# ECONOMIC ANALYSIS OF COTTON TEXTILE FINISHING PROCESSES PART 2 – AFTERTREATMENTS

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## Abstract

An economic analysis is conducted on two cotton textile aftertreatments designed for the coverage of neps while dyeing cotton fabrics in textile mills. Processes considered include aftertreatments which use either chitosan or cellulase enzymes. The benefits examined include the reduced rejection of fabrics, while the costs examined include the cost of the chitosan or enzyme, costs of associated chemicals, additional labor, and variable and fixed overhead costs. The estimated benefits and costs are considered in various scenarios to determine potential cost effectiveness. Results indicate that both aftertreatments are cost effective for textile mills to adopt at this time.

## Introduction

Cotton is the most commonly used natural textile fiber in the world, accounting for about 50 percent of total world fiber production (Starbird et al., 1987). Cotton represents about 38 percent of all fibers used in apparel, 18 percent in home furnishings, and about 12 percent of the fibers used in industrial products. The quality characteristics determine whether cotton is used to produce apparel or home furnishings. Cotton with a higher quality is used for clothing, while lower quality cotton is used for household or industrial products.

The Texas economy relies heavily on cotton production. In 1993, producers in the Southern High Plains of Texas (SHPT) produced 52 percent of the state's 5,095,000 bales of cotton (United States Department of Agriculture, 1995). The SHPT consists of the counties of Andrews, Bailey, Cochran, Crosby, Dawson, Gaines, Glasscock, Hockley, Howard, Lamb, Lubbock, Lynn, Martin, Midland, Terry, and Yoakum. Cotton produced within this region is used by textile mills throughout the world.

Cotton produced in the SHPT is subject to having low micronaire which contributes to a high percentage of small knots or fiber entanglements known as neps. Neps appear as white specs on the surface of dyed cotton fabric and are caused by immature fibers which become entangled. Low micronaire is caused primarily by the short growing season, cool night temperatures and early freezes resulting in cotton not maturing properly. The problem of neps is one reason for fabric rejection. Rejection of the fabric at the dyeing stage is expensive because of the cost of the value-added processes from production through processing. Because neps cannot be removed manually from the fiber, processors generally must use one of several treatments to enable the fabric to receive the dye uniformly.

One treatment used for the coverage of neps involves the use of a cationic polymer pretreatment by the pad/dry process (Mehta et al., 1990). This treatment is effective in covering neps when dyeing with direct, reactive and acid dyes. However, because this treatment is based on the pad/dry method, the fabric must be dried after scouring and/or bleaching prior to its application. An alternative to the pad/dry treatment is based on the exhaust method, which eliminates a drying process and is easily incorporated into most fabric preparation sequences already being used (Mehta and Combs, 1996). One treatment which uses the exhaust method involves the use of a derivative of chitin.

## Chitosan

Chitin is the second most plentiful, naturally occurring polymer, after cellulose, in the world. Chitin is found in the exoskeletons of arthropods. For commercial uses this product is primarily derived from shrimp and crabs. Chitosan, a derivative of chitin, is prepared by partial deacetylation of the chitin. Chitin and chitosan have a variety of special functions ranging from health and beauty aids to water purification, biomedical applications, agriculture, biotechnology, nutrition, and treatments in the finishing process of textile fibers. Chitosan can also be used in a process which covers neps in cotton fabrics. The chitosan aftertreatment is used on fabrics which have already been dyed and rejected due to the presence of neps. Unlike the chitosan pretreatment reported in Teal et al. (1998), only those fabrics which have already been rejected are treated which will decrease treatment costs.

The fabric containing neps is treated with a mixture of chitosan, a non-ionic wetting agent, and sodium sulfate (hereafter referred to as chitosan aftertreatment). The amount of chitosan used in the aftertreatment is more than that used in the pretreatment. The increased chitosan is necessary to overcome the dye already present in the fabric. However, the chitosan aftertreatment requires no additional machinery, and it does increase the dyeing ability of direct and reactive dyes. This treatment is also effective in eliminating differences in color between dyed immature and mature cotton fibers (Rippon, 1984). The binding of the chitosan with the cellulose already present in the cotton fiber increases the fiber's dyeing ability and reduces problems resulting from immature or entangled fibers that will not accept dye, thereby reducing the impact of the quality problem most SHPT producers must deal with.

