PRELIMINARY ESTIMATES OF THE COST OF EXTRUSION PROCESSING OF COTTON GIN BY-PRODUCT AS A LIVESTOCK FEED

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Abstract

Extrusion processing can be used on cotton gin by-product (CGB) to produce livestock feed (roughage) products. Using the economic-engineering approach, preliminary estimates of unit processing cost for CGB feed products were developed. Preliminary estimates suggest economies of size, with in-plant process cost as low as $9/ton.

Introduction

Over four million bales of cotton lint (25% of U.S. production) are produced in Texas each year. A significant residual of the cotton lint ginning process is cotton gin by-product (CGB). CGB is composed of leaves, stems, burrs, immature seed, and lint fibers, stripped from the plant along with the cotton lint during harvest. CGB currently has little economic value and is disposed of at an average cost to the gin plant of $1.44 per ton (Castleberry and Elam, 1998). Over 1.1 million tons of CGB are produced each year in the Texas High Plains, with a total annual disposal cost of almost $1.6 million.

Several methods of CGB disposal are in common use. CGB is disposed of by inclusion in livestock feed, soil amendment, and compost. A recent study reports that the nutritional value of CGB, when used in cattle feeding rations, may approach $70 per ton, far surpassing the disposal cost (negative return) of $1.44 per ton (Castleberry and Elam, 1999). This disparity suggests that the full potential value of CGB as livestock feed is not being realized, likely due to undesirable physical properties of CGB. The physical properties of CGB bring about a lack of palatability in animal diets, abrasiveness (wear) to milling machinery, and low bulk density that leads to high transportation costs. These effects reduce the feasibility of using CGB as livestock feed.

Experimental processing techniques have been identified that mitigate the nutritional and physical barriers, limiting the value of raw CGB in livestock feeding. Engineers at the Lubbock, TX, USDA-ARS cotton ginning laboratory have achieved promising results in tests of a CGB extrusion process (using an Insta-Pro dry extruder) that uses starch in solution to reduce wear on the extruding machinery (Holt and Laird, 2000). The patent pending process is known as the COBY (COtton BY-products) process. The COBY process includes the application of a slurry comprised primarily of gelatinized starch and water to the CGB, the blending in of various additives that are either helpful in processing or add value to the final product, and the extrusion of the CGB mixture to cook, gelatinize, and sterilize the product. The final product of the process is a livestock roughage feed product that has potential market value to cattle feeding operations.

Extrusion equipment is adaptable, allowing for processing of multiple ingredients, such as whole cottonseed, simultaneously with raw CGB. CGB contributes fiber (roughage) to the feed product, while whole cottonseed can be added in varying proportions to supply specified amounts of protein, energy, and fat. The extrusion process can be altered to produce feed products of various types, including range cubes/pellets and loose feed, each having improved palatability over products containing raw CGB. Another advantage of the process is the increased bulk density of CGB, decreasing transportation costs of CGB feed products and increasing the size of the area where products can be feasibly marketed. The physical restrictions that have limited the value and use of raw CGB in livestock feed products can be overcome by the use of the CGB extrusion process; however, the economic feasibility of a system that processes and markets raw CGB into a feed product with optimal nutritional and physical characteristics is unknown.

The research reported here is one component of a comprehensive research effort to determine the technical and economic feasibility of using extrusion processing of raw CGB to produce livestock feed products. The components of the feasibility study include estimation of: (1) the acquisition cost of the raw CGB product from the gin to the processing plant; (2) the cost of storing and handling raw CGB at the processing plant; (3) the cost of the CGB extrusion process inside the processing plant; (4) the cost of storing and distributing the output feed product(s) to final demand markets; and (5) the final product demand for CGB feed product(s).

The objective of this study is to estimate the costs of processing and assembly of CGB feed product(s) inside the processing plant (item (3) above). The specific objectives are to design and specify several model CGB extrusion-processing plants of varying sizes and to estimate the cost structure of each model plant. The cost functions of the processing plant are synthesized using the economic-engineering approach. A long-run cost curve was estimated to determine the economies of size for increasing size plants.

The outline of the rest of the paper is as follows. The second section explains the economic-engineering approach used to estimate CGB processing cost. Results of the analysis are found in the third section. The fourth section includes a discussion of the limitations of the analysis, and the final section provides a summary and plans for future research on the project.

