The *Journal of Cotton Science 20:375–385 (2016)*
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ENGINEERING & GINNING

Removal of Sheet Plastic Materials from Seed Cotton Using a Cylinder Cleaner

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ABSTRACT

U.S.-produced cotton is among the cleanest available in the world; however, pieces of sheet plastic are found occasionally in cotton bales produced in the U.S. Standard cotton ginning equipment is not efficient in removing plastic contaminating seed cotton. The purpose of this work was to examine how selected operating conditions affect the sheet-plastic removal efficiency and fiber loss of one type of gin cleaning machine, the cylinder cleaner. In the first part, two sources of plastic were each tested in a central composite design, varying air flow rate through the machine, seed cotton processing rate, and size of plastic contaminant. In the second part, only one plastic source was used, but two cotton cultivars were tested in a central composite design. An additional response surface variable, cylinder rotation speed, was evaluated. Plastic removal increased linearly with increasing air flow rate and decreasing size of the plastic pieces. The effect of seed cotton processing rate on plastic removal was less significant than the effect of air flow rate or plastic size in the first part and was not statistically significant in the second part. The plastic from shopping bag material was removed more effectively than module wrap material. More plastic was removed at lower cylinder rotation speeds. Fiber loss increased with higher air flow rates or cylinder rotation speeds and lower seed cotton processing rates. Lower cylinder rotation speeds increased plastic removal and decreased fiber loss; selecting the optimum air flow rate was a compromise between plastic removal and fiber loss.

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). Thus, the emphasis of previous cotton cleaning research has been primarily on naturally occurring plant materials because of the prevalence and the effect this material has on cotton grade and commercial value. 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 (example shown in Fig. 1) has increased since 2009. Minimizing plastic contamination is necessary for maintaining the U.S. cotton industry's status as a high-quality supplier. Plastic contamination of fiber is costly for textile mills, due to the expense of removal equipment, downtime, and material waste from contaminated finished goods.

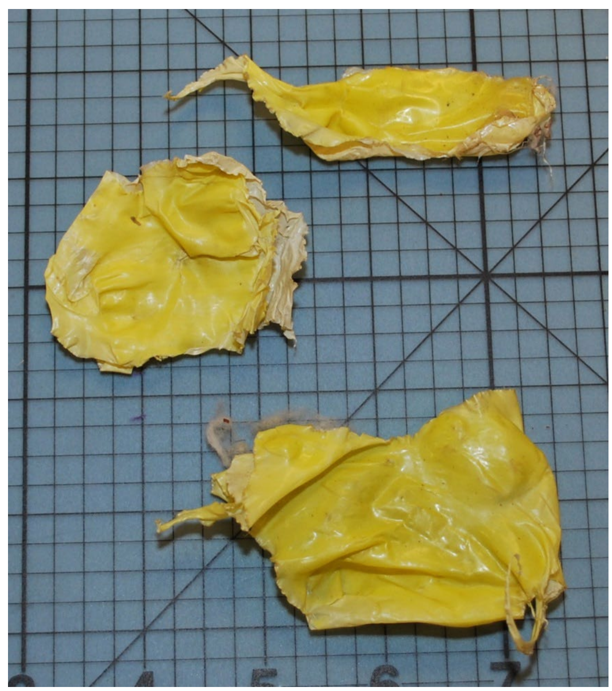

Figure 1. Yellow plastic material found in a bale of U.S. cotton by a foreign textile mill. Courtesy of Dale Thompson, National Cotton Council.

Additional industry concerns have arisen because of a recently introduced source of plastic contamination. In 2009, John Deere (Moline, IL) released the model 7760 harvester that forms a seed cotton module onboard and wraps it in plastic. Several systems are available for removing the plastic from the modules

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at the gin, but most cut the module cover. The first portion of the wrap in contact with the cotton has no adhesive material, and if the module is cut where this occurs, that portion of the wrap could be mixed with seed cotton. John Deere placed an RFID tag in the module cover to facilitate correct positioning of the cover for cutting so smaller pieces of plastic are not created; however, many systems do not use the RFID tag to determine the location for cutting the cover. John Deere (2008) and others (Cotton Incorporated, 2013) have issued recommendations regarding the cutting of the plastic used in the module wrap. Regardless of the system used, the module collapses when the plastic is removed. Therefore, pieces of the wrap can be covered by the collapsing module during removal of the wrap and enter the ginning machines.

A previous study of plastic removal by the entire ginning system, including all equipment normally part of a commercial gin plant, 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 et al., 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, whereas the cylinder cleaners removed 46% of 25-mm x 25-mm (1-in. x 1-in.) pieces, across all material thicknesses. Less than 1% of larger pieces (25 mm x 76 mm [1 in. x 3 in.] and larger) were removed by the cylinder cleaners. These cylinder cleaners were gravity fed and operated at a processing rate of 2.3 bales hr^{-1} m^{-1} (0.7 bales hr^{-1} ft^{-1}), much lower than commercial gins. Operating the cylinder cleaners with air flow through them in a manner similar to commercial gins might affect plastic removal rates. Furthermore, because the cylinder cleaners did remove significant amounts of small, thin plastic, modifying the cylinder cleaner operating parameters might improve plastic removal. Increased plastic removal by cylinder cleaners might justify the addition of machines of this design in cleaning lint after the gin stand. Byler et al. (2013) determined that saw-type lint cleaners removed less than 20% of the plastic remaining in the lint when they reached these cleaners.