Chitosan is biodegradable when used and distributed into the environment in a dispersed fashion. Thus, using chitosan treatments in the textile dyeing process represents

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an environmentally sound practice (Mehta 1996). With the introduction of chitosan aftertreatments for cotton fabrics, the fabric that had previously been rejected due to the presence of neps can now be sold to the original contracted buyer at the premium price.

A limitation of the chitosan aftertreatment is that it enhances the performance of some dyes better than others. Chitosan treatments, used in conjunction with direct dyes, increase the color strength more than reactive dyes (Mehta, 1996). An additional problem with the chitosan aftertreatment is that it reduces the quality of the wash-fastness and/or color-fastness properties. However, this problem is eliminated with the introduction of a post treatment consisting of fiber-reactive quaternary ammonium compounds (Rippon, 1984). However, this additional requirement adds to the already numerous stages through which mills must place their yarns without any assurance that their efforts will pay off. Another product used to overcome the problem associated with neps is cellulase enzymes.

## Cellulase Enzymes

Cellulase enzymes are used in the scouring, desizing, bleaching, and finishing phases of the textile manufacturing process. The enzymes are used to reduce fabric fuzziness, soften fabric, remove color for special effects, and for the removal of neps (Blanchard and Graves, 1995). The cellulase enzyme causes a chemical reaction with the cellulose on the surface of cotton fibers. The weak, extending fibers (e.g., those fibers which have ends protruding from the fabric providing an appearance of fuzziness) are then detached using mechanical agitation. The fibers must then be cleaned from the fabric.

The aftertreatment process is identical to the pretreatment using cellulase enzymes and is reported by Ankeny (1996). The bath is set at 27 degrees C with the fabric present, and a buffer is added to keep the pH stable. This mixture is allowed to circulate for five minutes, then the pH is measured and adjusted to between 4.5 and 5 (4.8 is considered optimum) with acetic acid. The temperature is then raised to 58 degrees C, and the pH is again measured and adjusted to 4.8. The cellulase enzyme is added, and the solution is circulated for 30 minutes with high agitation. The liquid is then extracted, the bath is filled with hot water and heated to 83 degrees C followed with 10 minutes of circulation. The bath is drained, and the fabric rinsed with cold water. The final step involves a mechanical treatment such as a tumble dry to remove surface fibers.

The hot water is needed quickly after the chemical reaction between the enzymes and the cotton. The enzymes are neutralized by the hot water before the enzymes can further react with all fibers in the fabric. By neutralizing the solution quickly, fiber strength can be maintained. After treating the fabric, there needs to be some mechanical agitation which will remove the surface fibers. In the above process, the tumble dry component removes all surface fibers which have been damaged by the enzymes. If the fabric is not tumble dried, an alternative mechanical treatment must be used to remove the surface fibers. This can be done in a continuous range with a mechanical arm which rubs against the fabric, removing fibers. To conduct an analysis of this treatment which can be used with the exhaust process, it is assumed that the mechanical action provided by the scouring process within a keir is sufficient to remove the surface fibers when combined with the knitting and weaving of the yarn into fabric.

## Specific Problem

Most textile processors are slow to adopt new and unknown practices. Because these aftertreatments are unfamiliar to many textile processors, they are reluctant to adopt these practices, thereby not potentially maximizing their profits. Processors should be made aware of the potential economic benefits and costs of these treatments.

The objective of this study was to conduct a benefit/cost analysis of the use of these aftertreatments for cotton fabrics. The major benefit examined is the decreased fabric rejection. Because only those fabrics already rejected are treated, the aftertreatment benefits are more than the pretreatment benefits reported by Teal et al. (1998).

