Cottonseed Preparation

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ABSTRACT AND SUMMARY

Conventional methods of cottonseed preparation are reviewed and described, including seed cleaning, saw delinting, dehulling, conditioning, and flaking. The use of screw presses for prepress conditioning ahead of solvent extraction is discussed as compared to conditioning for direct solvent extraction. Newer methods and proposed alternate methods of cottonseed preparation are discussed including: abrasive delinting, acid delinting by gas and liquid acid, and the decorticating of undelinted seed. The effect of cracking rolls, moisture addition, moist cooking and flaking on gossypol gland rupture, the binding of gossypol to protein, and the effect of these processing or preparation variables on the residual oil in the extracted meal and on the oil quality are discussed.

INTRODUCTION

The processing of cottonseed involves four or five times as many preparation steps as does that of soybeans, and these extra steps cause at least double the total crushing expense of cottonseed as compared to soybeans. Since the beginning of cottonseed oil milling about 100 yr ago, a great many improvements have been made in the extraction of oil; however, there has been very little change in the basic principles of seed cleaning, delinting, and dehulling of cottonseed within the past 75 yr.

SEED CLEANING

The development of mechanically harvested cotton in conjunction with high capacity gins has raised the average trash content of cottonseed from ca. 1% to from 3 to 4% in some areas. A commonly used cleaner consists of shaker trays with double screens designed to remove large trash on the upper screen and dirt and fines through the lower screen. Upper and lower fan hoods aid by suction in trash removal; however, under best conditions it is possible to remove only 95% of the dirt and fines, 40% of the sticks, and 60% of the bolls and other trash for an average of 60% of total trash removed (1). Attempts to increase the efficiency by adjusting either the screen size or the air aspiration usually have resulted in the loss of seed with the trash fraction, due to ca. 40% of the trash fraction being about the size or density of a cottonseed. Poor cleaning results in prematurely dull linter saws, danger of fire from sparks, and lowered linter quality (2).

SAW DELINTING

Cottonseed as it leaves the gin still has ca. 10% cotton lint remaining on the seed. This is partially removed in two or more saw delinting cuts that are similar to ginning. About 2½% lint is left on the seed as an aid in the separation of hulls from the meats. The first cut linters, about one fourth of the total weight of linters, are the longer tufts or fibers and are used in the manufacture of yarns or battings for mattresses and upholstery. The second cut linters are very short fibers and are called chemical linters. They are used for cellulose products competing with wood pulp.

The saw-linter, similar to the cotton gin, is almost identical in principle to the delinting machinery that was used in the first oil mill ever built (3). There have been improvements in mechanical design and in driving mechanism, but the process is essentially the same. Most linters have either 141 or 176 saw discs of 12-5/8 in. diameter on a cylinder with spacers between the saws that just allow a cottonseed to fall through between the saw discs. A feeder above the linter drops a uniform feed of seed into the saw cylinder, with a gratefall containing a series of ribs to guide the seed down through the saw cylinder past the rake that keeps seed from riding over, and out the bottom front of the linter into a conveyor below. Lint is removed from the saw teeth on the back side of the cylinder either with a brush cylinder or doffed by air from the saw teeth into an air stream. The lint usually passes through a moting box and a beater to help remove trash and hull pepper and then on to the bale press room for baling and storage.

The saw cylinders must be removed from the linter to sharpen the saw teeth every 8 to 36 hr, depending on the trash content of the seed and on the closeness of the cut. First cut linters do not need sharpening as often as second cut linters do. Sharpening is done on a machine such as the Truline gummer or other filing machine. The gummers or files move automatically from tooth to tooth. Extra saw cylinders are necessary to avoid waiting for a saw cylinder to be sharpened. Unless damaged, a saw disc may be sharpened from 12-5/8 in. to 11½ in. diameter or up to 280 times before replacement.

Since most lint movement is by air, a series of dust collectors and cyclones are necessary to prevent excessive air pollution.

It is estimated that saw delinting including baling and warehousing accounts for between 40 and 60% of the power requirements, labor including maintenance, and potential for accident; and probably 80% of the air pollution in a cottonseed oil mill. The delinting operation would not be tolerated except that seed with more than 4% lint remaining usually cannot be efficiently handled through hulling and separation and then later solvent extraction.

ALTERNATE METHODS OF DELINTING

The problems associated with delinting have stimulated interest in developing alternate methods, rather than facing the seemingly endless task of bringing saw delinting into compliance with EPA standards for dust emissions and OSHA standards on guarding of machines and on workroom dust and noise. Some mills, mostly foreign, have operated by hulling undelinted seed, and where there is not a good ready market for lint and hulls, both lint and hulls have been used as fuel for boilers. The result is usually excess oil loss in the hulls along with the problem of handling very bulky hulls. Some pelleting of hulls has been attempted to solve the handling and shipment of fuzzy hulls. Burning or flame delinting has been tried on planting seed; however, very close temperature control is necessary, and the value of the lint is lost unless a method can be devised to recover the heat of burning the lint.