Although 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 material removal by the first-stage cylinder cleaner decreased with increasing processing rates from 6.6 to 19.7 bales hr^{-1} m^{-1} (2 to 6 bales hr^{-1} ft^{-1}). No differences were observed in fiber loss from the cylinder cleaner due to processing rate. Hardin (2014a) 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 et al., 1984), however, only a single air flow rate was tested and this rate was not specified. Baker et al. (1982) found that increasing the processing rate through seed cotton cleaners resulted in increased fiber loss.

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: (1) determine effects of air flow rate, seed cotton processing rate, cylinder rotational speeds, and plastic size and source on plastic removal and fiber loss by the cylinder cleaner, and (2) develop models for plastic removal and fiber loss that could be used to optimize machine performance.

MATERIALS AND METHODS

A negative-pressure pneumatic conveying system was used in this experiment. Seed cotton was loaded into a chute above the feed-control rollers. Feed-control roller speed was adjusted using a variable frequency drive (VFD), which varied the seed cotton processing rate. Before conducting the experiment, multiple feed-control roller speeds were tested to correlate seed cotton processing rate to roller speed. A breaker cylinder was installed to disperse the seed cotton, similar to many steady flow feed controls in commercial gins. A 61-cm (24-in.) long by 30.5-cm (12-in.) diameter vacuum dropper was located immediately below the breaker cylinder to minimize air leakage.

Seed cotton was conveyed in a 25.4-cm (10-in.) diameter pipe to a 25.4-cm (10-in.) wide six-cylinder cleaner (Lummus Corporation, Savannah, GA; Fig. 2). The seed cotton exited the cylinder cleaner through a vacuum dropper and discharge chute. All material removed from the seed cotton by the cylinder cleaner was conveyed to a separator and discharged. Standard cylinder cleaner grid bars were used, 9.5-mm (0.375-in.) diameter round bars with 7.9-mm (0.3125-in.) gaps between them. The manufacturer's recommended cylinder rotation speed was 480 rpm. Multiple fan speeds were tested and varied using a VFD. The fan speed was varied with no cotton in the system to measure the air flow rate through the cylinder cleaner grid bars. Measurement of this air flow rate while conveying material was not feasible, as the material removed by the cylinder cleaner would quickly plug the pitot tube used for measuring air velocity. Additionally, recommended air flow rates in commercial gins are for measurements taken when no material is conveyed. Additional details of the pneumatic conveying system (without the cylinder cleaner) are found in Hardin (2014b).

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

Part 1. 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 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 air flow rate (AFR), seed cotton processing rate (SCPR), and plastic piece size (PSize) on plastic removal (PR%) and fiber loss (FL%) by the cylinder cleaner (Table 1). Air flow rates listed were measured with no material conveyed, and the seed cotton processing rates shown were the predicted rates at the corresponding feed-control roller speed. The actual controlled factors were the feed control and fan motor speeds. The minimum air flow rate tested (2.32 $m^3 s^{-1} m^{-1}$ [1500 $ft^3 min^{-1} ft^{-1}$]) was the manufacturer's recommended air flow rate through the cylinder cleaner. Higher rates were evaluated to test the hypothesis that increased air flow rates through the cylinder cleaner grids improve plastic removal. The center and factorial levels of seed cotton processing rate were within the range of rates observed in cylinder cleaners at commercial gins, on a unit machine width basis (Hardin et al., 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. The extreme levels of seed cotton processing rate were slightly outside the minimum and maximum rates observed at commercial gins by Hardin et al. (2011). 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. Because the operating parameters of the cylinder cleaner varied significantly from the study by Byler et al. (2013), a range of plastic piece sizes were tested with the extreme values of air flow rate and seed cotton processing rate. This preliminary testing was conducted to identify a range of plastic piece sizes that would be removed partially at all test conditions. Six replications at center point values were tested for each plastic source, resulting in 40 experimental runs that were conducted in randomized order. A single cotton cultivar, PHY 499 WRF (Dow AgroSciences, Indianapolis, IN), was used and the cylinder cleaner was operated at the manufacturer's recommended cylinder speed of 480 rpm.

Table 1. Experimental factor levels used in plastic removal experiment for Part 1 of the study

Level[z]	Air flow Rate (per unit width) $m^3 s^{-1} m^{-1}$ ($ft^3 min^{-1} ft^{-1}$)	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.

Part 2. Part 2 of the experiment featured several modifications to the experimental design to address additional concerns from the ginning industry that developed from the first part of this work. Although cylinder cleaners in commercial gins usually are operated at a constant speed according to the manufacturer's recommendations (typically at or near 480 rpm), gin operators have expressed interest in installing VFDs on cylinder cleaners for improved foreign matter removal. Therefore, a VFD was installed to control the cylinder cleaner drive motor speed for Part 2. The cylinder speeds tested are shown in Table 2, including all speeds tested by Hardin (2014a) and one speed lower than recommended. The highest speeds tested by Hardin (2014a) had significantly higher fiber losses than lower speeds, and even higher speeds are likely to have unacceptable fiber losses and would require additional motor horsepower. Although other foreign matter removal increases with cylinder speed, plastic removal has not been studied, and lower speeds could improve plastic removal. A semismooth leaf cultivar, ST 4946 (Bayer Crop Science, Research Triangle Park, NC), and a hairy leaf cultivar, ST 5458 (Bayer Crop Science, Research Triangle Park, NC), were used in this test. Although plastic removal was not expected to be affected by cultivar, fiber loss could be affected (Hardin, 2014a). To maintain a reasonable experiment size, only one plastic source was tested. Shopping bags (12.7-µm [0.0005-in.] thick polyethylene) were used for the second part of the experiment, as they commonly come into contact with seed cotton when blown into cotton fields and lodge in the plants. Furthermore, they are difficult to remove with normal ginning equipment. Thicker plastic materials, such as module wrap are more easily removed by the extractor-type cleaners, as opposed to cylinder cleaners (Byler et al., 2013).

