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Extraction Methods for Drying Oils

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This paper presents a general discussion of the methods of obtaining drying oils from oil-bearing materials from the view-point of processes, equipment, problems encountered, and cost considerations. As a general discussion, it is intended to serve as an introduction to the industry for young engineers and for people whose main interests lie in allied fields or nonengineering aspects of the industry. A number of combinations of the three basic methods, namely, solvent extraction, mechanical pressing, and hydraulic pressing, are discussed.

Centuries ago the Chinese carried out crushing by grinding under an edgestone and pressing in a wedge press; the wedges were driven in manually by hammering. The first step in modern processing came with the development of the hydraulic press in England in 1795. In the United States recorded history began about 1826 in Columbia, S. C., where a man named Waring operated hydraulic presses on flaxseed, sesame, and cottonseed. Linseed oil was his first product and the main reason for the existence of the mill.

The next significant step was the introduction of the continuous mechanical-pressing system. This reduced the investment required for larger capacities and oil recovered above a certain minimum. Solvent extraction followed in the United States on soybeans, which made economical very-large-capacity installations and more complete oil recovery. A natural consequence was the introduction of the combination of the two, the prepress system.

Extraction Methods

Oil is normally obtained from oil-bearing materials by one of three basic methods or combinations and variations of these. All these methods involve a physical separation of the oil from the remainder of the material rather than a chemical type of reaction in which one or all of the components loses its chemical identity. The three basic methods consist of a batch hydraulic-pressing in which the oil is squeezed out by exerting pressure on a mass of the oil-bearing material hydraulically; a continuous mechanical-pressing in which the material is conveyed (or extruded) through a gradually decreasing aperture and the oil is squeezed out by the resulting pressure; and solvent extraction in which the oil is taken into solution in a solvent, the solution is separated physically from the insoluble solids, and the oil is recovered from the solvent solution.

The most common systems in use on drying oils are continuous direct solvent-extraction; continuous mechanical pressing and continuous solvent-extraction (prepress process); continuous mechanical pressing (screw press or expeller process); batch hydraulic pressing plus batch solvent-extraction; batch hydraulic pressing; and batch solvent-extraction. These are approximately arranged in the order of commercial importance in the United States today. However the order is contingent upon the fact that indirectly soybean oil is a drying oil through modification. If not, continuous direct solvent-extraction is of minor importance. Several other combinations are possible and possibly even economically feasible (such as batch hydraulic pressing plus continuous solvent-extraction in the case of castor beans) but have not, as yet, found significant commercial usage.

Continuous Direct Solvent-Extraction. In this type of operation the raw material is first subjected to a cleaning operation to remove trash, stones, stems and leaves, and other foreign material which would impair operations, damage machinery, or affect product quality. This is usually followed by some means of holding a small supply of cleaned material and measuring and feeding it to the process. The next two steps involve size reduction, in order to reduce the dissolving time, and conditioning, in order to affect this size reduction without making an excessive amount of fine material. As in the case of soybean processing, these may be divided into two size-reduction operations with the conditioning intermediate. The prepared material is then extracted in a countercurrent manner (or some approach to it) with oil-free solvent. Fresh material is put in contact with solution (miscella), and the spent material leaves the extraction unit after being washed with oil-free solvent. The solution of oil in the solvent, after being completely separated from the residue solids, is then stripped of the solvent by boiling off the greater part by means of indirect steam heating, followed by open steam-sparging at elevated temperatures or under reduced pressure. Solvent is recovered from the solids by either direct or indirect steam-heating or a combination of both.

Figure 1 illustrates a continuous direct solvent-extraction operation through a simplified flowsheet for processing soybeans. In this case, as in the case of most of the oil-bearing materials, the solid residue is of importance also since it contains a valuable source of protein. Accordingly the extracted solid residue is carefully sized through screening and grinding to pro-

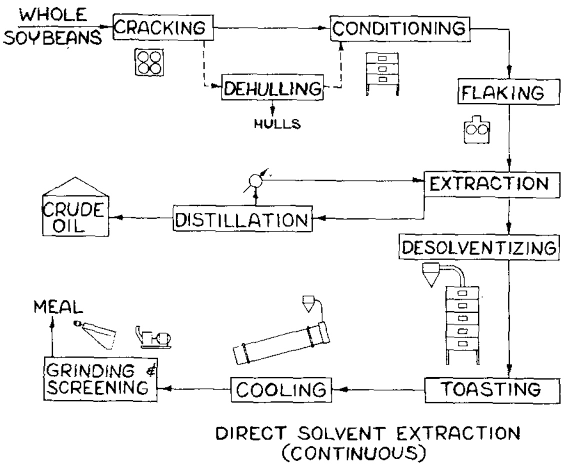

FIG. 1. Continuous solvent-extraction of soybeans.

duce soybean oil meal. Prior to sizing, soybean oil meal is toasted (prolonged heating with a hot surface in the presence of moisture) is order to improve its nutritive value when used as animal feed.