Economic-Engineering Approach

The CBG extrusion process is a series of processing operations that, like many other manufacturing processes, is relatively straightforward and does not require exceedingly complex components. Therefore, the process is technically feasible in a wide range of production configurations including small gin-scale operations as well as sophisticated, high-volume automated enterprises.

Along with the ranging set of feasible technical configurations, the per-unit production cost varies. Therefore, analysis of the full range of plant cost structure can provide insight into the long-run cost structure and economies of size in the processing component. The analysis of plant cost structure was carried out through estimation of processing costs for eight model plants that differ in plant size (throughput). For each model plant, the economic-engineering approach was used to develop a total cost per unit of plant output.

The economic-engineering approach does not strictly require the use of particular methods, however, it more generally prescribes a set of guiding principles that have come to be accepted as "standard good practice" (French, 1977). Statistical analysis of accounting records is the most common alternative method to the economic-engineering approach for evaluating plant cost structure. One advantage of the economic-engineering approach over the statistical analysis of accounting records is that the economic-engineering approach can be applied when accounting record

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data are not available, as in the current case of a new CGB extrusion processing plant. However, a major limitation of the economic-engineering approach is the high cost of implementing the approach. Estimation of stage production functions and a complete process cost function requires a significant amount of detailed technical data about each stage of the process.

Following the economic-engineering approach to estimate the plant cost structure for each model plant, a series of four procedural steps were followed. The steps include (1) development of a description of the processing system comprising the extrusion plant, (2) specification of the alternative production and processing stage techniques that are technically feasible, (3) estimation of the production functions for each stage or component in the extrusion process and accumulation of the stage functions into a plant production function, and (4) synthesis of the process cost functions by applying input factor prices.

A description of the complete CGB extrusion processing system, including consideration of alternative processing techniques and production function definition, was developed through: extensive discussion with USDA, ARS engineers; on-site examination and discussion with plant managers of plants using similar techniques; and live trial runs of a small-scale prototype design of the extrusion process. In general, four in-line plant stages are defined in the process. The stages include (1) intake, preparation, and mixing of the raw inputs, (2) preparation and mixing of the additive inputs, (3) extrusion of mixed materials, and (4) preparation for storage and shipping of the final product. Processing costs for each of the model plants were synthesized from the combination of estimated stage production functions and average factor prices for process inputs. Details of the cost synthesis follow.

Standard economic cost procedures were used to synthesize processing costs including a long-run fixed cost component and variable operating cost. Fixed costs include interest, depreciation, maintenance, insurance, and taxes on plant building, machinery, and equipment. Variable operating costs include labor, energy, and additive materials costs (with raw CGB included at zero acquisition cost). Building, machinery, and equipment investment costs are based on purchase of new fixtures without consideration of the cost and availability of used equipment. Planned work on this project includes development of investment estimates based on selective use of investment in used equipment and machinery where good quality is available at a reasonable cost. The cost of millwright services for installation and assembly of machinery and equipment and for fabrication is included in the investment cost.

Interest cost includes financing interest on the building, machinery, and equipment and is calculated as the interest rate (10%) multiplied by half the total investment cost of the plant. The interest cost approximates the "average" interest cost over the lifetime of the plant (as the value depreciates over time). The straight-line depreciation method was used to calculate depreciation cost of the building, machinery, and equipment to be fully depreciated over a useful life of ten years with zero salvage value. This approach represents a maximum depreciation cost estimate since major components of building, machinery, and equipment will have a useful life of more than ten years (or have a positive salvage value at the end of ten years). Annual maintenance cost was calculated as 2% of initial building, machinery, and equipment investment cost. Insurance cost is calculated using a typical commercial insurance rate for the given model plant and includes workers compensation and employee liability coverage, commercial property coverage, and commercial general liability coverage. Estimated taxes were calculated using tax rates from local taxing entities and a taxable value of one-half of the initial building, machinery, and equipment investment cost.

Variable operating costs, including labor, energy, and materials, are synthesized from the in-line stage and component production functions of the plant process and from off-line activity costs. Variable operating costs are based on an operating schedule that allows for process operation during (1) 22 hours per day, with two hours per day for shift changes, cleanup, and equipment repairs, (2) seven days per week, and (3) 49 weeks per year, with three weeks per year shut down to allow for annual repairs and adjustments to machinery and equipment.