The air flow processing rates at the axial and center points were the same as for Part 1 (Table 2). Because an additional variable was included in the central composite design, the relative difference between the axial and factorial points and the center point changes to maintain rotatability. A slightly smaller range was used for the seed cotton processing rate to match more closely the range of rates observed in commercial gins, although the center factor level remained the same. The axial levels for plastic size were changed by 1 mm (0.04 in.), so that the selected sizes were in increments of whole centimeters for easier measuring and cutting. The experimental design was similar to Part 1 of the study, except that two cultivars were tested, instead of two plastic sources, and a fourth factor, cylinder cleaner speed, was added to the central composite design, resulting in 60 experimental runs.

Analysis. Both experiments were analyzed using the same methods. One sample of seed cotton was collected from each test lot for moisture and foreign matter content determination (Shepherd, 1972). All samples were collected before processing, except the sample for moisture content determination in Part 2, which was collected prior to ginning. The seed cotton used was weighed prior to loading into the pneumatic conveying system. Twenty pieces of the specified source and size of plastic were mixed into the seed cotton. All seed cotton was processed 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 with the foreign matter being removed (i.e., remaining in the vacuum dropper under the separator), the piece was considered removed. Plastic pieces in the cylinder cleaner dropper exiting with the cleaned cotton were counted as remaining in the seed cotton. Any plastic piece remaining in the body of the cylinder cleaner above the grid bars or not recovered from either the cleaned seed cotton or the foreign matter removed 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.

Table 2. Experimental factor levels in plastic removal experiment, Part 2

Level[z]	Air Flow Rate (per unit width) $m^3s^{-1}m^{-1}$ (ft^3min^{-1} ft^{-1})	Seed Cotton Processing Rate (per unit width) kg min^{-1} m^{-1} (lb min^{-1} ft^{-1})	Cylinder Cleaner Speed rpm	Size (length of side) mm (in.)
- Axial	2.32 (1500)	52.1 (35.0)	330	30 (1.18)
- Factorial	2.71 (1750)	78.1 (52.5)	480	40 (1.57)
Center	3.10 (2000)	104.2 (70.0)	630	50 (1.97)
+ Factorial	3.48 (2250)	130.2 (87.5)	780	60 (2.36)
+ Axial	3.87 (2500)	156.3 (105.0)	930	70 (2.76)

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

For both parts, SAS JMP 11.1 (SAS Institute, Inc., Cary, NC) 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 because many fiber loss values were near zero, and the variance increased with increasing fiber loss. For each part of the experiment, the categorical treatment, plastic source or cultivar, was included as a main effect in the model and crossed with other main effects. Backwards stepwise elimination (terms eliminated with $p > 0.1$) was used to reduce the number of variables, subject to the effect heredity principle (interactions were only included if the corresponding main effects were also in the model). Model suitability was assessed by graphical analysis of residual values and lack-of-fit tests. No term was eliminated from the model if its removal resulted in a significant lack of fit.

Desirability functions, which vary from zero at unacceptable values of response variables to one at target values, were calculated for plastic removal and fiber loss and used to determine optimum operating parameters. Desirability functions for both the plastic removal and fiber loss response variables varied linearly between the upper and lower limit values (Table 3). 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. An overall desirability was calculated by taking the geometric mean of the desirability values for individual response variables. Economic data are not available to accurately define these functions; consequently, the values selected might not provide optimum operating parameters. The costs associated with plastic contamination have not been correlated with specific levels of contamination. Additionally, the quality of fiber removed by the cylinder cleaner is unknown; therefore, its value cannot be determined.

Table 3. Desirability functions for plastic removal and fiber loss

Desirability	PR%[z]	FL%[y]
0	0	≥ 0.1
1	100	≤ 0.03

[z] PR%, plastic removal

[y] FL%, fiber loss

RESULTS AND DISCUSSION

Seed cotton moisture content averaged 8.1% for Part 1 and 7.9% for Part 2. Mean foreign matter content was 6.6, 7.8, and 5.7% for PHY 499 (Part 1), ST 4946 (Part 2), and ST 5458 (Part 2), respectively. These values are typical for machine-picked cotton in the Mid-South. Nearly all plastic pieces were processed through the cylinder cleaner and recovered. One piece in Part 1 remained in the cylinder cleaner above the grid bars, whereas two pieces in Part 2 remained in the cylinder cleaner and an additional piece was not recovered.

Plastic Removal. For Part 1, all main effects and all two-way interactions between seed cotton processing rate, plastic source, and plastic size were included in the response surface model for plastic removal (Table 4). The plastic source had a large effect on plastic removal percentage, as the mean removal percentages for shopping bags and module wrap were 56.3 and 9.3%, respectively.

