's capacity can be doubled for only a 50% increase in installed cost of the processing equipment. One operator can handle a 3,000 TPD plant as easily as a 1,000 TPD plant with the help of the automatic controls which are standard with such plants. The only limits on size involve availability of beans and markets for the products. We engineers will build bigger and bigger as long as the commercial managers can secure the raw material and dispose of the products.

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