The operating schedule requires three daily working shifts of two to four in-line employees. Two off-line employees are required for management, sales, and service activities. The total salary package (labor cost) for in-line employees, including fringe benefits, was estimated at $30,000. The two off-line employees include (1) a plant manager responsible for production, management, and marketing of plant output, with a total salary package (labor cost) of $40,000 per year (including fringe benefits), and (2) a secretary-bookkeeper responsible for daily bookkeeping and secretarial duties, with a total salary package of $20,000 per year.

A preliminary estimate of plant energy cost includes electricity cost primarily relating to operation of motors throughout the plant and natural gas cost of operating the steam boiler plant and the product dryer. Estimation of electricity cost was made using the five-year average of industrial usage unit price for electricity ($0.0454 per kilowatt hour) and the total horsepower requirement for plant machinery and equipment. The cost of natural gas to power (1) the steam boiler used to supply heat to the starch cooking kettles and (2) the burners on the product dryer is based on the five-year average of industrial usage unit price ($3.18 per MMBTU).

Results

Model Plant Flow Diagram

The specific model plant designed here incorporates flexibility to produce both roughage products as well as value-added products with enhanced nutritional characteristics (energy and protein). Particularly, the model plant is designed to handle whole cottonseed along with CGB as primary inputs to the process. The output product is a livestock roughage feed product having added value from the additional protein and energy from the whole cottonseed.

The plant stages of the model CGB extrusion plant can be seen along with component equipment in the plant flow diagram in Figure 1. The reader should follow the discussion while viewing Figure 1. Keep in mind that an automated plant control system processes feedback data on product throughput and equipment parameters from each stage in the plant process in maintaining proper flow of intermediate materials. Raw CGB and whole cottonseed are brought into the plant building in separate lines and are stored in surge bins (separately) at the top left side of the plant flow diagram. The CGB and whole seed surge bins use live bottom augers with variable rate feeders to feed the raw CGB and whole seed into a combining auger which flow to the mixing auger where the CGB and seed are mixed and moved with a conveying auger (along the top of Figure 1) to a set of surge bins (one for each single-extruder processing line) that will each feed the mixed CGB and seed to an extruder. Bin-level indicators (bindicators) control the flow of CGB/seed into the surge bins to maintain the appropriate fill-level of input product. Each surge bin is equipped with a live bottom auger and a variable frequency drive. The plant control system regulates the flow of CGB/seed from the surge bins based on the optimal throughput of the extruders. A mixing auger (middle right of Figure 1) attached to each surge bin is used to mix a gelatinized starch solution (and other additive ingredients) with the CGB/seed. Remember that the starch is added to "grease" the flow of the abrasive CGB as it moves through the extruder (to reduce wear and tear on the extruder) and to add value to the feed product.

The starch solution processing equipment is located in the center section of the plant flow diagram in Figure 1. The starch solution processing equipment includes a bag splitter that splits the bags of starch for loading into the starch bin (the desired starch grade is typically sold in 50 and 100 pound bags—not bulk). The stored starch is taken from the bin and lifted, using a bucket elevator, to the conveying auger and dropped into weigh feeders that weigh out specified amounts to produce a given batch of starch solution. The dry starch is dropped into the two cooking kettles to mix with water and cook to form the starch solution used to coat the CGB/seed before it passes through the extruders. A low pressure, forced draft steam boiler (bottom center section of Figure 1) supplies heat to the starch cooking kettles.

Continuing with the discussion of the flow of the process, the starch-coated CGB/seed is fed into the extruders with 35 - 45% moisture (the moisture is added as part of the starch solution). The temperature in the extruder rises to approximately 230° F as the CGB/seed mixture is forced through the barrel of the extruder. The high temperature kills weed seeds and other living organisms in the CGB/seed mixture. The extrusion process produces a loose, fibrous feed product with a mild aroma and a medium-dark brown color.