Table 4. Effects remaining in the model for plastic removal, Part 1

Effect[z]	F Ratio	Probability > F
AFR	5.28	0.0282
SCPR	4.55	0.0408
PSize	21.01	< 0.0001
PSource	112.62	< 0.0001
SCPR*PSize	3.55	0.0686
SCPR*PSource	5.72	0.0228
PSize*PSource	5.01	0.0323

[z] PSource, plastic source; AFR, air flow rate; SCPR, seed cotton processing rate; PSize, plastic piece size; PR%, plastic removal; FL%, fiber loss

The model for Part 1 for plastic removal percent had an adjusted R^2 of 0.79 and a root-square mean error (RMSE) of 14.0% (variables are in SI units indicated in Table 1):

Shopping bags:

$$PR\% = 13.367\,AFR - 1.1086\,SCPR - 3.0451\,PSize + 0.015195\,SCPR \cdot PSize + 203.46 \qquad [1]$$

Module wrap:

$$PR\% = 13.367\,AFR - 0.73978\,SCPR - 2.0855\,PSize + 0.015195\,SCPR \cdot PSize + 70.077 \qquad [2]$$

The effects of the factors tested on plastic removal are illustrated in Fig. 3. Higher air flow rates and smaller plastic pieces resulted in increased plastic removal. Higher seed cotton processing rates reduced plastic removal for shopping bags, although the size of this effect decreased with larger plastic sizes, due to the interaction between seed cotton processing rate and plastic size (not indicated on figure). The model predicted increased removal of small pieces of module wrap at lower seed cotton processing rates and of large pieces of module wrap at higher seed cotton processing rates. With a module wrap piece size of 48.7 mm, the model predicted that seed cotton processing rate had no effect on plastic removal. However, predicted and actual removal of the module wrap and the largest pieces of both plastic sources was near zero.

For Part 2, air flow rate, cylinder cleaner speed, and plastic size were included in the response surface model, but not seed cotton processing rate, cultivar, or any interactions or quadratic terms (Table 5). Plastic size had the largest effect on plastic removal percentage, as the predicted removal percentage (at mean values of the other factors) varied from 96.6% for 30-mm (1.18-in.) plastic to 16.6% for 70-mm (2.76-in.) plastic.

Table 5. Significant effects in model for plastic removal, Part 2

Effect[z]	F Ratio	Probability > F
AFR	20.95	< 0.0001
CCS	13.98	0.0005
PSize	151.10	< 0.0001

[z] AFR, air flow rate; CCS, cylinder cleaner speed; PSize, plastic piece size

The model for Part 2 for plastic removal percent (PR%) had an adjusted R^2 of 0.76 and an RMSE of 11.2% (variables are in SI units indicated in Table 2):

$$PR\% = 19.290\,AFR - 0.040278\,CCS - 2.0000\,PSize + 122.20 \quad [3]$$

Higher air flow rates, lower cylinder cleaner speeds, and smaller plastic pieces resulted in increased plastic removal. The effects of the various factors tested on plastic removal are illustrated in Fig. 4. The model predicted a removal rate of 47.6% for 50 mm pieces at the recommended cylinder cleaner operating conditions (2.32-m^2 s^{-1} air flow rate and 480 rpm). Increasing the air flow rate to 3.10 m^2 s^{-1} and decreasing the cylinder speed to 330 rpm would increase removal rate to 68.7%. Although these improved operating conditions would be expected to remove all pieces smaller than 35 mm, the predicted removal rate of 70-mm pieces would be only 28.7%.

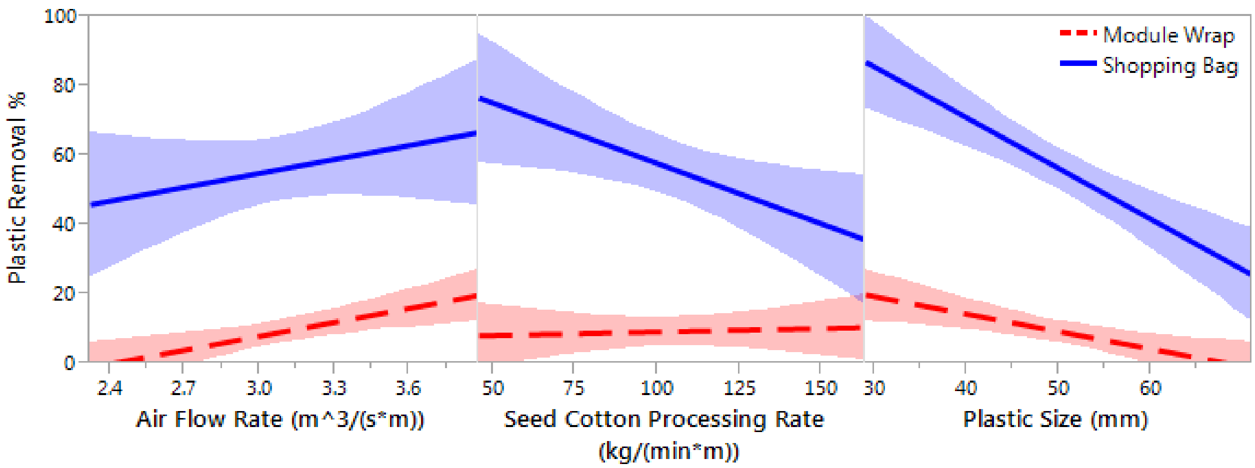

Figure 3. Predicted plastic removal with 95% confidence intervals, Part 1. The predicted values were calculated by varying each continuous factor while holding the other variables at their center values.

