REMOVAL OF PLASTIC MATERIALS USING ADJUSTMENTS AND REVISIONS TO STANDARD SEED COTTON CLEANING EQUIPMENT: PROGRESS REPORT

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Abstract

U.S. cotton is known to be relatively free of contamination but occasionally pieces of sheet plastic are found in cotton bales produced in the U.S. A previous study showed that current cotton ginning equipment is not very efficient in removing plastic included in the seed cotton. The purpose of this work was to examine how several operating conditions affect the sheet plastic removal efficiency and fiber loss of one type of gin cleaning machine, the cylinder cleaner. Two types of plastic were used in the study with five levels each of airflow through the machine, seed cotton processing rate, and size of plastic contaminant. Mathematical models were developed predicting the plastic removal and fiber loss given values of airflow, seed cotton processing rate, and plastic contaminant type and size within the ranges studied. Plastic removal decreased linearly with increasing processing rate while fiber loss increased quadratically with increasing processing rate. Desirability functions showed that at a given low airflow rate decreasing the seed cotton processing rate resulted in better operation (less fiber loss with slightly less plastic removed), but at a given high airflow rate higher processing rates resulted in better operation.

Introduction

Plastic contamination of fiber is costly for textile mills, due to the expense of removal equipment, downtime, and material waste from contaminated finished goods. U.S. produced cotton is among the least contaminated in the world, according to surveys of textile mills conducted by the National Cotton Council (2009) and the International Textile Manufacturers Federation (2014). Although contamination levels remain low compared to the rest of the world, the International Textile Manufacturers Federation survey indicated that contamination of U.S. cotton from plastic film has increased since 2009, Figure 1. Recently, a cotton picker was introduced that constructs round modules wrapped in polyethylene plastic film. Additional concerns from industry have arisen because of the potential to introduce additional plastic into cotton fiber.

Figure 1. Dark plastic material found in a bale of U.S. cotton by a mill.
Courtesy of Lance Murchison, National Cotton Council.

A previous study indicated that a significant portion of various sizes and thicknesses of plastic sheet materials mixed into seed cotton were not removed with normal ginning machinery (Byler, Boykin and Hardin 2013). Specifically, thinner materials and larger pieces were more likely to contaminate the lint. The stick machine and extractor-feeder were most effective at removing thicker materials, while the cylinder cleaners removed 46% of 25 mm x 25 mm (1 in. x 1 in.) pieces, across all material thicknesses. The cylinder cleaners tested in the previous study were gravity-fed and operated at a low processing rate. Operating the cylinder cleaners in a manner similar to commercial gins may affect plastic removal rates. Furthermore, because the cylinder cleaners did remove significant amounts of small, thin plastic, modifying the cylinder cleaner operating parameters may improve plastic removal. Increased plastic removal by cylinder cleaners may justify the use of cylinder cleaners with lint, as saw-type lint cleaners removed less than 20% of the plastic remaining in the lint.

While research focused on plastic removal by cylinder cleaners is limited, the effects of various operating parameters on foreign matter removal (primarily leaf) by cylinder cleaners have been studied. Hardin and Byler (2013) found that more material was removed by the first stage cylinder cleaner at lower processing rates. No differences were observed in fiber loss from the cylinder cleaner due to processing rate. Hardin (2014) also tested the effect of cylinder speed on material removal and fiber loss. Higher cylinder speeds increased both the total material removal and fiber loss from the cylinder cleaner. In both of these previous studies, the cylinder cleaner was gravity-fed. Air-fed cylinder cleaners were found to have increased fine trash removal compared to gravity-fed cleaners with no difference in fiber loss (Laird, Baker and Childers 1984). However, only a single airflow rate was tested and not specified.