## Methods and Procedures

Estimation of the cost effectiveness of adoption of these aftertreatments was accomplished by conducting a benefit/cost analysis for the use of one of these treatments in a representative mill setting. Estimated cost values from the dyeing process of a representative mill are included in Table 1. This representative mill is assumed to be a medium sized textile mill, which uses between 18,000 and 22,000 bales of cotton per year to produce apparel and furniture upholstery. It is assumed that approximately 80 percent of this cotton is used to produce light weight fabrics for apparels and the remainder is used for household and industrial upholsteries.

Textile mills often spin cotton into yarn, weave the yarn into fabric, and dye the fabric only to find that it is unsuitable for use in the final product because of the presence of neps. It is assumed that the representative mill has a rejection rate of 3.5 percent of the fabric. It is further assumed that 10 percent of this rejection is due to the presence of neps. Thus, it is assumed that 0.35 percent of the light weight fabric is rejected due to the presence of neps. This rejected fabric is then sold on a secondary market for a discounted price. If the textile mill were to adopt either of the considered aftertreatments, this fabric could be sold to the original buyer at the premium price.

Cost-effectiveness of the aftertreatments considered in this study was determined by whether benefits outweigh costs.

The major benefit examined in this study is the decrease in the amount of fabric rejected due to the presence of neps. The reduction in the amount of dye used is not considered a benefit for the chitosan aftertreatment as it was for the pretreatment (Teal et al., 1998) because the fabric must be redyed once the aftertreatment has been completed. The use of the cellulase enzyme aftertreatment does not affect the amount of dye used when dyeing fabrics.

The cost of adopting either pretreatment can be expressed in the following form:

$$TC = CP + CAC + VOH + FOH + CAL.$$

Where TC is the total cost of the treatment, CP is the cost of the treatment product (i.e., chitosan or cellulase enzymes), CAC is the cost of the additional chemicals (i.e., sodium sulfate, wetting agent, buffer, acetic acid, etc.), VOH is the increase in variable overhead, FOH is the increase in fixed overhead, and CAL is the increase in cost of additional labor. The total benefits (TB) are the value of the decrease in fabric rejection. The economic efficiency of adopting the pretreatments is determined by whether TB is greater than TC, or if net returns (NR) are greater than zero, where NR = TB - TC.

## Results

### Chitosan Aftertreatment Costs

Table 1 presents the estimated costs of three wet processes from a representative textile mill. This data was supplied from an actual mill setting. To preserve the anonymity of the mill, the identification will not be disclosed. The first procedure for which data is presented is a bleach formula process. Yarn treated by this process will be used in white fabrics only. These values are expressed in dollars per pound of yarn. The total cost of putting yarn through the bleaching process was found to be $0.14990 per pound of yarn. This total cost consists of labor, variable overhead (which includes water and electricity), fixed overhead (representing a percentage of the firm's fixed costs), and chemical costs. Also in Table 1 are the various costs for putting a yarn through a process that involves scouring, not bleaching, and being dyed black. Scouring is a process in which the fabric or yarn is cleansed, using detergents and soaps, and either an abrasion or rubbing treatment. This process is used to remove dirt, grime, soil and other foreign matter or particles. The final process presented in Table 1 is a process in which the yarn is scoured and bleached, then dyed red. The bleach process is less expensive than the other two representative processes because it requires less time to complete the process and there are no dye costs associated with this process. The bleaching process requires approximately 90 minutes to complete, while the dyeing processes require an additional 40 to 50 minutes.

The chitosan aftertreatment is reported by Mehta and Combs (1996). Because this process is an aftertreatment, all costs incurred before the treatment is applied are sunk costs. Sunk costs are those costs which cannot be recovered once they have been paid. In this case, sunk costs include the cost of all processes from scouring and bleaching through the dyeing process, as well as all associated chemical, labor, variable, and fixed overhead costs. These sunk costs are not included in the costs specified for the cost of the aftertreatment.

