COATING COTTONSEED FOR IMPROVED HANDLING CHARACTERISTICS

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Abstract

A study to take a cottonseed coating process developed in the laboratory by Cotton Incorporated and develop an industrial scale process was successful in demonstrating that it is feasible and can be done at economical cost. The process consists of coating gin-run cottonseed with a concentrated water solution of hot gelatinized starch then drying the wet seeds in a belt conveyor dryer to harden the coating. The product produced meets well the goals of flowability and durability.

Introduction

Cotton Incorporated (CI) has identified a new market opportunity for whole cottonseed if fuzzy cottonseed can be made free flowing. There is a substantial potential for use of whole cottonseed in high energy livestock rations for ruminants, but fuzzy cottonseed requires expensive special handling that has limited its' use. Fuzzy cottonseed has unique characteristics, (Wilcutt and Mayfield, 1994) that obstruct the use of grain handling equipment typically found in livestock feed mixing and conveying systems. Saw delinting is used to prepare seeds for mill use but has not been widely adopted for feed applications. A system for burning off the lint and coating the seeds was developed by Coles et. al. in Australia (U.S. Patents 5,363,754 and 5,204,102). Both of these methods have the disadvantage of eliminating the linters fiber which is valuable in ruminant feed rations. Cotton Incorporated originated a process in the laboratory for making gin run cottonseed into a free flowing commodity by coating it with a hot gelatinized cornstarch solution. The process is uniquely different from, and an improvement over, existing patented technology. This EasiFlo Cottonseed™ can be used directly in the handling systems of the livestock feed industry. This paper is a progress report on work to move the process from the laboratory to a procedure adaptable to commercial application.

Objective

A cooperative agreement funded by Cotton Incorporated was arranged with the USDA - ARS ginning laboratory at Lubbock, Texas to design, develop, and install a pilot plant system for coating cottonseed with materials that improve seed handling characteristics. This agreement was based on the availability of a belt conveyor dryer and seed handling equipment in the gin lab. The objective of the cooperative agreement was to take the laboratory data and develop a system for coating cottonseed on a scale usable in commercial operations, and to generate quantities of the product for demonstrations. The particular objectives were to assemble a continuous flow starch coating pilot plant system to prepare wet coating material, apply the coating material to fuzzy cottonseed, dry the resulting product, and determine what other handling might be necessary. A broad range of further objectives include studying the effects of type of materials, application techniques, and drying conditions on seed handling characteristics and storage requirements. The objective also included evaluating costs and finding the most economic process. The desired cost objective was for a process that can be done for less than $ 20.00 per ton of seeds.

Procedure and Equipment

The first tasks to be accomplished included adapting the belt dryer to handle the wet cottonseed and dry it. Designs for a cottonseed feeding system connected to a mixing system to apply and thoroughly disperse the coating material on the seeds and a starch preparation and heating system of the correct capacity were needed.

The dryer is a 50 foot long by two foot wide experimental belt conveyor dryer in the gin lab. The active surface area of the dryer is 21-3/4 inches wide by 50 feet long. It is equipped with a variable speed drive capable of moving the wire belt at speeds from about 1 to 100 feet per minute. It can be used in continuous or batch operating mode. A natural gas burner and push pull fan system provides adjustable aeration capacity up to approximately 8000 cubic feet per minute and up to 4 million BTU per hour heating capacity. The 1/2 by 1/2 inch modified flat wire belt used for handling seed cotton in the dryer will not hold cottonseed and was replaced with a tighter mesh balanced weave wire belt (Maryland Wire Belt specification BFS-60-48-16-18). This wire has 60 spiral loops per foot of width and 48 loops per foot of length giving an 0.2-in by 0.25-in mesh of 18 gauge wire with 16 gauge connecting rods.

The volume of material needed for complete coverage on the existing belt surface is 7.6 ft^3 per inch of depth. Bulk density of gin run cottonseed from ASAE standards is 27 lb/ft^3 packed, 25.6 lb/ft^3 standard, and 23 lb/ft^3 loose. We assumed the seed on the belt would occupy a volume about equal to the dry density of loose cottonseed. Therefore the belt would handle 175 pounds of gin run cottonseed per inch of depth. Operating at 3 to 4 inch depths would require 525 to 700 pounds for filling the belt.