From the extruder, the product drops into a conveying auger and into a single-pass belt dryer (bottom of Figure 1). Coming out of the extruders, the extruded product contains 25 - 30% moisture. The dryer further reduces the moisture to 14% to accommodate densifying the product in compression machinery, if desired. The reduced moisture level is needed to maintain the form of the compressed product. The final step in the production process is to cool the extruded product in a cooler where the moisture level is reduced to 8 - 10% to accommodate short-term storage before shipping.

Processing Cost Estimates

Preliminary estimates of the cost of processing CGB and whole cottonseed into a livestock feed product in eight varying-sized model extrusion plants were developed. The total cost estimate includes only costs incurred inside the plant building and does not include costs of acquiring, transporting, and storing of the raw input products and distribution costs of the output product. The cost estimates are shown in Figure 2 for each model plant (starting with a single-extruder plant processing 4 tons per hour up through an eight-extruder plant processing 32 tons per hour). Economies of size are achieved with increasing plant capacity. The estimated processing cost is about $27.50 per ton for 4-ton per hour plant capacity and decreases to just over nine dollars per ton for the 32-ton per hour plant capacity. The long-run average cost curve turns approximately flat as plant capacity increases to 20 tons per hour with average cost of about $9.53 per ton and decreases only slightly for larger size plants.

We remind and caution the reader that the plant cost estimates presented in Figure 2 are preliminary and will be checked and reviewed before a final report is given. Moreover, these estimates include only the cost of processing the CGB/seed inside the processing plant, and do not include the cost of acquisition and handling of raw CGB or the cost of distributing the livestock feed (output) product to final markets. As we work to complete this project, other such costs will be included to obtain the full cost of processing to produce the final, CGB/seed livestock feed product.

Discussion

Important to point out are some of the limitations of the economic-engineering approach to estimating processing cost so the reader will have a better understanding of the results presented here. As mentioned above, a major limitation of the economic-engineering approach is the high research cost (French, 1977). After working on this study for some time, we can attest—as economists—to the inordinate, daunting, and unexpected amount of technical engineering detail and time required to compete a study using this approach. For example, we discovered that it is not a simple process to price a screw conveyor used to move material from one stage to another in the plant. To clarify, a screw conveyor consists of several components including a tube, flighting, a trough, a trough cover, spouts, multiple bearings, flanges, etc., each with numerous selections to be specified about the quality and size of the component. All of these components should be priced and totaled to obtain the price estimate of a "screw conveyor." Many stage equipment components are included in the configurations for the model CGB processing plants, including, *inter alia*, live bottom bins with variable surge rate sensors, combining augers, mixing augers, bucket elevators, a dryer, a cooler, a bag splitter, electrical wiring, plumbing, a plant control system, etc. The system development and design of such a complex plant stretches the knowledge of non-engineers, like the two senior authors, and even engineers as well. As noted by Black (1955) and reported in French (1977), "As the size and complexity of the operation increases, so does the possibility that the model builder will omit some aspect of cost."

Another potential limitation of the economic-engineering approach at cost analysis is the specification of the model plants. As French (1977) points out, the model plant approach is most appropriate in cases where the researcher is confident of being able to select, *a priori*, the best methods for each of the model plants. In developing the model plant designs, we consulted with agricultural engineers, animal scientists with feed manufacturing expertise, commercial plant designers, and several equipment companies. But even with all of this assistance, we had to use independent judgment in calls on plant design and equipment use and specification. To the best of our knowledge, we made reasonable, judicial choices that should err on the conservative side. For example, in selecting cooking kettles for the plant, we could have included a large 1,500-gallon kettle to obtain the lowest cost. However, based on discussions with engineering personnel, we chose two 800-gallon kettles at a higher total cost but with the potential of reducing risk in the production process. That is, in a 32-ton-per-hour plant, two kettles showed advantages because if one kettle develops mechanical problems, half of the production line can continue to run. Another advantage is in the case where a bad batch of starch solution is created. Again, only 800 gallons of solution is wasted in a two-kettle plant compared to 1,500 gallons for a single-kettle plant. The point we want to make is that model plant design involves some difficult choices, with the opportunity of second-guessing any design. In the case at hand, there could be better model plants but we feel fairly confident that our design is reasonable and includes the major pieces of equipment for processing CGB feed products with consideration given to economic issues of risk, return, and time and product-flow management.