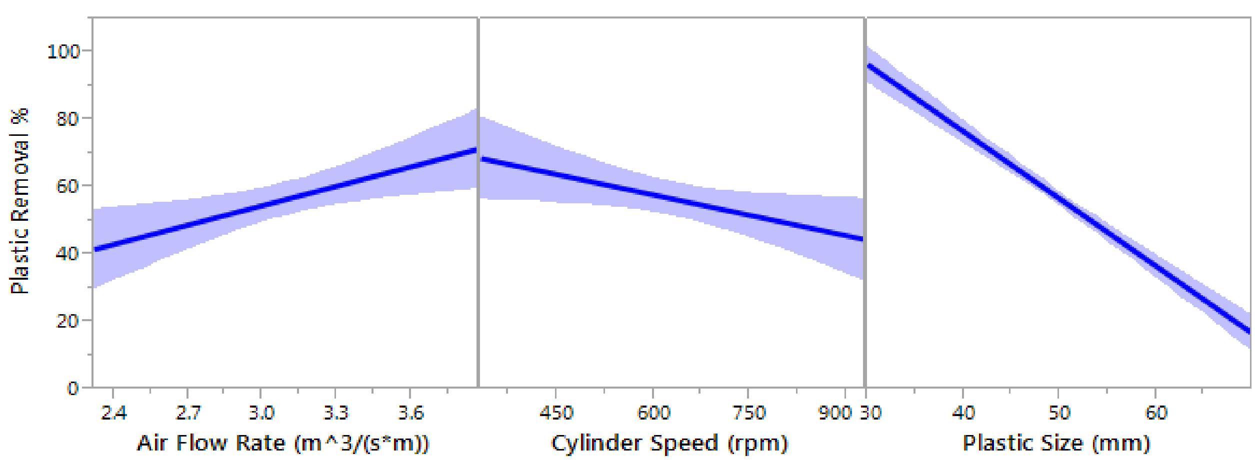

Figure 4. Predicted plastic removal with 95% confidence intervals, Part 2. The predicted values were calculated by varying each continuous factor while holding the other variables at their center values.

The results of the study by Byler et al., (2013) cannot be compared directly to the plastic removal values predicted by this model, because the cylinder cleaners in that study were gravity fed and used a low seed cotton processing rate (approximately 30 kg min^{-1} m^{-1}) . 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 less than 1% of pieces larger than 25 mm x 25 mm (1 in. x 1 in.) were removed in the previous study. Similar relationships between plastic removal and air flow rate or plastic size were found in both parts of this study. In the first part of the study, the seed cotton processing rate had a significant effect on plastic removal; however, the *p*-value for the main effect was only 0.0408, and seed cotton processing rate was the least significant main effect. The seed cotton processing rate x plastic size interaction was the least significant term included in the model in Part 1.

Fiber Loss. In Part 1, air flow rate, seed cotton processing rate, their interaction, and the quadratic terms for both significant main effects were included in the response surface model for fiber loss (Table 6). The model for fiber loss percent using the square-root transformation had an adjusted R^2 of 0.80 and an RMSE of 0.0297 (variables are in SI units indicated in Table 1):

Table 6. Significant effects in model for fiber loss, Part 1

Effect[z]	F Ratio	Probability > F
AFR	91.69	< 0.0001
SCPR	40.81	< 0.0001
AFR*SCPR	9.76	0.0036
AFR*AFR	10.35	0.0028
SCPR*SCPR	5.24	0.0284

[z] AFR, air flow rate; SCPR, seed cotton processing rate

$$\sqrt{FL\%} = 0.083430AFR^2 + 1.0432*10^{-5}SCPR^2 - 0.0014477AFR \cdot SCPR - 0.24794AFR + 0.0012657SCPR + 0.35793 \quad [4]$$

With low air flow rates, fiber loss was nearly zero. Fiber loss increased significantly at higher air flow rates, as reflected by the quadratic term in the model for fiber loss. However, higher seed cotton processing rates reduced fiber loss as the air flow rate increased (Fig. 5). The fiber lost per unit time was nearly constant for a given air flow rate; consequently, a higher seed cotton processing rate will decrease the fiber loss as a percentage of total seed cotton mass. A possible explanation is that there is a constant amount of fiber likely to be removed in the cylinder cleaner at any given time, regardless of processing rate, as only a portion will be exposed to the grid bar openings.