Continuous Mechanical Pressing. As in the preceding method, a preliminary cleaning usually comprises the first step. The whole seed is then subjected to a size reduction, followed by a conditioning or cooking operation to facilitate removal of the oil by subsequent pressing with a minimum of fine solids in the oil. In the pressing step the material is subjected to gradually increased pressure as it is forced through the press, and the oil drains laterally from the material. The cake discharging from the press is then cooled, ground, and bagged or stored in bulk. The oil is collected in troughs and flows to a settling, or "screenings," tank in which the coarser particles of solids ("foots") are settled out of the oil. The final traces of fines or solids are then removed from the oil by filtration. The foots and filter cake are then either returned to the system ahead of the presses or pressed separately to remove entrained oil. The normal flow for this process is illustrated in Figure 5 and the first half of Figure 2.

Although completely continuous (except for handling the filter cake), mechanical pressing is characterized as a "multiple unit" type of installation as contrasted to continuous solvent-extraction. In other words, larger capacities are obtained by adding additional presses because of the existence of an economical limit on the capacity that can be built into one press. Maintenance is relatively high on this operation as well as power consumption because of the high pressures involved. Percentage of oil recovery is intermediate between hydraulic pressing and solvent extraction.

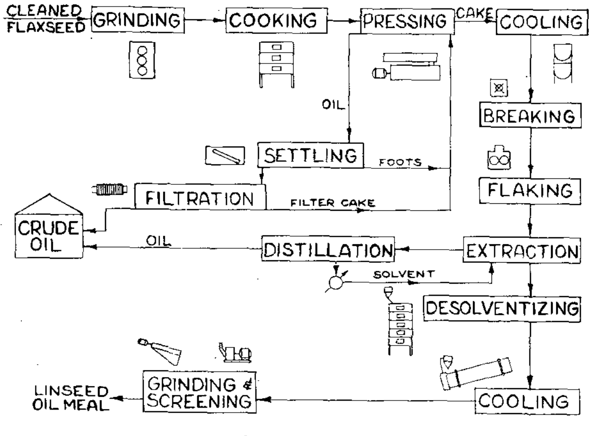

FIG. 2. Mechanical prepressing, followed by continuous solvent-extraction.

Prepress Extraction (continuous mechanical pressing, followed by continuous solvent-extraction). The process is simply a combination of the two previously discussed with some modifications. The mechanical pressing is usually carried through the same steps as above but at higher through-puts per machine and reduced pressures. Where straight mechanical pressing strives for low residual oil content in the cake (*e.g.*, below 4% on flaxseed) a prepress operation is usually carried out to produce cake to feed to extraction with a residual ranging from 10% to 20%. The remainder of the oil is then obtained by subjecting the cake to the solvent-extraction process described above. However in some cases, particularly cottonseed processing, the subsequent size-reduction step is simplified, and granulated cake is fed to the extractor without flaking. Figure 2 illustrates the prepress process.

Prepressing is characterized primarily by ease of operation. The pressing operation is not critical since the oil remaining will be recovered in the subsequent solvent-extraction. The cake produced in the prepressing is relatively very easy to extract and handle so that the solvent-extraction operation is less critical than in the case of direct extraction. The decrease in power required for prepressing as compared to straight pressing will balance the power gained by adding the solvent-extraction operation. Investment is actually higher than for a direct operation, but this is somewhat softened by the suitability and use of used presses as prepresses.

Batch Hydraulic-Pressing. Preliminary cleaning is the first step in this process as in the others. The cleaned material is subjected to size reduction and then cooking or conditioning. The rolled, cooked material is then manually loaded into the presses. In the case of the box press the material is formed in a cake former externally while, in the cage press, the material is automatically spread in layers within the press. Pressure is then applied to force the oil from the material. Assuming that the preparation is constant and the rate of pressure application is satisfactory, the residual oil in the cake is determined by the drainage time allowed. The pressed cake is removed manually. Box-press processed cake is then trimmed to remove the soft edges, which are recycled to the presses or processed separately to recover the excess oil. The oil is usually settled and filtered, and the cake is either sold as slab or ground for meal. The pressing portion of Figure 3 outlines the process flow.

This type of processing has virtually disappeared in the United States for drying-oil recovery except as a prepressing operation on castor beans. In the nondrying oil field a significant amount of cottonseed is still processed this way, but that is rapidly diminishing as well. The process is characterized by very high labor costs per unit through-put, low production rates, and higher oil losses to the cake (5% and up) than the other methods. The operation is extremely simple and is carried out by common labor.

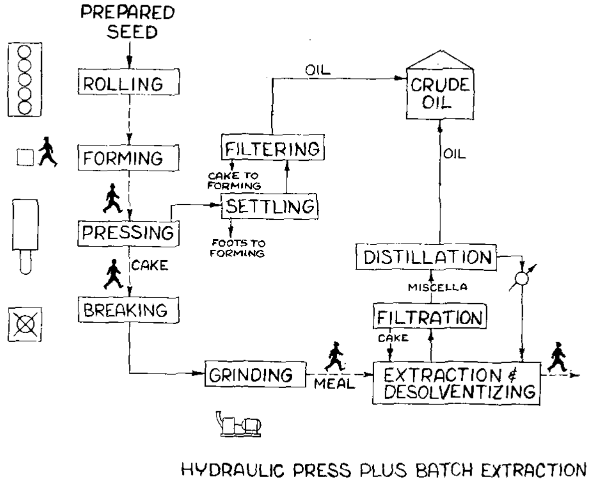

FIG. 3. Hydraulic pressing, followed by batch solvent-extraction.