Like the pretreatment, the cost effectiveness of the aftertreatment is determined using the cost values of the representative mill. The treatment itself takes approximately one hour to complete before the fabric is redyed. To determine the price that the textile mill would pay for the chitosan, the amount of chitosan which would be used per year must be determined. The representative textile mill processes 18,000 bales per year, or 8,640,000 pounds of cotton lint (at 480 pound bales). The mill uses 80 percent of this cotton to produce light weight fabrics. The aftertreatment is used only on light weight fabrics destined for apparel because neps are generally not a problem in heavier weight fabrics used in furniture upholsteries. The amount of chitosan used for the exhaust process is 0.6 percent on the weight of the fabric. Therefore the amount of chitosan needed annually is 1,452 pounds (e.g., 18,000 bales * 480 pound bales * 0.8 * 0.035 * 0.006).

The chemical costs of the chitosan aftertreatment are assumed to be similar to that presented for the pretreatment (see Teal et al., 1998). The amount of sodium sulfate used is 10 percent on the weight of the fabric and is sold for $0.22 per pound. The amount of non-ionic wetting agent used is 0.1 percent and the cost of the wetting agent is assumed to be $0.89 per pound. The cost of additional dye will be presented later.

Costs presented by the representative mill are examined to determine the costs of labor, water, electricity, and time it takes to complete the process. The chitosan aftertreatment takes approximately one hour to complete. The bleach process presented takes approximately 90 minutes; therefore, the costs of running the dye machines for the aftertreatment are assumed to be two-thirds of the cost of running the bleach process. In the case of the representative textile mill, the costs of the aftertreatment would be: $0.02157 per pound of fabric for labor, $0.046364 per pound of fabric for variable overhead, and $0.023048 per pound of fabric for fixed overhead. The aftertreatment also requires that the fabric be redyed.

The costs presented by the representative textile mill include costs for both a black and a red dye treatment. The black dye process includes scouring, but not bleaching, while the red dye process includes bleaching, but not scouring. Actually, the red dye process is bleached with what is known as a one step bleach, which includes both scouring and bleaching in the same process. Once the chitosan aftertreatment has been completed, it is necessary to redye the fabric. In order to determine the cost-effectiveness of the aftertreatment, the red dye process, which is less expensive, was used and the black dye process will be considered in the sensitivity analysis. The cost of the red dye treatment is $0.84910 per pound of fabric. It is assumed that this process uses approximately 2 percent dye on the weight of the fabric (o.w.f.). However, when using the aftertreatment, the fabric requires approximately 0.2 percent (o.w.f.) of the same dye. Therefore, the cost for the red dye process will be the same as the values presented by the representative mill, except for the dye cost, which will be 10 percent of the dye cost of the original process. Thus, the dye cost for the second dye process would be $0.00979 instead of $0.09790. With the costs of labor, variable and fixed overhead, and chemical costs, the redye process would cost approximately $0.76 per pound (i.e. 0.1569 + 0.33670 + 0.1675 + 0.00979 + 0.0901).

The total cost for the chitosan aftertreatment is the sum of the cost for labor, variable overhead, fixed overhead, dye, and chemicals for both the aftertreatment and the second dye process. Table 2 contains each of these costs. As can be seen in Table 2, the total cost of treating the fabric with chitosan, then redyeing the fabric would cost approximately $0.92 per pound of fabric. This value will be compared to the total benefits received from using the chitosan aftertreatment once that value has been developed in the next section.

**Chitosan Aftertreatment Benefits**

As stated previously, the benefits received by using the aftertreatment are specified in the difference between the contracted fabric price and the secondary market price. The average premium price received for the finished product is $3.25 per linear yard of fabric. The rejected fabric is sold on the secondary market for $1.25 per linear yard of fabric. The difference in price between the two grades of fabric is $2.00 per linear yard. Assuming the chitosan aftertreatment covers 90 percent of all neps, and assuming this meets the specifications set forth in the contract with the buyer, all fabric rejected because of the presence of neps can be sold for the premium price. Therefore, rather than receive the $1.25 per linear yard of rejected fabric, the textile mill will receive the $3.25 per linear yard of recovered fabric after the treatment. To compare this benefit with the treatment costs, the $2.00 difference must be converted from linear yards of fabric to pounds of cotton.