Yet another possible limitation of using the economic-engineering approach is reliability. Black (1955) and French (1977) maintain that the estimates using the economic-engineering cost approach are "cut adrift from the standard measures of reliability." Given the complexity of designing a model plant and the complex and varied pieces of equipment involved, this certainly appears to be a valid criticism of the approach. French points out that synthetic economic-engineering cost estimates clearly need to be verified against alternative sources of information; however, in the case at hand, there are no CGB extrusion processing plants currently in operation. Therefore, careful review of our results by an engineer-consulting firm seems advisable and indeed we plan to do this before developing the final report on this project.

Summary and Future Research

The economic-engineering approach was used to estimate the cost of processing raw CGB and whole cottonseed into a livestock feed product. The extrusion process is based on an experimental processing technique that utilizes a starch solution applied to raw CGB to reduce wear on processing machinery and add value to the feed product. Eight model-processing plants were developed that range in size from a single-extruder plant processing 4 tons per hour to an eight-extruder plant processing 32 tons per hour. Combining varying proportions of CGB and extruded whole cottonseed, the plant design and process flow allows for production of feed products with varying amounts of fiber (roughage), protein, energy, and fat.

The cost structure of each of the eight model plants was estimated and a long-run cost curve was developed. The results indicate that economies of size exist for average plant processing cost, with the highest average cost ($27.50 per ton) for the smallest (one-extruder) plant and the lowest average cost ($9.03 per ton) for the largest (eight-extruder) plant. The long-run average cost curve turns approximately flat as plant capacity increases to a five-extruder plant size with average cost of $9.53 per ton and remains relatively constant for larger capacities. The reader is reminded again that the processing cost estimates reported here include only those costs that occur inside the plant building, and do not include costs of acquisition and handling of raw CGB or distribution of the output feed product to final markets. A final reminder is that the results reported here are preliminary results and will be checked and reviewed before a final report is made.

We plan to continue our research effort on CGB extrusion. The immediate objective will be to develop the full cost of operation of the model CGB extrusion plants developed in this research. Additional costs to be included, beyond the plant processing cost estimated in this research, are: (1) the cost of acquiring and transporting CGB from the gin to the processing plant; (2) the cost of storing and handling the raw CGB at the processing plant; and (3) the cost of storing and distributing the output CGB feed product to the final demand markets.

The results from this research will have benefits for the cotton and livestock industries and the regional economy, including: higher revenue for cotton producers/ginners; a more digestible/palatable roughage feedstuff for livestock producers; and an environmentally friendly, sustainable, value-added enterprise that creates jobs and increases income for rural communities in cotton producing regions.

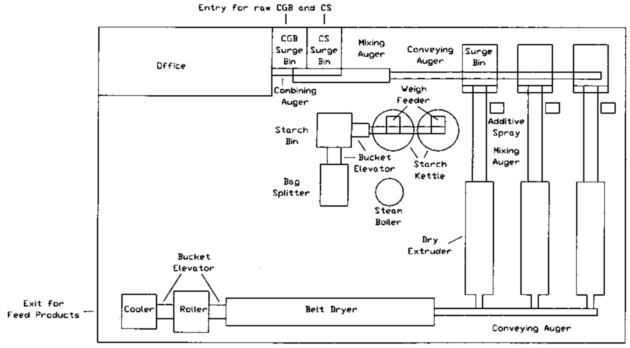

Figure 1. Plant flow diagram for CGB extrusion processing plant (CGB = cotton gin by-product; CS = cottonseed, whole).

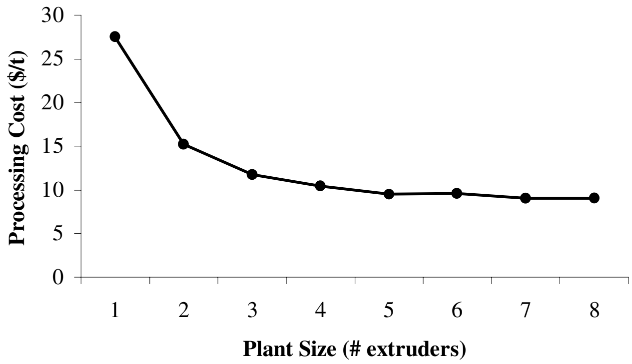

Figure 2. Preliminary estimate of in-plant CGB livestock feed processing cost.

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