A greater understanding of the factors affecting plastic removal and fiber loss by the cylinder cleaner is needed to optimize existing ginning machinery for plastic removal. The objectives of this study were to:

- Determine effects of airflow rate, seed cotton processing rate, and plastic size and source on plastic removal and fiber loss by the cylinder cleaner
- Develop models for plastic removal and fiber loss that can be used to optimize machine performance

Materials and Methods

The pneumatic conveying system described by Hardin (2014) was used in this experiment. This system is comprised of a variable-speed feed control, a conveying section, separator, variable-speed fan, and instrumentation for measuring static pressure and velocity. The pneumatic conveying system was modified for this test by adding a 25.4-cm (10-in.) wide six-cylinder cleaner (Lummus Corporation, Savannah, Ga.) in the conveying section, Figure 2. The seed cotton exited the cylinder cleaner through a vacuum dropper and discharge chute, while all material removed from the seed cotton by the cylinder cleaner was conveyed to the separator and discharged. Standard grid bars were used, 9.5 mm (3/8 in.) diameter round bars with 7.9 mm (5/16 in.) gap between them, and the cylinders were operated at the recommended speed of 480 rpm. Multiple fan speeds were tested with no cotton in the modified system to estimate air leakage into the system, and consequently, the airflow rate through the cylinder cleaner grid bars.

Figure 2. Six cylinder cleaner used to collect data on plastic removal and fiber loss at several airflow rates, seed cotton processing rates and particle sizes.

Two plastic sources that commonly contact seed cotton were used in these tests- shopping bags (12.7 µm (0.0005 in.) thick polyethylene) and John Deere (Moline, Ill.) module wrap (76.2 µm (0.003 in.) thick polyethylene). For each plastic source (PSource), a rotatable central composite design was used to evaluate the effect of airflow rate (AFR), seed cotton processing rate (SCPR), and plastic size (PSize) on plastic removal (PR%) and fiber loss (FL%) by the cylinder cleaner (Table 1). Airflow and seed cotton processing rates listed are only target rates provided for informative purposes, as the feed control and fan motor speeds were varied to achieve the desired rates. The minimum airflow rate tested is a typical cotton gin design value. Higher rates were evaluated to test the hypothesis that increased airflow rates through the cylinder cleaner grids improve plastic removal. The seed cotton processing rates selected for testing span the range of rates observed in commercial gins, on a unit machine width basis (Hardin, Valco and Byler, Survey of seed cotton cleaning equipment in Mid-South gins 2011). The center point rate corresponds to a processing rate of 9.8 bales hr^{-1} m^{-1} (3.0 bales hr^{-1} ft^{-1}), with 635 kg (1400 lb) seed cotton needed to produce one bale. All plastic pieces mixed into the seed cotton were square, with the appropriate scaling applied to the length of the sides, as opposed to the area. Preliminary testing was used to identify a range of plastic piece sizes that would be partially removed at all test conditions, since much smaller plastic pieces are removed efficiently and very large pieces are not removed by the cylinder cleaner. Six replications at center point values were tested for each plastic source, resulting in 40 experimental runs, which were conducted in randomized order.

Table 1. Independent factor (variable) levels used in plastic removal experiment

Level[z]	Airflow Rate (per unit width) m^2 s^{-1} (ft^2 min^{-1})	Seed Cotton Processing Rate (per unit width) kg min^{-1} m^{-1} (lb min^{-1} ft^{-1})	Size (length of side) mm (in.)
- Axial	2.32 (1500)	45.8 (30.8)	29 (1.14)
- Factorial	2.64 (1700)	69.4 (46.7)	37.5 (1.48)
Center	3.10 (2000)	104.2 (70.0)	50 (1.97)
+ Factorial	3.56 (2300)	138.9 (93.3)	62.5 (2.46)
+ Axial	3.87 (2500)	162.6 (109.3)	71 (2.80)

[z]Labels for different levels of the independent variables using nomenclature of central composite design.