As mentioned previously, it is assumed that the textile mill will use this treatment only on those light weight fabrics used for apparel. Assuming a light weight yarn of 5 ounces per square yard of fabric, and a 60 inch fabric width, one linear yard of fabric contains 0.52 pounds of cotton. Therefore, the $2.00 is divided by 0.52 pounds resulting in the value of the benefits received from using the chitosan aftertreatment is $3.846 per pound of cotton treated. This represents the value of the benefits if only that fabric rejected due to neps is treated. If there are other defects in the fabric which contains neps, it could still be rejected, thereby reducing these benefits.

Subtracting the treatment costs from the benefits results in a positive net revenue of $2.923138 per pound of cotton. Given the above assumptions, the use of chitosan aftertreatments in the representative mill is cost effective.

**Cellulase Enzyme Aftertreatment Costs**

Because the process for the enzyme aftertreatment is identical to the process for the pretreatment examined in Teal et al. (1998), the costs will be similar, and the only difference will be the price of the enzyme. Using a pretreatment, all cotton used in apparel must be treated, but with the aftertreatment, the only fabrics treated are those which have been rejected due to the presence of neps. The amount of fabric rejected by the representative mill due to the presence of neps is approximately 24,192 pounds. Thus, the amount of enzyme needed for the aftertreatment would be approximately 222.5664 pounds per year (i.e., 0.0092 * 24,192). This amount of enzyme is not enough to qualify for a price discount. Therefore the price per pound of cellulase enzymes is assumed to be $4 per pound. The remaining costs are assumed to be those presented in Table 3. As can be seen in Table 3, the cost of adopting the cellulase enzyme aftertreatment is approximately $1.09.

**Cellulase Enzyme Aftertreatment Benefits**

The benefits received by using the cellulase enzyme aftertreatment are the same as the benefits received by using the chitosan aftertreatment. As stated previously, the benefits received from using the cellulase enzyme aftertreatment are the difference between the premium price and the salvage price of the rejected fabric. The average premium price received for the finished product is $3.25 per linear yard of fabric. The rejected fabric is sold on the secondary market for $1.25 cents per linear yard of fabric. The difference is $2.00 per linear yard of rejected fabric. Assuming the treatment removes enough neps to meet the specifications set up by the contracted buyer, all fabric rejected because of the presence of neps can be sold for the premium price. Therefore, instead of receiving the $1.25 per linear yard of fabric, the textile mill will receive the $3.25 per linear yard of fabric. To compare this benefit with the treatment costs, the $2.00 difference must be converted from linear yards of fabric to pounds of cotton.

As mentioned previously, it is assumed that the textile mill will use this treatment only on those light weight fabrics used for apparel. Assuming a light weight yarn of 5 ounces per square yard of fabric, and a 60 inch fabric width, one linear yard of fabric contains 0.52 pounds of cotton. Therefore, the $2.00 is divided by 0.52 pounds resulting in the value of the benefits received from using the cellulase enzymes as a salvage operation as $3.846 per pound of cotton treated. Subtracting the cost of $1.09 from the value of the benefits results in a net return of $2.756 per pound of cotton treated. Therefore, the cellulase enzyme aftertreatment would be cost effective for textile mills to adopt.

## Sensitivity Analysis

A sensitivity analysis was conducted on each of the processes considered to determine whether changing certain costs would change the cost effectiveness. Another purpose for the sensitivity analysis was to determine how sensitive the results are to the data used. Certain values could not be determined with 100 percent accuracy. These values were changed to consider various techniques used in different textile mills, different amounts of product used, and different prices for these products. The total costs and benefits received from adoption of a process were also changed to determine what would need to change to make the aftertreatments become less cost effective. Additional changes are made to determine if the treatment would be cost effective in a different time frame.