Preliminary batch tests to dry wet seeds prepared by hand mixing with hot starch solution indicated that about 5 minutes drying at 300 °F might be enough. We used the volume assumptions and batch drying test data in

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calculating the dimensions and capacity for the starch preparation and heating equipment.

CI laboratory tests had shown that plain corn starch will mix with cool water and remain in suspension up to a ratio of 0.83 pound of starch per gallon of water (0.1 pound of starch per pound of water). The starch tended to lump and not mix well at temperatures above about 140 °F. The tests also had shown that the starch water mixture must be heated above 170 °F to cause the starch to gelatinize, creating a sticky paste to form the coating on the seeds.

Data from laboratory tests done by Cotton Incorporated showed that about 5 percent corn starch (dry weight) applied to fuzzy cottonseed gave a good coating. Based on the pounds of dry starch per pound of water in the starch mixture, adding 0.05 pound of starch per pound of cottonseed would also add 0.5 pound of water. This would increase moisture content of the seed to about 36 % depending on the starting seed moisture content. The seeds need to be dried below about 10 percent moisture for safe storage.

Assume that the dryer was operated at a 4 inch depth and held 700 pounds of wet seeds. In continuous operation, the processing rate in the 50 foot dryer, if drying was accomplished in 5 minutes, would be 140 pounds per minute (4.2 tons per hour). The heat for removing 26 points of moisture was calculated based on the published heat of evaporation for water of about 1000 BTU per pound. This calculation showed that drying the seeds would require approximately 2,184,000 BTU per hour. This appeared to be within the capability of the 4 million BTU dryer burner if we get 55 % efficiency. We knew from previous tests on seed cotton that this should be feasible. There is some uncertainty in the heat of evaporation because we do not know at what temperature the moisture evaporation takes place. Also drying wetted cottonseed could be significantly different from drying seed cotton.

Initial calculation of the capacity of the starch preparation system was based on preparing coating material for 140 pounds per minute of cottonseed. At 5 % add-on (0.05 pound of dry starch per pound of cottonseed) this meant using 7 pounds dry weight per minute of starch in 8.4 gallons of water. Heating 8.4 gallons per minute of water to 140 °F assuming a 50 °F starting temperature requires 378,273 BTU per hour. Final heating of this volume of mixture from 140 °F to 170 °F with electric resistance heating which we proposed to use requires an additional 126,091 BTU/hr, (37 kW). This seemed to be a fairly large requirement in relation to the ginning laboratory equipment so we scaled back and designed the beginning system for about 1/4 of the estimated maximum capacity. The starch preparation equipment was designed for a 2 gallon per minute flow rate. We installed a 75 gallon water heater with a 75,000 BTU per hour rating for the initial hot water supply. The final stage was built with electric resistance heat elements rated at 41,000 BTU/hr (two 6000 watt elements). A positive displacement piston pump with a maximum output of 7 gallons per minute powered by a variable speed drive was installed for generating the flow of starch solution. The starch was pumped through the final heating vessel and through a hose to a flat fan spray nozzle positioned over a mixing conveyor system transporting the cottonseed.

A cottonseed holding bin with a live bottom driven by a variable speed drive to control the feed rate was designed and built. The holding bin was a rectangular sheet metal bin five feet long by three feet wide and six feet high. This bin was capable of holding about 1500 pounds of fuzzy cottonseed. The seeds were blown into the holding bin as needed from the seed blowing system of the laboratory gin. The live bottom on the bin was formed by five specially built 6-inch diameter augers on 4 inch diameter pipe cores. These augers were driven as one unit by chains and sprockets connected to a variable speed drive motor for control of feed rate. The sides and ends of the holding bin were sloped outward toward the bottom at about 5 degrees to avoid bridging by the fuzzy cottonseed.