A single cultivar of cotton, PHY 499 WRF (Dow AgroSciences, Indianapolis, Ind.), was used in this study. One sample was collected from each test lot for moisture and foreign matter content determination (Shepherd 1972). The mean seed cotton moisture content was 8.1 percent wet basis. The seed cotton used was weighed prior to loading into the pneumatic conveying system, with an average lot size of 15.3 kg (33.8 lb). Twenty pieces of the specified type and size of plastic were mixed into the seed cotton. All seed cotton was conveyed through the conveying system, and the number of plastic pieces remaining in the seed cotton and the number removed by the cylinder cleaner were recorded. In some cases, a few plastic pieces remained in the system. If a piece had passed through the cylinder cleaner grid bars (i.e. remaining in the vacuum dropper under the separator), the piece was considered removed. Plastic pieces in the cylinder cleaner dropper were counted as remaining in the seed cotton. Any plastic piece remaining in the body of the cylinder cleaner above the grid bars was not considered when the percentage of plastic pieces removed was calculated. The material removed by the cylinder cleaner was weighed and manually sorted to determine the fiber loss from each test lot. Total fiber loss included both loose fiber and fiber hand-ginned from seed cotton. The fiber loss was calculated as a percentage of the initial seed cotton weight before processing.

SAS JMP 8.0 (SAS Institute, Inc., Cary, N.C.) was used to fit a response surface model to the plastic removal and fiber loss data. A square root transformation was applied to the fiber loss response variable, as many fiber loss values were near zero, and the variance increased with increasing fiber loss. Plastic source was included as a main effect in the model and crossed with other main effects. Insignificant terms ($p > 0.05$) were eliminated sequentially while maintaining model hierarchy. Desirability functions were calculated from the plastic removal and fiber loss response variable and used to determine optimum operating parameters. Desirability functions vary from zero at unacceptable values of response variables to one at target values. An overall desirability is calculated by taking the geometric mean of the desirability values for individual response variables.

Results and Discussion

Plastic Removal

Plastic removal was significantly affected by all main effects and the interactions between seed cotton processing rate and plastic source and plastic size and plastic source (Table 2). The plastic source had the largest effect on plastic removal percentage, as the mean removal percentages for shopping bags and module wrap were 56.3% and 9.3%, respectively.

Table 2. Significant effects in model for plastic removal.

Effect	F Ratio	Probability > F
AFR	4.903	0.0338
SCPR	4.220	0.0479
PSize	19.498	0.0001
PSource	104.538	< 0.0001
SCPR*PSource	5.307	0.0277
PSize*PSource	4.651	0.0384

The model for plastic removal percent (PR%) had an adjusted R^2 of 0.78 (variables are in SI units indicated in Table 1):

$$PR\% = \begin{cases} 13.367\,AFR - 0.34888\,SCPR - 1.4622\,PSize + 124.31 & \text{(shopping bags)} \\ 13.367\,AFR + 0.019975\,SCPR - 0.50262\,PSize - 9.0676 & \text{(module wrap)} \end{cases}$$

Higher airflow rates and smaller plastic pieces resulted in increased plastic removal. Higher seed cotton processing rates reduced plastic removal for shopping bags. Although the model showed increased plastic removal at higher seed cotton processing rates for module wrap, only a 2.3% difference would be predicted between the maximum and minimum processing rates tested in this study. The effects of the various factors tested on plastic removal are illustrated graphically in Figure 3.