Batch Hydraulic-Pressing plus Batch Extraction. This is a combination of the operation just described plus a batch extraction-processing to recover additional oil from the cake (Figure 4). An unusual incentive for this pecular combination exists in that, by keeping the oil from each process separate, two distinct grades are produced. This is particularly desirable in the case of castor with its diverse markets. Batch extraction will be described in more detail later. Essentially it consists of the same steps followed in the continuous system but carried out in a relatively fewer number of machines since several steps are normally carried out in the same piece of equipment. The character of the pressing portion is the same as for the batch hydraulic pressing. The subsequent batch-extraction is characterized by higher labor per unit processed and generally higher solvent and utilities (steam particularly) required per unit. Again this is applied usually to smaller capacities and, with one exception, has suffered the same fate as the hydraulic press.

Batch Solvent-Extraction. Figure 4 illustrates one type of batch-extraction system. As in all recovery operations, the processing begins with a preliminary cleaning, followed by preparation including size reduction. Batches of the prepared material are then loaded into the extraction vessel where it is steeped, washed, and drained. The solution of oil in the solvent is then subjected to separation by distillation and stripping (after filtration) in one piece of equipment. Removal of the residual solvent from the solids frequently is carried out in the same vessel as is the extraction.

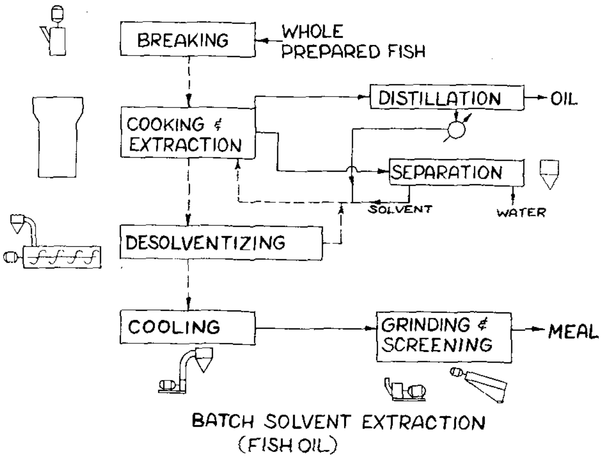

FIG. 4. Batch solvent-extraction of fish.

This operation's characteristics are as outlined for the batch extraction of cake above. The simplified basic difference between the batch extraction and continuous extraction is that solids are physically carried through a continuous system while they remain stationary in a batch system and the desired effect is obtained by control of liquid movement.

Drying Oil Recovery

This section of the paper discusses the application of the methods described previously to the recovery of the more common drying oils.

Linseed Oil. From a strictly drying oil viewpoint the recovery of linseed oil from flaxseed is the most widespread of any of the recovery operations. Soybean oil extraction is much more prevalent, but only a portion of the oil finds its way into the drying oil market so we will consider this operation a less important one.

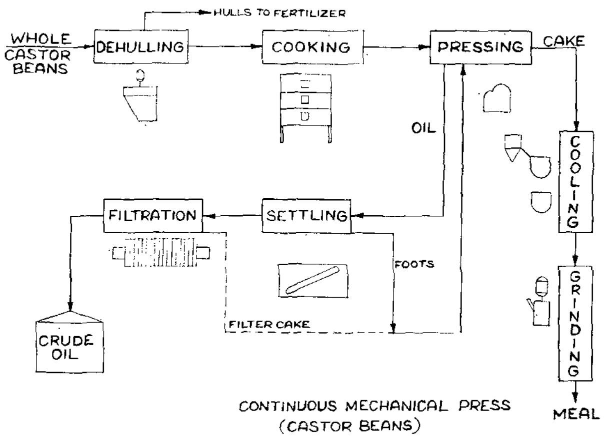

FIG. 5. Continuous mechanical pressing.

The recovery of linseed oil from flaxseed is complicated by two major problems. The first of these is the intermediately high oil content of the material. This complicates the recovery in several ways: conventional preparation methods are made difficult by oil exuding to the surface and, through sticking, preventing the production of discrete particles (direct solvent-extraction); the extracted material is extremely fragile and gives rise to fines in the miscella and dust problems (direct solvent-extraction); mechanical expression of the oil tends to carry considerable fine solids with the oil; and handling and conveying continuously are made more difficult, in general, by the tendency to stick. The high oil problem is made even more important by the relatively poor extraction characteristics of flaxseed. Possibly because of the small size of the seed, it must be reduced to a very small particle size, subjected to more shearing action, or both, in order to be able to extract the oil with solvent in a practical length of time or to express the oil with a reasonable pressure for a practical length of time. Again the tendency is toward the production of an excessive amount of fine material.