The holding bin dropped seeds down into a mixing conveyor built from a pair of 10-inch diameter paddle augers in a common trough. These paddle augers were specially constructed with four paddles per standard pitch to get aggressive mixing action. The mixing conveyor pair was six feet long and the starch nozzle was positioned over the center between augers about one foot outside the holding bin. The mixing augers were counter rotating and driven so that their rotation was toward the center from the bottom to allow working the cottonseed between the augers to distribute the starch solution. The mixing conveyor was designed to drop the wet cottonseed into a single cross conveyor that delivered it to the drying belt. This cross conveyor was also a 10-inch diameter paddle auger and was 14 feet long.

Results

After construction of each of the system components, a few runs were made to get the system working and develop operating parameters for each part. Operating speed charts and temperature relationships were developed for each component. Coordinated rates of operation for starch preparation, heating, application, seed feeding, and drying were found that gave a system for applying 5 % add-on of starch (dry weight basis) that fully wetted all the seeds and dried to a hard coating. Some problems encountered were that the temperature of the electric resistance elements had to be closely controlled to remain below about 185 °F or the starch mix would become too viscous and bake onto the elements. Also gin run seeds contain occasional tufts of a few long fibers that cause entanglements forming large clusters of seeds.

By the time seeds had traversed the mixing and cross conveyors the hot starch solution had thoroughly wetted all the seeds and pasted the fuzz fibers down. The paddle augers tended to trap most of the seed entanglements and alleviated the problem for the time being. We expect to develop a method later to remove the few long fibers from the seeds before coating them to avoid having to stop and clean the paddle augers after about four hours of operation. The long fibers were removed from several small samples and found to be about 2 to 3.5 percent of the seed weight. The fiber was mostly staple fiber about 3/4 inch long and a marketable product if it can be removed inexpensively.

After a working system was put together, we began a series of test runs looking for ways of improving the performance and to generate large lots of coated seeds for use in handling and feeding demonstrations by various interested groups. These test runs consisted of lots sufficient to fill one or more large commodity bags holding 1500 to 1700 pounds of coated seeds. This size lot gave at least a half hour of operation and enough time to get the system leveled out in continuous operation.

Operating data for a series of these test lots is given in table 1, and moisture test data for the same lots in table 2. The moisture test data is the mean from three standard five hour oven moisture samples. The data in these two tables tracks the effect of the various evolutionary changes we made in developing the system to its present state. The first thing to overcome in developing dryer performance was that the seeds need to be applied to the belt in a very even layer because drying occurs from the top down and the air flow pattern is very sensitive to depth. Air flow would divert to the thinner areas and overdry them and only partially dry the bottom of thick areas. Because the layer of seeds dried from the top down, we built and installed three horizontal rotating shafts with rubber fingers as stirring devices to mix the seeds bringing wet ones to the top. These stirring reels were installed at about 12 foot intervals down the belt. Stirring enhanced drying rate and prevented overdrying of the top layer. This stirring also helped level out seed depth on the belt. The stirring fingers also helped smooth the coating before it dried and prevented the seeds from sticking together.

The preliminary runs showed that we needed about 10 minutes drying time with about 300 °F hot air temperature at the entrance to the hot air supply plenum on top of the belt dryer to dry about a 2 inch depth of seeds on the belt from about 30 percent to below 10 percent moisture. Some of the early runs were insufficiently dried and also came out of the dryer at about 100 °F. These lots were dumped into a large sheet metal bin then picked up by the gins' suction unloading system connected to a separator on the belt dryer and given a second cooling pass through the dryer. Some of the cooling passes were without heat and some used about 115 °F air temperature to get additional drying. After running ten lots it was evident that cooling was consistently required so a blocking partition was installed inside the upper plenum of the belt dryer at the 42 foot mark and the discharge end was opened allowing the pull fan to draw cooling air through the seeds for the last 8 feet of belt travel.

By about lot 10 we also saw that apparently the seeds do not pick up any heat until they are nearly dry but are mostly subject to evaporative cooling. We found that we could increase dryer temperature and decrease dryer time to get higher throughput. We also found by about lot 25 that by running an aggressive stirrer in the starch mixing tank we could get a higher starch concentration and use less water to apply the 5 % starch, lowering the load on the dryer. We expect that more progress can be made in both of these areas.