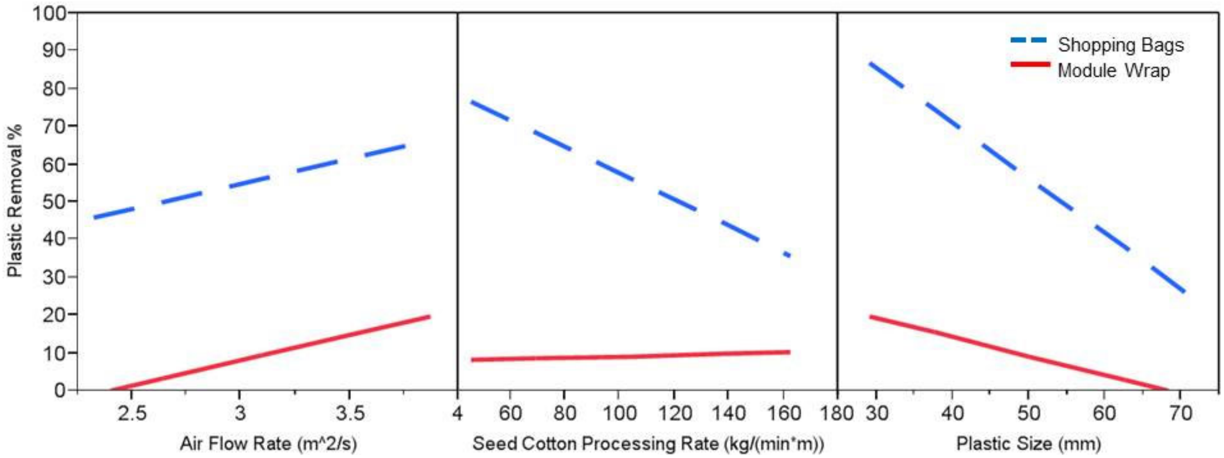

Figure 3. Predicted plastic removal. The predicted values were calculated by varying each continuous factor while holding the other variables at their center values.

The results of the study by Byler, Boykin, and Hardin (2013) cannot be compared directly to the plastic removal values predicted by this model, since the cylinder cleaners in that study were gravity-fed and a low seed cotton processing rate (approximately 30 kg min^{-1} m^{-1}) was used. However, trends observed in that study parallel the results of this experiment. In both cases, a higher percentage of shopping bag pieces were removed than module wrap pieces in the cylinder cleaner. Larger size plastic pieces were more difficult to remove, as only one piece larger than 25 mm x 25 mm (1 in. x 1in.) was removed in the previous study.

Fiber Loss

Fiber loss was only significantly affected by airflow rate, seed cotton processing rate, their interaction, and the quadratic terms for both significant main effects (Table 3).

Table 3. Significant effects in model for fiber loss.

Effect	F Ratio	Probability > F
AFR	91.686	< 0.0001
SCPR	40.811	< 0.0001
AFR*SCPR	9.755	0.0036
AFR*AFR	10.351	0.0028
SCPR*SCPR	5.240	0.0284

The model for fiber loss percent (FL%) had an adjusted R^2 of 0.80 (variables are in SI units indicated in Table 1):

$$\sqrt{FL\%} = 0.083430AFR^2 + 1.0432*10^{-5}SCPR^2 - 0.0014477AFR \cdot SCPR - 0.24794AFR + 0.0012657SCPR + 0.35793$$

With low airflow rates, fiber loss is nearly zero. Fiber loss increases significantly at higher airflow rates, as reflected by the quadratic term in the model for fiber loss. However, higher seed cotton processing rates reduce fiber loss as the airflow rate increases (Figure 4). The likely explanation is the fiber lost per unit time was nearly constant for a given airflow rate; consequently, a higher seed cotton processing rate will decrease the fiber loss as a percent of total seed cotton mass.