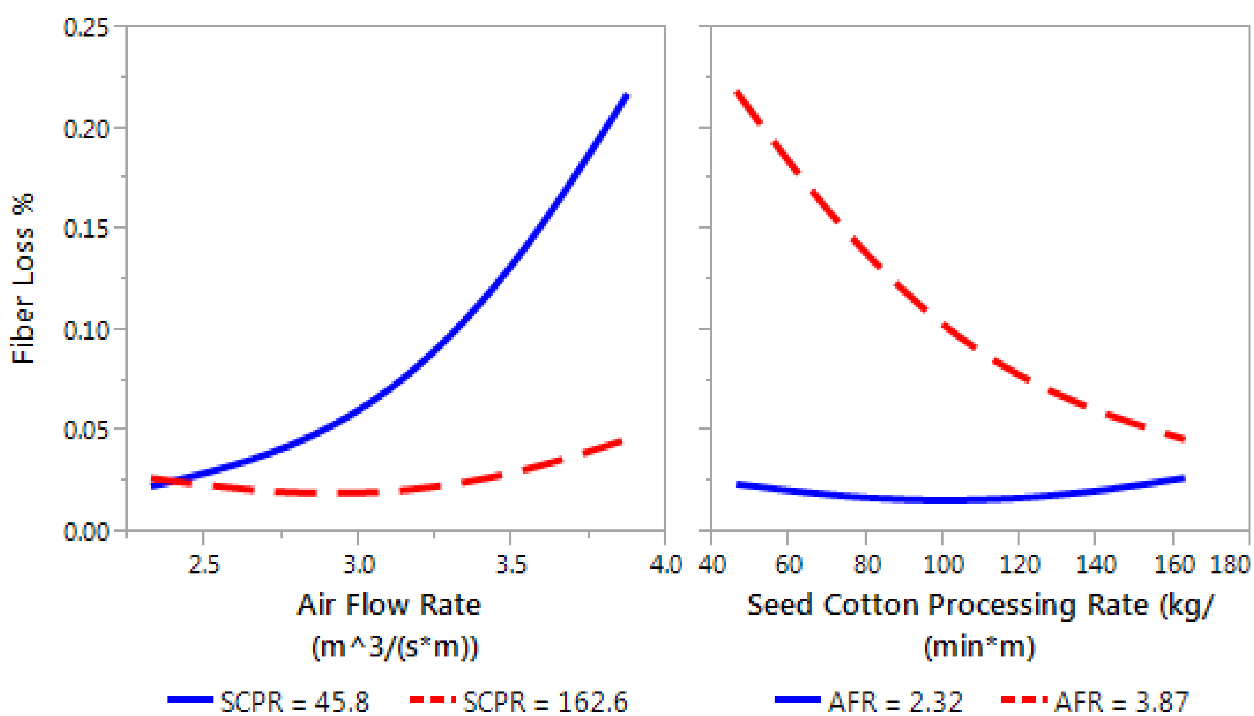

Figure 5. Interaction plots for air flow rate and seed cotton processing rate factors in fiber loss model.

In Part 2, the fiber loss model included terms for air flow rate, seed cotton processing rate, and its quadratic term, cylinder cleaner speed (CCS), and cultivar (Table 7). Although cultivar was the least significant effect in the model, removing the cultivar term resulted in a significant lack of fit for the model.

Table 7. Significant effects in model for fiber loss, Part 2

Effect[z]	F Ratio	Probability > F
AFR	14.78	0.0003
SCPR	7.04	0.0104
CCS	11.45	0.0013
Cultivar	3.57	0.0643
SCPR*SCPR	4.49	0.0387

[z] AFR, air flow rate; SCPR, seed cotton processing rate; CCS, cylinder cleaner speed

The model for the square root of fiber loss percent had an adjusted R^2 of 0.38 and an RMSE of 0.0437 (variables are in SI units indicated in Table 2):

ST 4946:

$$\sqrt{FL\%} = 1.7975 * 10^{-5} SCPR^2 + 0.062594\, AFR - 0.0043873\, SCPR + 1.4219 * 10^{-4} CCS + 0.18990 \quad [5]$$

ST 5458:

$$\sqrt{FL\%} = 1.7975 * 10^{-5} SCPR^2 + 0.062594\, AFR - 0.0043873\, SCPR + 1.4219 * 10^{-4} CCS + 0.16860 \quad [6]$$

Higher variability in fiber loss resulted in the much lower R^2 and higher RMSE in Part 2 of the study. In Part 1, fiber loss was near zero for many of the samples. The model-independent estimator of the standard deviation of the square-root transformed fiber loss (root of the mean square for pure error from the lack-of-fit test) was greater than 40% higher for Part 2 (0.0394) than Part 1 (0.0277). Consequently, the maximum R^2 that any model could have in Part 2 was 0.74. Graphical analysis of the residual values showed no trends, only the high variability of fiber loss. Testing higher cylinder cleaner speeds resulted in greater fiber loss and variability in fiber loss. Cultivar differences also could have affected the differences in fiber loss and fiber loss variability between the parts of the study.

Higher air flow rates, lower seed cotton processing rates, and higher cylinder cleaner speeds increased fiber loss (Fig. 6). Greater fiber loss with increasing cylinder cleaner speeds also was observed by Hardin (2014a). The model predicted a 0.01% higher fiber loss from ST 4946 than ST 5458. Cultivar differences in fiber loss from gin machinery also were found by Hardin and Byler (2013).

Seed cotton processing rate had a similar effect on fiber loss in both parts of the study. Whereas the model in Part 2 only predicted a linear relationship between fiber loss and air flow rate, the range of fiber loss with varying air flow rates was similar between the two parts of the study. Although the model for fiber loss in Part 2 of the study did not include the quadratic term for air flow rate or the interaction between air flow rate and seed cotton processing rate, the *p*-values for these terms were 0.1014 and 0.1330, respectively, when eliminated from the model. Given the high variability of fiber loss in Part 2, additional replications might have increased the significance of these two effects to where they remained in the model.