### Chitosan Aftertreatment

Many scenarios were considered for each aftertreatment. In the sensitivity analysis for the chitosan aftertreatments, costs were increased and benefits were decreased to determine whether it would be less cost effective for textile mills which use different processes or have different costs than those presented by the representative mill.

The original net revenues for the representative textile mill was approximately $2.92 per pound of cotton treated. Changing several benefits and costs did not reveal any scenario that would make the treatment not cost effective. The scenario which came closest to not being cost effective was when the value of the rejected fabric was reduced from $2 per linear yard to $1 per linear yard, thus decreasing benefits. In this scenario the cost of chitosan was increased from $8 per pound to $12 per pound in this scenario and the net revenues from adopting the aftertreatment remained at approximately $0.98 per pound of cotton treated. With positive net revenues for all scenarios considered, it was determined that the chitosan aftertreatment would be cost effective for any textile mill to adopt at this time.

### Cellulase Enzyme Aftertreatment

Again, several scenarios were considered to determine at what point the cellulase enzyme aftertreatment would become not cost effective. Benefits were decreased and costs were increased to determine if the pretreatment would become less cost effective for other textile mills incurring different costs.

The original net revenues from adoption of the cellulase enzyme aftertreatment were approximately $2.75. After considering a number of changes in both benefits and costs, the cellulase enzyme aftertreatment was cost effective in all scenarios considered. The lowest net revenues considered in the sensitivity analysis were approximately $0.58. This took place when all overhead costs were increased by as much as 200 percent and the costs of all inputs were also increased by up to 200 percent. With positive net revenues for all scenarios considered, it is determined that the cellulase enzyme aftertreatment would be cost effective for textile mills to adopt at this time.

## Conclusion

Aftertreatments using both chitosan and cellulase enzymes are cost effective for the representative textile mill in this study. Also, the sensitivity analysis shows that the treatments would be cost effective in every scenario considered.

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Table 1. Costs for Various Textile Processes in a Representative Textile Mill ($/lb of yarn).

| Process | Labor | Var OH[1] | Fix OH[2] | Dyes | Chem | Total |
|---|---|---|---|---|---|---|
| | | $/lb of Cotton Treated | | | | |
| Bleach | 0.032 | 0.069 | 0.034 | 0.000 | 0.014 | 0.150 |
| Black[3] | 0.171 | 0.367 | 0.182 | 0.490 | 0.165 | 1.374 |
| Red[4] | 0.157 | 0.337 | 0.168 | 0.100 | 0.090 | 0.850 |

[1] Var OH represents costs of variable inputs such as electricity, water, and others not described elsewhere.
[2] Fix OH represents costs of fixed inputs as well as time required for the prices.
[3] Scoured, not bleached.
[4] Scoured and bleached before being dyed.

Table 2. Input Costs for the Chitosan Aftertreatment.

| | Cost ($/lb) | Amount Used (o.w.y.*) | Cost ($/lb) |
|---|---|---|---|
| Chitosan | $8.50 | 0.6% | $0.0510 |
| Sodium Sulfate | $0.22 | 10% | $0.0220 |
| Non-ionic Wetting Agent | $0.89 | 0.1% | $0.00089 |
| Labor | | | $0.02305 |
| Variable Overhead Costs | | | $0.04636 |
| Fixed Overhead Costs | | | $0.02305 |
| Redye Process | | | $0.7610 |
| Total Cost of Process | | | $0.92286 |

* On weight of yarn.

Table 3. Costs per Pound of Cotton Treated for Cellulase Enzyme Aftertreatments.

| Input | Cost ($/lb) | Amount Used (lbs.) | Total Cost ($/lb) |
|---|---|---|---|
| Cellusoft L® | 4.00 | 0.0092 | 0.0368 |
| Buffer-In 5 | 0.50 | 0.0565 | 0.02825 |
| Acetic Acid | 0.50 | 0.000029195 | 0.000014598 |
| Labor | | | 0.24282 |
| Var OH | | | 0.521282 |
| Fixed OH | | | 0.259292 |
| TOTAL | | | 1.0885 |