Acid delinting, using either sulfuric acid or HCl gas, has been used in several planting seed operations. Some tests have been made to design an acid delinting plant for oil mill operation (4,5). In the case of the wet process the value of the lint is lost, and in the gas process the value of the lint is lowered to that of hulls. Both the lint and the seed have to have the acidity neutralized, usually with ammonia gas. The gas acid delinted residue could be added to the hulls or sold

TABLE I

Chemical Linter Average Prices[a]

Season beginning August 1	Season average price per pound (with cellulose adjustment)
1940	3.13
1942	3.50
1944	3.21
1946	8.22
1948	2.85
1950	14.19
1952	4.33
1954	2.77
1956	4.38
1958	2.15
1960	3.29
1962	2.91
1964	2.52
1966	5.69
1968	3.50
1970	2.75

[a]Beginning in 1965 the pulp plants established a cellulose adjustment schedule with increasing premiums above 73% and discounts below 73%.

as feed, thereby eliminating the problem of disposing of the mixture of lint and spent acid from the wet process. With either acid process there can be some problems with corrosion, potential for injury, and pollution.

At least five mills have tried the abrasive delinter (6), where the seed are rubbed or rolled around a cylinder against concave abrasive stones to remove the lint. The abrasive linter method shows a considerable savings in power and labor; however, the investment cost is high and there is still a problem in meeting air pollution and noise standards.

Clark (7) has presented an evaluation of the economics of saw delinting as compared to abrasive delinting, to the hulling of undelinted seed, to acid delinting using both sulfuric acid and gaseous HCl, and to extracting whole seed. The economics of the alternative processes vary with price of linters, which has varied from 2.15 cents to 14.19 cents per lb over a 30 yr period as shown in Table I. The price of chemical lint accelerates during wartime when there are large demands for smokeless powder. During peacetime the larger markets are in the manufacture of rayon and acetate. Table II shows the comparative results, adjusted for amortization, estimated production costs, and at 3 cents, 4 cents, and 5 cents linters price per lb. A comparison of net monetary return per ton of seed, and of discounted cash flow rates of return has shown no alternative processes to be attractive with linters selling for 4 cents/lb or above. However, at a break-even linters price of 3 cents/lb, the hulling of undelinted seed or acid delinting appeared to be attractive alternates. As labor and power costs increase, the break-even point is expected to increase, and we urge each mill operator to recalculate costs using his own production costs and time value of money for his own discounted cash flow rate of return before considering an alternate method for saw delinting.

Energy requirements are becoming an especially important factor in a manufacturing process. Table III shows an estimate of the fossil fuel requirements for the alternate processes. It is estimated that the cost of natural gas or fuel oil each will triple by 1980, and that sometime in the future the use of natural gas as a boiler fuel may be prohibited. In years to come the energy requirement may be the most important deciding factor in a proposed process, and mills may be forced to resort to burning lint or hulls for boiler fuel.

DEHULLING AND SEPARATING

After the linters are removed, the seed are cut so that the kernels can be separated from the hulls. Hulls are used primarily as a roughage in livestock feeds, and are comparable to a good quality grass hay in value. The accepted method of cutting seed is a bar huller, where a cylinder with slotted knives projecting about 1/8 in. rotate between fixed concave breast knives. The spacing between rotating and fixed knives is adjustable so that at least 85% of the seed are cut without mashing or pulverizing seed or hulls. The cut seed pass over an inclined shaker-separator where the hulls are aspirated from the top tray to a hull and seed separator. Uncut seed are returned to the huller or to a second set of hullers that are adjusted to cut closer than were the first cut hullers. A second aspiration is usually made from the second tray to a purifier that separates fine hulls from meats that may be aspirated with hulls. Between 10% and 12% by weight of hulls are usually left with the meats stream as a means of controlling protein in the finished cottonseed meal to 41% or to some other standard for protein content of meal. The huller knives need to be kept sharp and both hullers and separators need to be in

TABLE II

Comparison of Gross Returns, Partial Production Costs and Adjusted Returns at Linters Price of $0.04/lb Compared with Adjusted Returns for Linters Prices of $0.05 and $0.03/lb