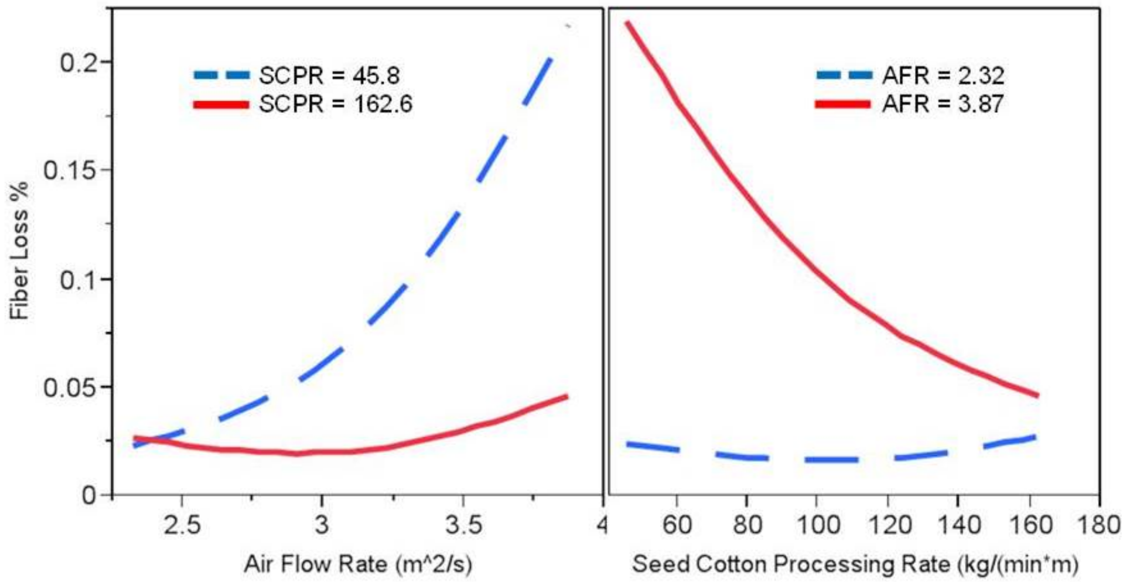

Figure 4. Interaction plots for airflow rate and seed cotton processing rate factors in fiber loss model.

Discussion

Additional variables, beyond the factors tested in this study, likely affect the response variables. Hardin and Byler (2013) found that cultivar had a significant effect on the fiber loss from gin machinery. One cultivar may have a fiber loss level at a given set of operating parameters that is acceptable to gin operators, but a different cultivar may have excessive fiber loss with the same operating conditions. Gins may encounter many kinds of plastic contamination, both in terms of the source and size of plastic pieces. However, previous research indicated that thicker plastics, such as module wrap, are more effectively removed by extractors in the gin than thinner plastics, like shopping bags. Consequently, the following discussion of optimum operating parameters focuses on plastic from shopping bags.

Desirability functions were defined for both the plastic removal and fiber loss response variables that varied linearly between the upper and lower limit values in Table 4. Optimum fiber loss was not strictly set to zero, as some fiber loss is inevitable, and there is variability in the measurement of fiber loss. Economic data is not available to accurately define these functions; consequently, the values were selected may not actually provide optimum operating parameters.

Table 4. Desirability functions for plastic removal and fiber loss.

Desirability	PR%	FL%
0	0	≥ 0.1
1	100	≤ 0.03

A contour plot of the overall desirability function for removing 50 mm x 50 mm (1.97 in. x 1.97 in.) shopping bag pieces is shown in Figure 5. The maximum overall desirability occurs at an airflow rate of 2.47 m^2 s^{-1} (1600 ft^2 min^{-1}) and a seed cotton processing rate of 45.8 kg min^{-1} m^{-1} (30.8 lb min^{-1} ft^{-1}). The model predicts that 68.3% of the plastic pieces will be removed and fiber loss will be 0.029%. The size of the plastic pieces does not have much effect on the shape of the contour plot as plastic size only affects plastic removal and does not interact with airflow rate or seed cotton processing rate. The region with nearly horizontal contours on the left side of the plot corresponds to combinations of factors resulting in fiber loss less than 0.03%. Therefore, higher plastic removal increases values of the overall desirability. At a given seed cotton processing rate, airflow should be increased, until the desirability function decreases due to higher fiber losses. Likewise, at lower airflow rates, reducing the seed cotton processing rate increases plastic removal and maximizes overall desirability. At higher airflow rates, the seed cotton processing rate must be increased to reduce fiber loss. The lower right portion of the graph corresponds to combinations of airflow rate and seed cotton processing rate that result in fiber loss greater than 0.1% and the resulting desirability is zero.