The work so far has been developmental and we are now at the point of being able to design more rigorous experiments to study the effects of various design parameters.

One important finding is that the starch solution becomes more aggressive at wetting the fuzz fibers after reaching the gelatinization temperature above 170 °F. This effectively softens the fuzz fibers and binds them tightly to the seed coat to form a dense free flowing product. The apparent bulk density of the coated seed after drying is about 28 pounds per cubic foot. Independent measurements made by a cooperator on coated seeds shipped to Wisconsin showed that bulk density for loose seeds was 27.0 pounds per cubic foot for the EasiFlo Cottonseed™, 20.2 pounds per cubic foot for uncoated fuzzy seed, and 32 pounds per cubic foot for uncoated machine delinted seed.

Air for drying the wet coating material on the cottonseed is supplied to and exhausted from the belt conveyor dryer through 16-inch diameter round pipes. Air volume measured in the input pipe with the current configuration was 8216 cfm and the exhaust was 9332 cfm. The 1116 cfm air flow difference was cooling air which also was pulled out through the single exhaust. At typical ambient conditions of 50 °F and 35 % RH at Lubbocks' elevation, enthalpy was 7.36 BTU/lb air. After heating to the hot air temperature of 315 °F, enthalpy was 71.29 BTU/lb air. The difference of 63.93 BTU/lb air is the amount of heat added by the dryer burner. Air flow was 33,275 lb air per hour and multiplying this by 63.93 BTU/lb air gives 2,127,271 BTU/hour total drying heat use rate. Dividing by the lower heating value for methane of 896 BTU per cubic foot to estimate fuel use gives 2374 cubic feet per hour natural gas consumption in the dryer burner. Seed processing rate averaged 35 to 40 pounds per minute (2100 to 2400 pounds per hour). This results in 1013 to 886 BTU per pound of seed (2,025,972 to 1,772,726 BTU per ton) available for drying, or 2261 to 1978 cubic feet of natural gas per ton of seed processed.

Starch preparation also requires energy for heating the water and starch mixture above 170 °F to gelatinize the starch. As stated earlier we used two heat sources, initial hot water (≈

140 °F) from a hot water heater using 75,000 BTU per hour, and final heating of the solution by 12 kW of electric resistance heating elements. The final temperature is controlled by a thermostat and the resistance heaters ran at an average watt usage of about 85 % of capacity or 10 kW. Converting the kilowatt usage to heat units gives 34,144 BTU per hour. Total starch solution heating was 109,144 BTU per hour or 103,947 to 90,953 BTU per ton of seed processed.

Cost for power to operate the system will be estimated using average public utility prices. Fan horsepower for blowing the air through the dryer was estimated by interpolating in fan charts for centrifugal fans moving 8216 and 9332 cfm against about 4.5 inches of static pressure. The push fan required 20.4 hp and the pull (exhaust) fan required 26.5 hp. Power consumption by the fans was about 35 kW. At 7.5 ¢ per kilowatt hour the power cost is $ 2.63 per hour or $ 2.50 to $ 2.19 per ton of seed processed. The starch pump, seed feeder and belt dryer each required 3/4 horsepower electric drives. If they were fully loaded these drives would use 1.9 kW and cost $ 0.15 per hour or $ 0.12 per ton of seed processed.

Total heat for preparing starch and then drying the coated seeds ranged from 2,129,919 to 1,863,679 BTU per ton of seed processed. In a commercial operation this heat would all be supplied by the most economical heat source available, so we will use the local natural gas price for computing the energy cost per ton of seed. Based on the lower heating value, the natural gas required to heat and apply the starch solution and dry the seeds was 2377 to 2080 cubic feet per ton of seeds. The local gas price is $ 6.10 per mcf which results in a fuel cost of $ 14.50 to $ 12.70 per ton processed.