The greater portion of the flaxseed in this country is processed by means of the prepress extraction process described previously and illustrated (Figure 2). The initial rolling operation begins the successive size-reductions and readies the seed for the subsequent cooking operation. This is included to aid in coagulating the protein (''fines'' reduction) and to facilitate the prepressing step. The prepressing step *via* continuous mechanical pressing not only completes the solution of the ''fines'' (high oil) problem through compactness but also aids the solution of the extraction problem through its shearing and oil-cell rupturing action. As a final step in solving the problem of difficult extraction, the prepress cake is subjected to conventional soybean preparation like that used for direct solvent-extraction; *i.e.*, cracking, conditioning, and flaking. As an indication of the seriousness of the problem, it should be pointed out that certain other prepress cakes (such as cottonseed) may be extracted directly without this expensive step because of their greater ease of extraction. In some cases whole flax (after drying) is fed to the prepresses. When this is done, the pressing capacity per machine is greatly reduced in order to get the desired results. The resulting prepress oil (cold-pressed) has advantageous properties for some uses.

A portion of the linseed oil production in the United States is still obtained by straight continuous mechanical-pressing, which is similar to the first prepressing operation described above but carried out at higher pressures and reduced through-put per machine. Hydraulic batch-pressing has virtually disappeared although all linseed oil was originally obtained in this manner. One plant employing a direct continuous extraction-process was built about 10 years ago, operated initially on castor beans and, until recently, on flaxseed. In this case the solution to the problem was very fine grinding plus equipment (centrifuges) designed to handle the fines. It is the author's understanding that this plant has been, or is being converted to a prepress conventional continuous solvent-extraction system, probably because the centrifuge type plant is less economical at the larger capacities.

As an interesting sidelight there is a characteristic of flaxseed which presents a problem while it is advantageous in conveying and handling. The tendency of flaxseed to ''flow like water'' (it has an extremely low angle of repose) necessitates that the seed be stored in silos or vertical tanks. Any dense object, such as a man, falling into such a tank of seed will rapidly sink to the bottom and precautions must be taken to avoid accidents since suffocation can easily result from a fall into a bin of raw flaxseed.

Soybean Oil. A substantial quantity of soybean oil finds its way ultimately into drying oil markets. The residue from the extraction of oil from soybeans is one of the primary sources of protein for animal feeding, and one of the primary problems involves producing a satisfactory residue. Enzymes occur in the beans, which must be destroyed in order to enhance the nutritive value of the extracted residue. Otherwise soybeans seem to be ideally suited for solvent extraction and, though problems exist, the solutions are readily available in direct continuous solvent-extraction.

Continuous mechanical pressing is still used to a limited extent in the recovery of soybean oil. This operation is similar to that already described on flaxseed except that the beans are just cracked in corrugated rolls, and the cooking is much less severe. The destruction of the enzymes is accomplished primarily by the high temperatures generated during the pressing operation; there is some reduction during the preliminary conditioning. Abrasion from the hulls is one of the problems encountered which leads to high maintenance on the presses. The most common solution to this is the stocking of spare parts and setting a regular replacement schedule.

From the view-point of the quantity of beans processed, practically all of the soybean oil is obtained by direct continuous solvent-extraction (Figure 1). The enzyme problem in this case is handled by cooking or ''toasting'' of the extracted solids residue. The most popular method combines the removal of the solvent from the solids with the subsequent toasting. In this system the temperatures used are much lower than those used in mechanical pressing since advantage is taken of the considerable effect of high moisture content during toasting and elapsed time during toasting. The problem of dust production has been alleviated in this system as well since the high moisture tends to toughen the solids as well as agglomerate the fines already in existence. One incidental solution to the abrasion and excessive wear problems has been accrued as a side benefit in the production of ''50% meal.'' More or less complete removal of the hulls is required to make this product, and these are processed separately so that the abrasion is confined to this system rather than spread through the extraction plant.

Castor Oil. The recovery of castor oil is an interesting subject since the problems are so numerous and varied and the extraction methods are varied as a consequence. Castor-bean processing has the ''high oil'' problem amplified since the beans have an unusually high oil content. In addition, the hulls are extremely abrasive so that this problem is very significant, especially compared to flaxseed. An extremely difficult problem from an operating view-point exists in the toxic nature of the products. A large majority of people are subject to extreme respiratory reaction to the dust from the extracted solids. Since oil quality is affected by processing conditions, the solutions which may be applied to the problems are influenced by their potential effect on the oil.

The greater part of the oil recovered in the United States is extracted by a combination of batch hydraulic pressing (yielding a very high quality oil) followed by batch solvent-extraction. The batch hydraulic pressing is carried out in the cage type of presses where the meats are positively confined to minimize solids carry-out with the oil. Since low temperatures are maintained, hull removal is not essential. The pressing operation results in a cake which can then be handled in the solvent-extraction system. In the past a certain amount of oil has been produced in continuous mechanical presses, but extremely high maintenance costs were involved because of the presence of the hulls which were required to retain substance in the solids and avoid making a paste with pressure. A newer development by the V. D. Anderson Company involves a special preparation of dehulled meats (cooking and drying) which permits their processing in a continuous mechanical-pressing operation (Figure 6). No installations are in existence in the United States to the writer's knowledge, but a plant is reported to be operating successfully overseas. As previously mentioned, a direct solvent-extraction plant was built and operated for approximately one