Process	Total gross return ($)	Partial production cost ($)	Adjusted return for linters price of: $0.04/lb ($)	$0.05/lb ($)	$0.03/lb ($)
Saw delintering	138.54	5.85	132.69	134.50	130.88
Abrasive delintering	138.54	5.22	133.32	135.13	131.51
Hulling undelintered seed					
-41% protein meal	135.31	2.15	133.16	133.92	132.40
-50% protein meal	134.04	1.20	132.84	132.84	132.84
Sulfuric acid delintering	137.50	5.14	132.36	132.36	132.36
HCl acid delintering	136.26	4.78	131.48	131.48	131.48
Extracting whole seed	132.40	2.70	129.70	129.70	129.70

Estimated Investment Costs and Discounted Cash Flow Rates of Return (DCFRR) for Conversions from Saw Delintering to Alternative Processes

Alternative process	Investment ($)	DCFRR with linters price of: $0.04/lb	$0.03/lb
Abrasive	650,000	6.7%	6.7%
Undelintered seed			
-41% protein	271,700	5.0%	30.1%
-50% protein	160,300	0	56%
Sulfuric acid	400,000	0	22.8%

TABLE III

Comparison of Estimated Gross Energy Requirements for Alternative Delintering Processes

	Energy form and equivalent fossil requirement, in BTU per ton of seed[a]					
				Natural acid &		
	Electric		Steam	Gas	Ammonia	Total
Process	kwh	BTU[b]	BTU[c]	BTU[d]	BTU[e]	BTU
Saw	66	792				792
Abrasive	90	1080				1080
Undelintered seed[f]						
-41% protein	20	240				240
-50% protein	3	36				36
Acid-sulfuric	18	216		270	142	628
Acid-HCl	18	216		180	58	453
Whole seed[f]	8	96	406			502

[a]Multiply BTU figures shown by 1000, to give uncoded values.

[b]BTU includes estimated losses in generation and transmission, resulting in a conversion factor of 12000 BTU per kwh.

[c]Conversion factor was 1230 BTU/lb steam corresponding to 140 lb steam with 65% boiler and distribution efficiency.

[d]Conversion factor was 1000 BTU per cubic foot of gas.

[e]Conversion factors were 90 BTU, 4483 BTU and 20024 BTU per lb of sulfuric acid, anhydrous HCl and anhydrous ammonia respectively, combined electrical and fuel energy. These factors were calculated from data supplied by others (7).

[f]Power for pelleting hulls was not included.

proper adjustment to assure that a minimum of absorbed oil or of seed and meats are left in the finished hulls. Huller capacity is important, because when the tonnage approaches a maximum, the oil in hulls will increase directly in proportion to the tonnage (8). Either a Bauer Bros. separator-purifier or a Carver hull and seed separator (commonly called H & S machine) in conjunction with a hull beater will be satisfactory for separating uncut seed and hulls that may be aspirated with the hulls. Both protein control and expected oil in hulls will be affected by seed moisture, with the optimum moisture ca. 10% to 12%. The absorbed oil in hulls will increase for seed both wetter and drier than optimum. A laboratory analysis of hulls regularly is important to assure a minimum loss of oil in hulls. Expected oil in hulls will vary from 0.54% to 0.80%.

CONDITIONING

The most important factors controlling the optimum conversion of cottonseed to good quality oil and meal are in the preparation room. Proper preparation, of course, is not the same for all plants, but in general consists of the following (Hay, C., unpublished observations):

1. Getting the meats from the separation room to the cooker with a minimum hold-up time to prevent free fatty acid (FFA) rise.
2. Good rolling or flaking with adequate moisture.
3. Maintaining adequate uniform cooking temperatures and moisture conditions.
4. For prepress, producing a cake with the proper oil and moisture content that will flake or granulate with a minimum of fines.
5. For direct extraction, rolling ahead of conditioning is eliminated, but conditioning or cooking takes on more importance. The control of moisture and temperature is even more critical since the extraction rate and oil quality are largely dependent on this step and on subsequent flaking.
6. Flaking for prepress or direct extraction to produce the proper size and thickness of flake to achieve good drainage and the best extraction. Flake thickness is the controlling factor in the rate of solvent extraction. With free circulation of solvent, the rate at which oil diffuses from a seed particle is directly proportional to the surface area of the particle and inversely proportional to its thickness. Thus it would seem that an extremely thin flake would be most desirable, but consideration must be given to flake stability, amount of fines, drainage, etc., so flake