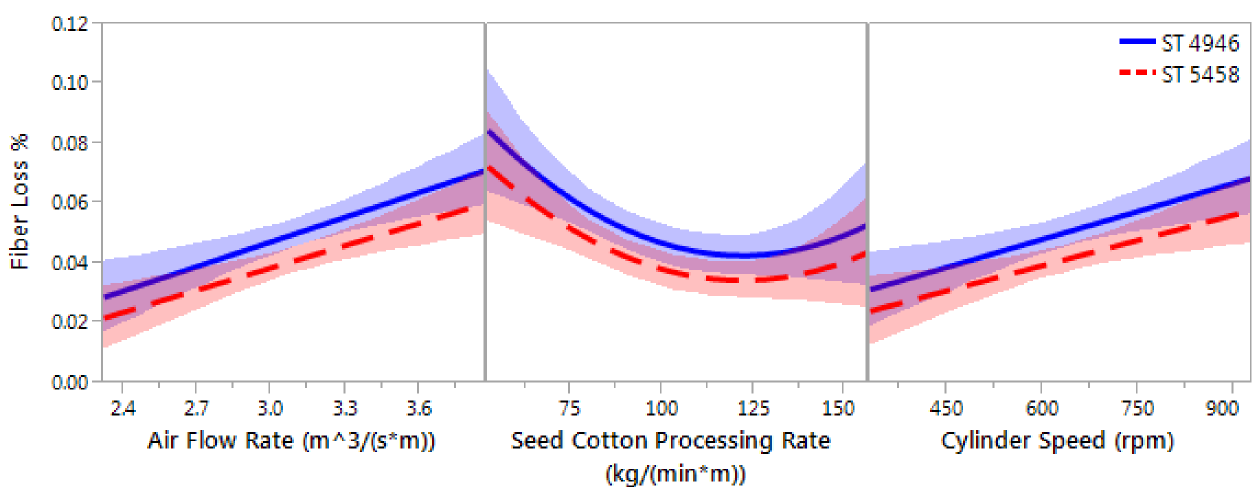

Figure 6. Predicted fiber loss with 95% confidence intervals, Part 2. The predicted values were calculated by varying each continuous factor while holding the other variables at their center values.

DISCUSSION

Gins will 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 removed more effectively by extractors in the gin than thinner plastics, such as shopping bags. Consequently, the following discussion of optimum operating parameters from Part 1 focuses on plastic from shopping bags. A contour plot of the overall desirability function from Part 1 for removing 50-mm (1.97-in.) shopping bag pieces is shown in Fig. 7. The maximum overall desirability within the range of conditions tested occurred at an air flow rate of 2.50 $m^3s^{-1}m^{-1}$(1610 ft^3min^{-1} ft^{-1}) and a seed cotton processing rate of 46.1 kg min^{-1} m^{-1} (31.0lb min^{-1} ft^{-1}) for this data set. The model predicted that 68.5% of the plastic pieces will be removed and fiber loss will be 0.03%. The size of the plastic pieces did not have much effect on the shape of the contour plot, as plastic size only affected plastic removal, and the interaction with seed cotton processing rate did not have a large effect on plastic removal rate. For 37.5-mm (1.48-in.) pieces, desirability was maximized at nearly the same conditions—an air flow rate of 2.49 m^3 s^{-1} m^{-1} (1610 ft^3 min^{-1} ft^{-1}) and a seed cotton processing rate of 45.8 kg min^{-1} m^{-1} (30.8 lb min^{-1} ft^{-1}), resulting in predicted plastic removal of 97.9%. An air flow rate of 2.70 m^3 s^{-1} m^{-1} (1740 ft^3 min^{-1} ft^{-1}) and a seed cotton processing rate of 61.8 kg min^{-1} m^{-1} (41.5 lb min^{-1} ft^{-1}) maximized desirability with 62.5-mm (2.46-in.) pieces, with predicted plastic removal of 39.4% and fiber loss of 0.03%. However, operating the cylinder cleaner under the same conditions that maximized the desirability function for 50-mm (1.97-in.) pieces would reduce plastic removal to 39.2% with no change in fiber loss.

The region on the left side of Fig. 7 corresponds to combinations of factors resulting in fiber loss less than 0.03%. Therefore, desirability in this region is increased by higher plastic removal rates. At a given seed cotton processing rate, air flow should be increased, until the desirability function decreases due to higher fiber losses. Likewise, at lower air flow rates, reducing the seed cotton processing rate increases plastic removal and maximizes overall desirability. At higher air flow rates, the seed cotton processing rate must be increased to reduce fiber loss. The lower right portion of the graph corresponds to combinations of air flow rate and seed cotton processing rate that result in fiber loss greater than 0.1% and the resulting desirability is zero.

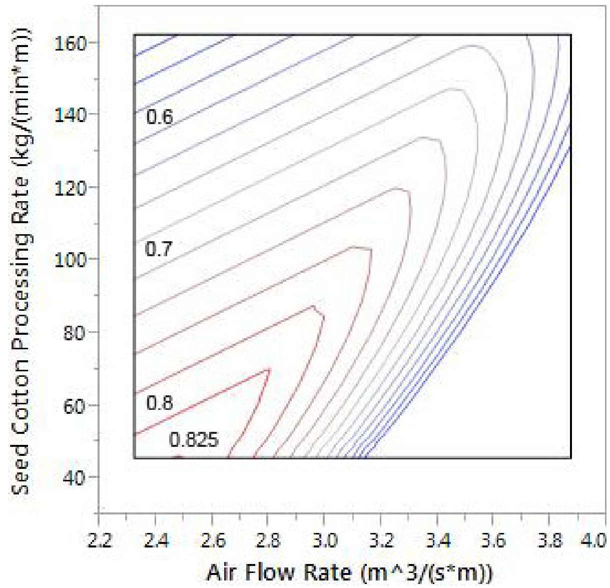

Figure 7. Contour plot of overall desirability function, Part 1.

In Part 2, plastic removal increased and fiber loss was reduced with decreasing cylinder cleaner speeds, so the maximum overall desirability within the range of factors tested occurred at a cylinder cleaner speed of 330 rpm. A contour plot of the overall desirability function from Part 2 for removing 50-mm pieces using a cylinder cleaner speed of 330 rpm with cultivar ST 4946 is shown in Fig. 8. An air flow rate of 3.26 $m^3s^{-1}m^{-1}$(2110 ft^3min^{-1} ft^{-1}) and a seed cotton processing rate of 120.7 kg min^{-1} m^{-1} (81.1 lb. min^{-1} ft^{-1}) maximized the overall desirability. The model predicted that 71.8% of the plastic pieces will be removed and fiber loss will be 0.03%.The same air flow rate and seed cotton processing rate maximized desirability with 40-mm pieces, whereas a slightly higher air flow rate, 3.44 m^3 s^{-1} m^{-1} (2220 ft^3 min^{-1} ft^{-1}), and seed cotton processing rate, 122.0 kg min^{-1} m^{-1} (82.0 lb min^{-1} ft^{-1}), maximized desirability with 60-mm pieces.