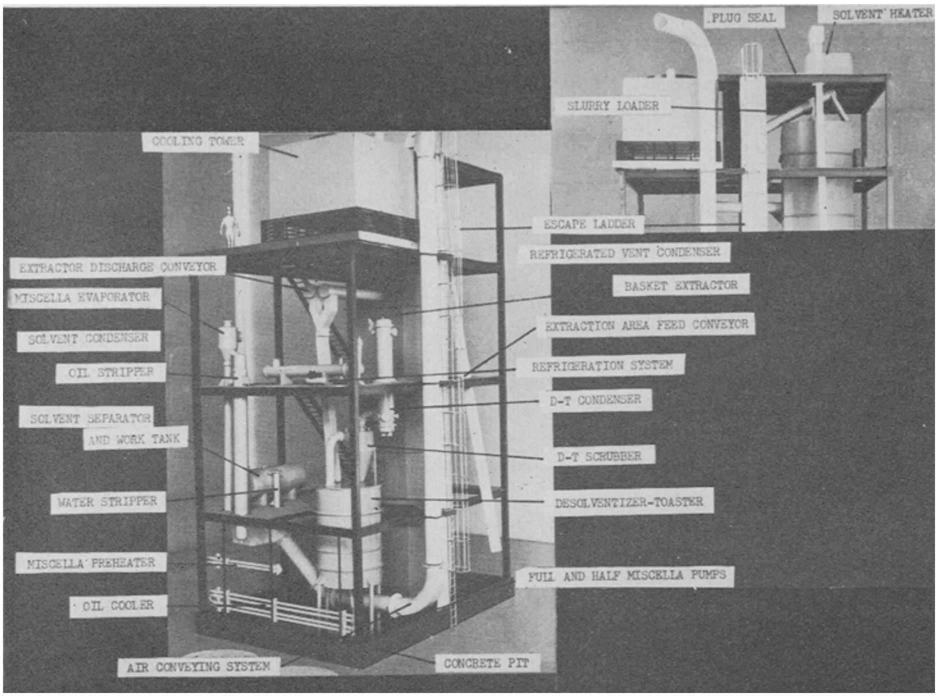

FIG. 6. Continuous-extraction plant (model).

year with some degree of success but was discontinued in favor of a flaxseed operation.

The batch system minimizes the abrasion problem through manual handling while the Anderson solution is hull removal. The dehulling operation is far from satisfactory as a continuous process because of the sticky, oily nature of the meats but is workable with periodic clean-outs. The allergy problem has been met only by careful screening of operating personnel and precautions in plant design to keep the amount of dust to a reasonable level and to provide for its efficient collection.

Tung Oil. Tung oil recovery has associated with it the usual "high oil" problems, but in this case it is not complicated with the hull problem common to castor processing. One unusual problem involves the tendency of the oil to solidify through the formation of an isomer under certain conditions probably catalyzed by the presence of direct light.

With one exception tung oil is extracted in the United States by the continuous mechanical-pressing method. One plant combines this with continuous solvent extraction (prepress process) so that the prepressing is the solution to the "high oil" problem. Normal solvent-recovery systems which are totally enclosed in any event handle the isomerization problem.

Safflower Oil. This is mentioned because it is relatively new (in any quantity) in the United States. Processing has been largely confined to continuous mechanical pressing and prepressing (continuous mechanical pressing followed by continuous solvent-extraction). The problems encountered in addition to those encountered in flaxseed processing are centered in the removal of the hulls. If not decorticated, the residue solids have a limited market because of their high fiber content, and abrasion difficulties are encountered. Obviously a good dehulling process answers the main problems.

Fish Oil. Fish oil is normally obtained as a by-product of normal fish-dewatering processing to make feed supplements. Mechanical continuous pressing is employed to remove water and oil, and the oil is then separated from the stickwater. The high water content precludes use of the normal solvent-extraction processes or separate mechanical recovery of the oil alone. Figure 5 illustrates a batch solvent-extraction process (Ezra Levin Enterprises Inc.), which removes the water azetropically while extracting the oil as a solution to the problem. One such full-scale plant is presently in operation.

Other Drying Oils. Several other drying oil-containing materials are not discussed (such as perilla and oiticica) since they are rarely processed in this country. The oil itself is imported. Tall oil is used as a less expensive drying oil in significant quantity but is not discussed in detail since its recovery is a simple separation of a by-product of sulfate pulping.

Unit Operations in Oil Recovery. The various steps in the recovery processes described previously can be conveniently grouped into similar operations and equipment. These groups are discussed briefly in the following section.

Cleaning. This operation will vary with the type of raw material. Essentially it consists of the removal of light chaff, small foreign seeds, tramp metal, sand, and stones by screening, air aspiration, magnets, gravity tables, and combinations of these.

Size Reduction. This is an extensive subject and one of the most important operations. To avoid unnecessary complications, this operation is discussed in terms of the general types of equipment used for the purpose.

1. *Cracking.* Reduction to a coarse granular state, known as cracking or granulation, is usually carried out in roller mills fed vertically. The rolls are corrugated so that the action is a cutting one rather than grinding or shredding. It is used to prepare soybeans for conditioning and prepress cakes for direct extraction (primarily cottonseed) or for conditioning. Usually two pair or more of rolls are used so that the reduction is gradual.