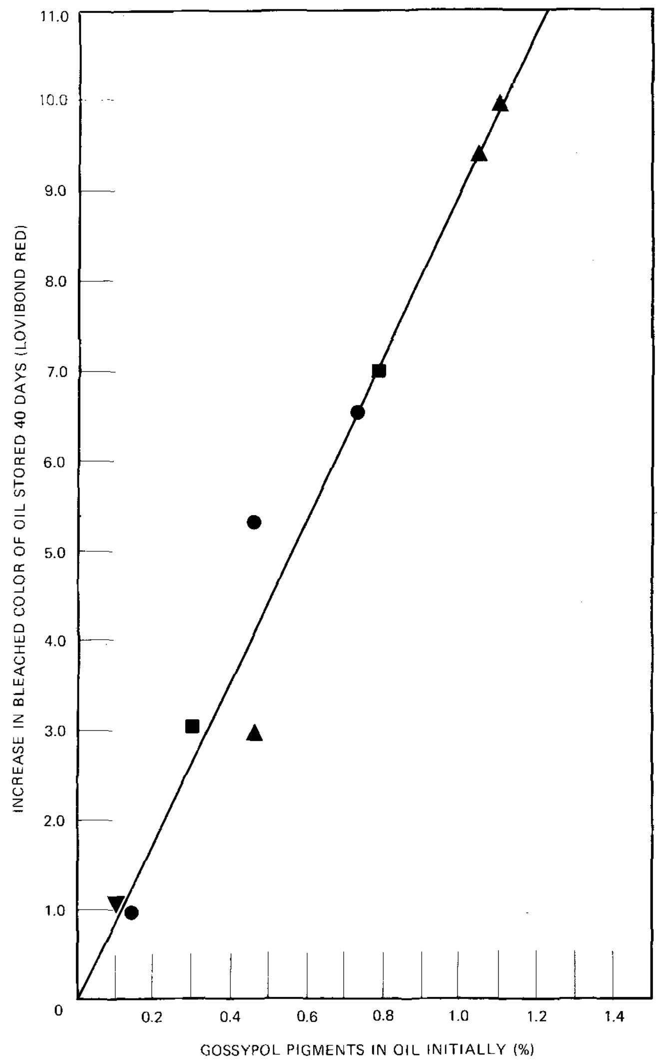

FIG. 1. Increase in lovibond bleach vs. percent of gossypol pigments in crude cottonseed oil stored 40 days at 95-100 F.

thickness usually is somewhat thicker than the optimum indicated by theoretical studies.

Unfortunately, the achievement of these six goals is not as simple as it seems. Cottonseed contains a toxic polyphenolic compound called gossypol along with related pigments. Phosphatidic or gum compounds found in cottonseed meats if extracted with the oil have a direct relationship to refining loss and to refined color of oil. Figure 1 as reported by Watkins shows that the color reversion of cottonseed oil in storage as measured by the increase in lovibond bleached color of the refined cottonseed oil has a direct relationship to the percent of gossypol pigments in the oil. Watkins (9) reports that where gossypol glands are ruptured by the combination of adding moisture to meats, rolling wet meats to .008 in. to .010 in. and binding the gossypol to the protein or reducing sugars by moist cooking, that the gossypol level in the oil should be below 0.1% and that color reversion is very small, and that the bleached color of solvent oil can be as low as the bleached color of prepress oil but only if the gossypol content of the oil is controlled.

Many mills that have converted from screw press to solvent extraction have retained enough presses to operate a prepress-solvent operation. We consider that in this case the screw press should be considered as one part of conditioning for solvent extraction. The combination of moisture, heat, and shearing pressure does an excellent job of rupturing gossypol glands. In an area where there is market demand for poultry or nonruminant protein the use of a screw press to condition meats for solvent extraction will allow production of cottonseed meal well below the standard of 0.045% free gossypol; however, the total or "bound" gossypol will still be high and the protein solubility will be lowered.

Jones et al. (10) have patented a process for adding moisture, crushing the meats, cooking at a mild temperature of 160 F to 185 F for 30 to 40 min, and then increasing to a final temperature of 210 F to 230 F with 13 to 14% moisture. Meats are then pulverized to break up balls and flaked to .005 in. to .008 in. After direct gravity solvent extraction, it is claimed that meal below 1% residual oil and .05% free gossypol may be produced and with a refined oil bleachable to 1.5 red lovibond color.

In the mills that we have visited, the cooking of cottonseed meats has varied from a mild cooking at 160 F to a so-called hydraulic cook of 230 F to 260 F. In any case, the combination of temperature, moisture, and flaking that allows optimum conversion of cottonseed to meal and oil of good quality is considered somewhat of an art and is subject to variation from area to area and with seasonal variations of seed quality. The conditioning variables that produce the optimum in oil recovery and oil quality are detrimental to the protein quality. In most areas where cotton is grown, there exists a market for cottonseed meal that does not demand high protein solubility and digestability. Cottonseed meal is an excellent source of protein for feeding cattle and other ruminant animals with a digestive system that may utilize protein of low solubility. A ready market for cottonseed meal has always existed, and as we enjoy our steaks and roast beef we may only hope that this market will always be there.

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