With the current process total utility costs (power plus heat) for coating and drying the seeds ranged from $ 17.00 to $ 14.89 per ton of seed processed. There would be other facility and labor costs not included in this analysis. Also, we expect that with further research, the costs may be reduced since the system in its present configuration is fairly primitive and there are economies of scale to be gained. The system in the laboratory is constructed of galvanized sheet metal with no insulation. Childers (1978) has shown that insulating cotton gin dryers saves approximately 25 % of the drying energy cost as well as enhancing the drying. Therefore, the costs after insulation of the present system would drop to $ 12.75 to $ 11.17 per ton of seed processed. We expect also that changes and improvements to the stirring process and modifying the starch preparation method to give a hotter more concentrated solution should yield another 50 % reduction in energy cost. The projected energy cost for the improved system would be about $ 5.60 per ton.

Plain cornstarch used for the coating material is available in large quantities for about $160.00 to $ 280.00 per ton, the price is directly linked to the price of corn. Cottonseed in the feed market varies in price in relation to supply and demand. Dependent on time of year and location the cottonseed market recently has ranged from $ 140.00 to $220.00 per ton. Adding 100 pounds (5 %) cornstarch to treat a ton of cottonseed and reselling it at the cottonseed price could result in either a gain or loss. This could vary from a gain of $ 3.00 to a loss of $7.00 per ton of coated seed. However this does not take in account a possible premium that could be charged for the EasiFlo Cottonseed^{TM}. Also some percentage of gelatinizable starch is needed to form a good coating but we have found it is possible to load it with cheaper feed grade starch to get to the desired add-on.

Summary and Conclusions

The system constructed for this experiment has shown the industrial scale process is feasible and the cost is within the required range. The product produced is very acceptable from the flowability and durability standpoint. Tests have shown a number of areas for improvement. Processing rate for the present system per unit width needs to be scaled up by about a factor of four to give a desirable capacity level within an economical facility size. The changes needed to make the upgrade have been projected, some can be directly applied, some will need more research.

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Table 1. Process operating data for an initial series of cottonseed lots coated and dried in establishing operation of a system for preparing starch, coating seed, and drying it at the USDA - ARS Ginning Laboratory at Lubbock, Texas.

Lot no.	Dryer + cooling time, min.	Dryer temp. °F	Seed feeder setting	Seed depth in.
1	10	280	4.5	. . .
3	10	300	4.5	1.5
4	10	300	4.5	1.5 to 2.0
5	10	300	4.5	. . .
9	10	300	4.5	. . .
10	10	300	. .	. . .
11	10+1.9	310	4.75	2 to 3
12	10+1.9	310	4.5	. . .
13	10+1.9	320	4.5	2 to 3
15	10+1.9	320	3.8 to 4.0	2 to 3
17	10+1.9	320	4.0	2
20	10+1.9	310	3.9 to 4.1	2.5
23	10+1.9	310	3.8 to 4.0	2 to 3
25	10+1.9	300	4.0	2.5
28	9.2+1.8	320	4 to 4.2	2.5
31	9.2+1.8	320	4.0	2.5
34	9.2+1.8	320	4.2	2.5
38	9.2+1.8	335	4.8	3
42	9.2+1.8	315	4.5	2.5 to 3

Table 2. Mean moisture content (%) of seeds at the specified position for an initial series of lots of fuzzy cottonseed which were coated with hot starch solution and mixed to mat down the linters then dried to give a flowable condition.

Lot no .	Before treatment	Wetted	Dried	Cooled
1	...	30.64	15.53	8.65
3	7.05	25.45	9.65	8.80
4	6.00	24.91	8.96	8.21
5	5.97	27.57	14.61	9.35
9	6.37	28.61	13.34	7.95
10	6.75	28.16	11.64	10.12
11	6.61	23.51	7.92	na
12	...	24.96	13.33	na
13	...	26.87	7.57	na
15	...	27.26	9.22	na
17	...	33.04	13.81	na
20	5.58	23.76	6.45	na
23	6.34	29.28	11.98	na
25	...	24.90	7.63	na
28	5.41	23.46	5.88	na
31	5.98	26.31	8.47	na
34	5.86	23.14	5.77	na
38	5.43	26.29	7.07	na
42	. . .	. . .	. . .	na