2. *Rolling.* This is actually a form of grinding since the material is subjected to a series of reductions without size separation by passing downward through a number of smooth rolls (usually 3 or 5) fed laterally. These are used to prepare flaxseed and similar materials for continuous mechanical recovery or for prepressing.
3. *Flaking.* Flaking consists of rolling the cracked material or whole particles into thin (usually .005 to .020 in. in thickness) sheets known as flakes. This is done by passing the material through a pair of smooth rolls fed vertically and held close together under substantial pressure. This operation is used to prepare cracked soybeans and most press cakes for solvent extraction.
4. *Grinding.* This operation is carried out in the conventional size of reduction equipment such as hammermills and attrition mills. Its primary use is in sizing the solids residue into meal for animal feeds but it has been used occasionally as preparation for recovery.

Conditioning. This operation could more properly be called tempering since, when properly done, it consists of adjusting the temperature and moisture content to desired levels and then holding these conditions for a sufficient time to insure uniformity. Using mild conditions, this operation is employed to condition soybeans and prepress cakes for flaking so that a minimum of fines are produced and the power required is not excessive. More severe conditions are used for "cooking" or "crisping" to prepare flaxseed, castor, tung, and similar materials for continuous mechanical pressing or hydraulic pressing. The conditioning is usually carried out in steam tube driers (where moisture reduction is a problem) or stack type cookers, or ideally a combination of both.

Hydraulic Pressing. This operation in essence consists of placing batches of the material, surrounded by cloth or similar substance, into containers; slowly subjecting these "cakes" to very high pressures hydraulically; holding the material under pressure to permit maximum oil drainage; and removing the pressed solids in the form of a hard, dense slab. For intermediate oil content materials (high, but not as high as castor and similar materials) such as flaxseed, a box type of press has been used in which the cakes are prepared outside of the press in a former. Then the boxes are loaded into the press. The higher-oil-content materials, such as castor, must be better confined and require a cage type of press. In the latter the material is loaded directly into the press, and the cakes are formed in the cage, using metal plates to separate cakes along with the cloths. The cage press makes a round cake with less "trim" or soft area to be recycled.

Mechanical Pressing. Two common types of equipment are used for continuous mechanical pressing in the United States. These are the Anderson "Expeller" and the French Screw Press. The machines are very similar in principle, differing primarily in physical features and methods of accomplishing the same thing. Both apply the hydraulic press principle of an initial lower pressure (feed section), followed by the high pressure, but the Anderson Expeller feed screw is normally set at right angles to the main shaft while the French press has straight-line flow. Again, both employ barrel and shaft cooling to aid in dissipating the heat generated by friction, but the French machine uses water while the Anderson circulates a portion of the oil being recovered through a cooler and back to the machine where it is used for cooling. Since a great deal has been written regarding this operation, we will not go into any greater detail at this time.

Solvent Extraction. From a strictly technical point of view this is a leaching operation, and the main problems involve separation of the liquid phase from the solid phase, providing efficient contact and providing sufficient time for the extraction to take place. Again the literature contains considerable material on the various extractors available in the United States so we shall avoid too much detail in our discussion. Extractors fall into three classes, *i.e.,* percolation, in which the solvent flows by gravity through a bed of solids; immersion, in which the solids are immersed in the liquid; and extractors which are combinations of the above. The immersion type is rapidly being replaced in this country by the other two, primarily by the percolation type. The two principal disadvantages of the immersion type are the limitation on the concentration of solution (miscella) obtainable because of the tendency to float fine solids and even flakes and the need for an auxiliary separation and handling of the fines which are carried out with the miscella. The inherent advantage of small size through high efficiency is more than overcome by the disadvantages mentioned. Through recirculation of miscella within the percolation type extractor, both increased miscella concentrations and relatively clear miscellas are posble. In addition, the percolation type usually incorporates much better drainage of liquid from the spent solids which further decreases steam requirements for solvent recovery (increased miscella concentrations also do this). Recirculation also aids in making the percolation type approach the immersion type in efficiency and consequently reduces the size. The classic example of the percolation type of extractor is the vertical basket (or Bollman type) which was originated in Germany and adapted in the United States by several manufacturers of equipment. The largest number is produced by French Oil Mill Machinery Company along with their rectangular and horizontal basket extractors. Essentially the solids are carried through successive washes with decreasingly concentrated miscella in baskets with perforated bottoms rotating around a horizontal axis. Characteristic of these extractors is their relatively large size. Figure 6 illustrates the use of a vertical basket extractor in a continuous solvent-extraction installation. The photograph actually shows a scale model which was used by our company in the design and construction of a recent extraction plant. The layout presented extremely difficult problems, and the urgency for getting the plant completed and in operation was great. The model proved to be invaluable in getting the job done quickly and getting the best possible arrangement of equipment from an operating and safety view-point.