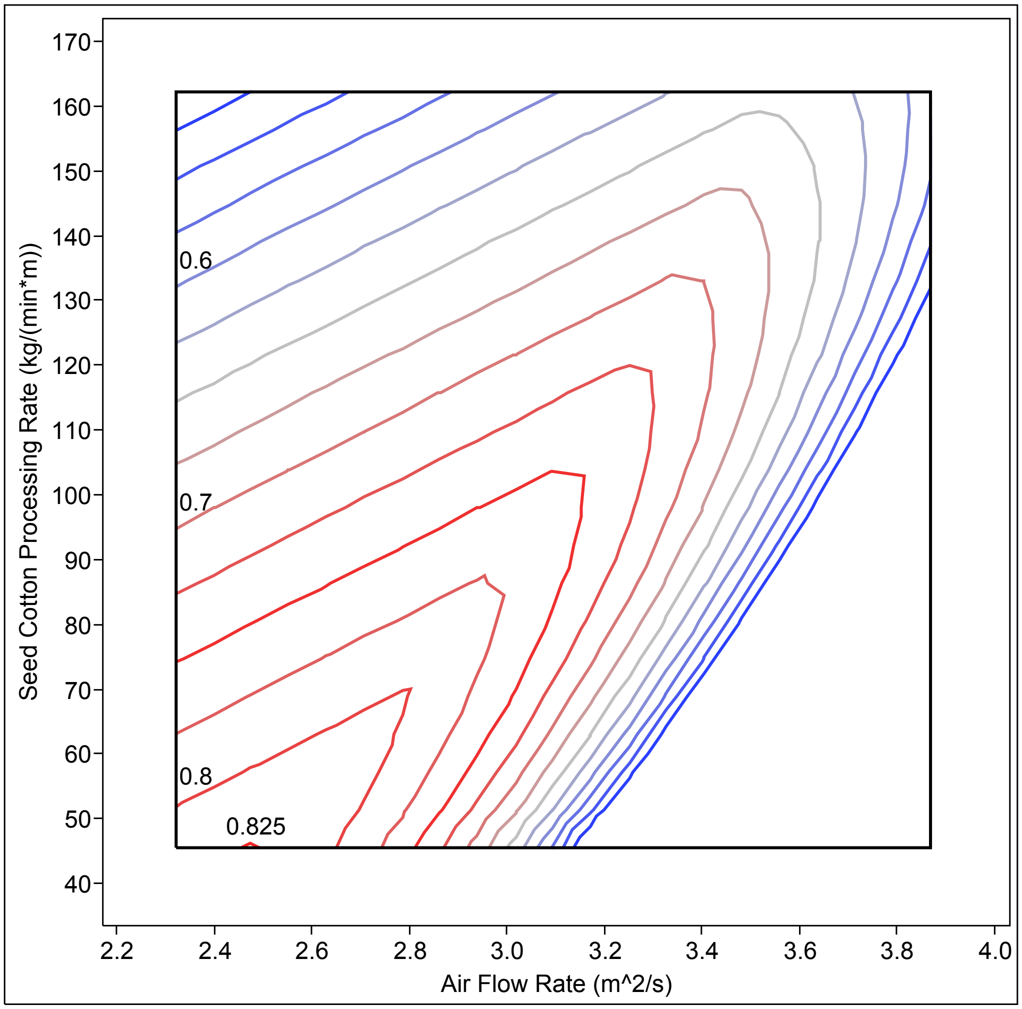

Figure 5. Contour plot of overall desirability function.

Conclusions

Plastic removal by a cylinder cleaner was affected by the airflow rate and seed cotton processing rate, as well as the plastic size and source. The cylinder cleaner was much more effective at removing the thinner shopping bag pieces than the thicker module wrap pieces. Higher airflow rates increased plastic removal. Lower seed cotton processing rates increased the removal of shopping bag pieces, but higher rates resulted in a slight increase in the removal of module wrap pieces. Larger plastic pieces were more difficult to remove, and the effect was more pronounced with plastic from shopping bags.

The fiber loss model contained the main effects of airflow rate and seed cotton processing rate, the quadratic terms for both effects, and their interaction. Fiber loss increased significantly at high airflow rates, but higher processing rates reduced the fiber loss at a given high airflow rate. This result likely occurred because the fiber loss per unit time was nearly constant for a given airflow rate. Therefore, higher seed cotton processing rates decreased the fiber loss as a percent of total seed cotton mass.

Desirably functions were created to find operation with low fiber loss and higher plastic removal for the shopping bag pieces. These functions showed that at a low airflow rate decreasing the processing rate resulted in a more desirable combination of fiber loss and cleaning while at a high airflow rate increasing the processing rate resulted in a more desirable combination.

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