Another class of percolation extractors is headed by the Blaw-Knox Rotocel. This extractor operates on the same principle except that the baskets (or cells in this case) rotate around a vertical axis. Since the cells are adjoining, this extractor is characteristically smaller than the basket type. Figure 7 is an artist's conception of the Rotocel. A traveling-belt type of horizontal extractor has found limited use in the United States (DeSmet-Belgium). The immersion type of extractors in use in the United States are in operation primarily in the smaller sizes. These include the column type as manufactured by V. D. Anderson and Allis-Chalmers, in which the solids travel downward through the column by gravity with fresh solvent pumped into the bottom and miscella overflowing the top. A number of Iowa State extractors manufactured by Crown Iron Works are in service in small capacities. In this kind the solids are conveyed coun-

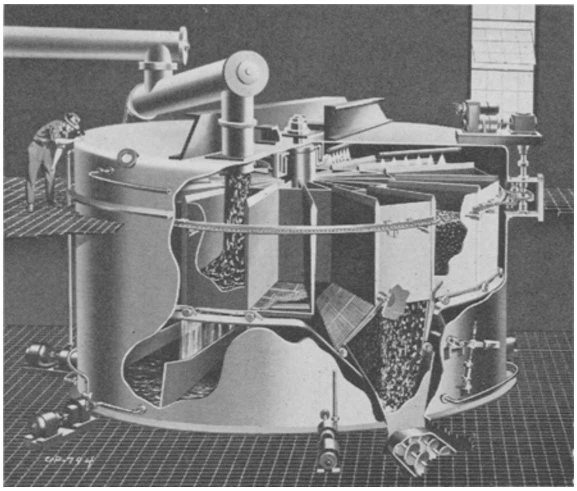

Fig. 7. Rotocel extractor.

tercurrently through a stream of solvent in a small casing, using *en masse* type of flighting. The U.S.D.A. extractor (Southern Regional Laboratory, available through Wurster and Sanger) is used in two plants on cottonseed and consists of an immersion step, followed by washing in a rotary continuous filter. A number of other extractors exist and have been used but are simply variations of the basic types already described or are no longer in use.

Oil Recovery. In the case of mechanical and hydraulic pressing, the operations consist of clarification, usually comprising settling, followed by filtration in a plate and frame type filter (Figure 8 shows a settling tank with mechanical sediment removal), and cooling (usually with water in a shell and tube exchanger).

Oil recovery in the case of solvent extraction is more complicated since the solvent present must be removed completely. Clarification may or may not be required, depending on type of extractor, type of distillation equipment, and end-use of the oil. The bulk of the solvent is usually removed in the tubular type of vertical evaporators heated indirectly by steam usually at atmospheric pressure. The final traces of solvent are removed countercurrent, stripping the oil with direct steam, usually under vacuum. Good contact of the oil with the stripping steam is insured by using a column containing packaging and bubble caps, or discs and donuts. As above, cooling is sometimes included, following the stripping. New developments in this operation, and the solids desolventizing described below, have comprised the more radical improvements in processing which have been made in the past few years. These improvements have resulted in radically reduced consumption of utilities.

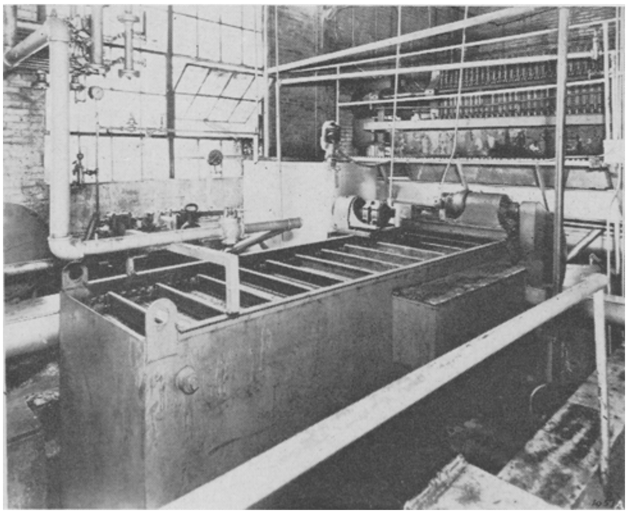

Fig. 8. Screening tank.

Solids Desolventizing. This operation is limited to the solvent-extraction processes. The older equipment and processes employed indirect steam heat or superheated vapor to remove the bulk of the solvent, followed by steam sparging to remove the remainder of the solvent and solvent vapor. The most popular method at present (especially applied to soybean processing) involves the application of direct steam to the solvent wet solids, followed by drying with a heated surface. Two incentives exist for using this method. The first is that it is positive and insures complete removal of solvent under practically all conditions. The second concerns toasting of the solids for subsequent animal feeds, and this system provides for an extremely desirable product from the viewpoint of color density and granular nature. The equipment used for this is an adaptation of the old vertical stack type of cooker as manufactured by Davidson-Kennedy Company and French for many years. Figure 9 shows one type of D-K desolventizing and toasting vessel. Desolventizing essentially takes place in the top compartment.

Materials Handling. This operation is extremely important in the continuous processes. The liquid-handling problems are not particularly unusual except that the presence of a small amount of solids in the recycle miscellas do dictate certain precautions in selecting proper pumps.

The solids-handling equipment proves to be a substantial portion of any solvent-extraction plant and to a more limited extent in the continuous mechanical pressing. The problems are excessive breakage, plugging, and abrasion. At points where minimum breakage is important *en masse* type of conveyors are used. Screw conveyors are used extensively where breakage is not important; however they are over-sized to run slowly when the solids contain solvent and a sealing problem exists. Pneumatic conveying (sometimes combined with cooling) is used extensively on extracted solids, hulls, and similar streams. Belt conveyors are frequently used on the raw material, especially where long runs are involved. Nearly all of the available types of conveying equipment have found at least limited use in the industry. Abrasion and corrosion are usually handled by extra heavy construction, stainless steel, and occasionally rubber lining.

Cooling and Drying. Equipment used for this service falls into two general classes, *i.e.,* rotary and stationary. Rotary equipment employs a horizonal rotating element (usually the shell), which is used for both agitation (for contacting the solids with air or heated surface) and for conveying. In general appearance it resembles a cement kiln. It has an advantage in cooling in that a countercurrent air flow can be used so that lower solids temperatures can be realized.

Stationary equipment is usually less expensive but has higher operating cost because of fuel use efficiency. It is primarily used in seed drying for storage, cake cooling, and pellet cooling.

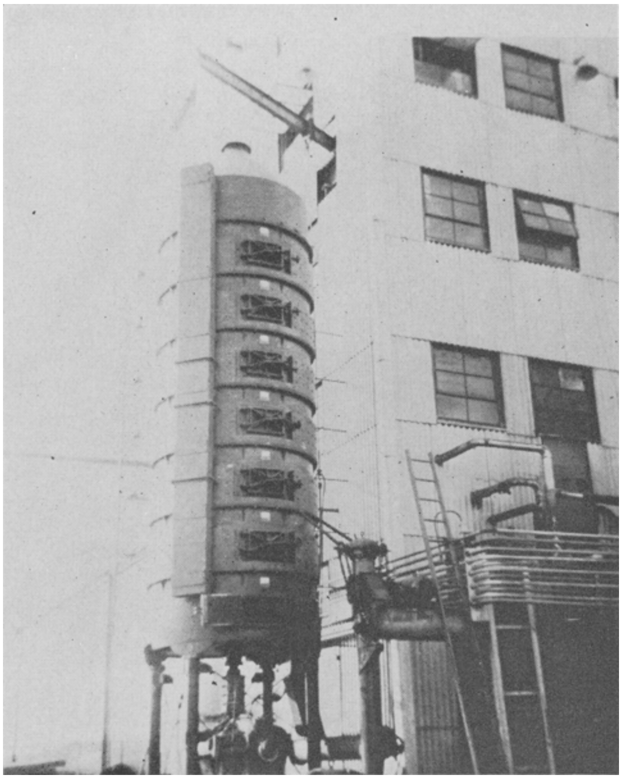

FIG. 9. Desolventizing and toasting unit.

Economic Considerations

The following describes briefly some of the major economic considerations connected with drying oil recovery. No attempt is made to give specific figures since the situation varies so widely with each type of material, plant location, plant design, plant capacity, and a number of other factors.

Manufacturing Costs. As in most process type of plants one of the major items of manufacturing cost is the fixed charges, including such things as taxes, insurance, interest charges on investment, and depreciation or amortization, which are all proportional to investment. In small plants mechanical pressing has the lowest investment, followed by hydraulic pressing and then solvent extraction. As the capacity of the installation increases, the order reverses until solvent extraction has the lowest investment per unit of processing capacity in large plants.

The labor required is much higher for hydraulic pressing than continuous mechanical pressing or continuous solvent-extraction regardless of capacity. Batch solvent-extraction has a higher labor requirement than either continuous process. In very large capacities, continuous solvent-extraction would have a lower labor requirement than any other process.

Electric power requirements are generally lower for solvent extraction than for either method of pressing. Steam and cooling water requirements are somewhat higher for solvent extraction than for the others. Solvent usage, through losses, is a significant item of cost in solvent extraction and, of course, is not present in the others.

Maintenance costs are generally higher for pressing than for solvent extraction. They are a very significant factor in continuous mechanical pressing although greatly reduced when the presses are used in prepressing.

Factors Influencing Profit. Since investment (and fixed charges) do not increase directly with plant capacity, larger installations are usually more profitable. This is especially true of continuous solvent-extraction, more so than for pressing. The labor required (except for hydraulic pressing) likewise does not increase very rapidly, which also tends to increase the profitability of a larger installation.

Raw material costs are generally beyond the processor's control except for selecting plant location properly and extending his operation into such things as storage elevator operation. Since large quantities of solids are involved, freight considerations (on products as well as raw material) are important.

Product upgrading is available to the processor to increase his profit. The increased oil obtained by the solvent-extraction process effectively does this since oil is usually worth more than meal or cake. The production of 50% meal or industrial protein in the soybean industry is another example.

Marketing methods may have a considerable effect. Processing by a raw-material supplier or a consumer usually is more profitable than an isolated operation. This is especially true where the two plants can be located together to save handling and share utilities and overhead costs.

Recent developments have made substantial reductions possible in steam and cooling water possible in solvent-extraction plants. Since utilities and solvent loss are such a substantial portion of the operating costs, it is important that these be kept at the proper level through careful operation and improved equipment.

Summary

The general trend in the industry is toward solvent-extraction recovery and to larger plants. Technological change in recent years has been largely in improved equipment and process improvements to decrease operating costs and improve product quality. It is the author's opinion that the trend mentioned above and this type of technological change will continue in at least the near future. It is expected that any radical change in processing will come about only by a radical change in raw material or products desired rather than by the development of really new equipment or process methods. One interesting development in recent years is the increasing relative importance of the residue solids compared to the oil in the case of some of the materials. Plants have been built primarily as a source of protein rather than oil in certain cases. It also accounts for the incidence of some small plants in the raw material "fringe" areas contrary to the general trend.