The vertical contours on the left side of Fig. 8 correspond to seed cotton processing rates resulting in fiber loss less than 0.03% because seed cotton processing rate did not appear in the model for plastic removal in Part 2. The models for Part 2 indicated that the seed cotton processing rate that minimized fiber loss should be used, along with the air flow rate that maximized the desirability function due to the tradeoff between plastic removal rate and fiber loss. Because of lower fiber losses at reduced cylinder cleaner speeds, lower air flow rates are suggested by the response surface model at higher cylinder speeds to minimize fiber loss. An air flow rate of

2.97 m^3 s^{-1} m^{-1} (1920 ft^3 min^{-1} ft^{-1}) and a seed cotton processing rate of 122.0 kg min^{-1} m^{-1} (82.0 lb min^{-1} ft^{-1}) maximized desirability with 50-mm pieces and a cylinder speed of 480 rpm, the manufacturer's recommended operating speed.

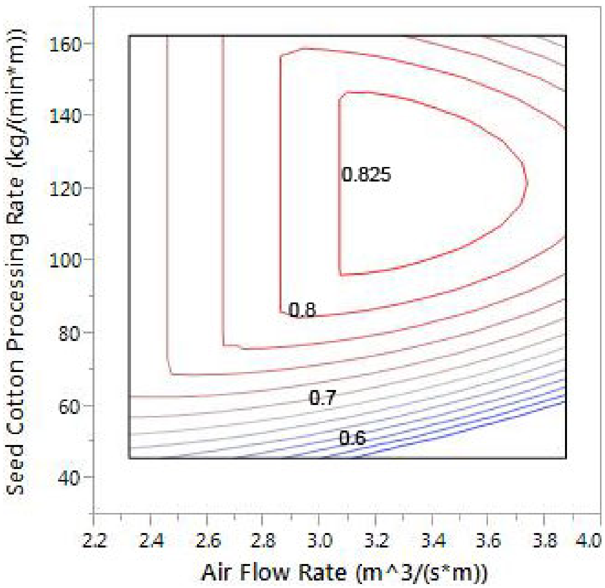

Figure 8. Contour plot of overall desirability function, Part 2.

CONCLUSIONS

Plastic removal by a cylinder cleaner was affected by the air flow rate and plastic size in both parts of this study. Higher air flow rates increased plastic removal and smaller plastic pieces were easier to remove. Seed cotton processing rate had a significant effect on plastic removal only in the first part of the study. 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. In Part 1, the cylinder cleaner was more effective at removing the thinner shopping bag pieces than the thicker module wrap pieces. In Part 2, only one plastic source, shopping bags, was tested, but cylinder cleaner speed was also varied. More plastic was removed at lower cylinder cleaner speeds.

For both parts of the study, the fiber loss model contained the main effects of air flow rate and seed cotton processing rate and the quadratic term for seed cotton processing rate. The model for fiber loss in Part 1 also contained the quadratic term for air flow rate and the interaction between air flow rate and seed cotton processing rate. Although these terms were not included in the Part 2 model, their significance levels approached 0.1. Due to high variability for fiber loss in Part 2, additional replication might have resulted in the inclusion of these terms in the model. Fiber loss increased with increasing air flow rate and decreased with increasing seed cotton processing rates. This result likely occurred with the fiber loss per unit time nearly constant for a given air flow rate. Therefore, higher seed cotton processing rates decreased the fiber loss as a percentage of total seed cotton mass. The additional factors tested in Part 2, cylinder cleaner speed and cultivar, were included in the model for fiber loss. Fiber loss increased at higher cylinder cleaner speeds, and a 0.01% difference in fiber loss was predicted between cultivars.

Desirability functions were created to find operating conditions with low fiber loss and high plastic removal. In Part 1, because seed cotton processing rate had a significant effect on plastic removal and the air flow rate x seed cotton processing rate interaction had a significant effect on fiber loss, lower air flow (2.50 m^2 s^{-1} [1600 $ft^2 min^{-1}$]) and seed cotton processing rates (46.1 kg min^{-1} m^{-1} [30.8 lb. min^{-1} ft^{-1}]) resulted in the highest overall desirability for removing 50-mm shopping bag pieces. In Part 2, the lowest cylinder cleaner speed, 330 rpm, had the highest plastic removal and lowest fiber losses. Because fiber loss was reduced at this speed, a higher air flow rate than in Part 1, 3.26 m^3 s^{-1} m^{-1} (2110 ft^3 min^{-1} ft^{-1}), maximized the overall desirability for removing 50-mm pieces at a cylinder cleaner speed of 330 rpm. Because the seed cotton processing rate did not have a significant effect on plastic removal rate in Part 2, the optimal processing rate of 120.7 kg min^{-1} m^{-1} (81.1 lb. min^{-1} ft^{-1}), was also higher than in Part 1 because of reduced fiber loss.

Lower cylinder speeds should be used to increase plastic removal and reduce fiber loss, although the selection of air flow rate is a tradeoff between increasing plastic removal and decreasing fiber loss. The effect of seed cotton processing rate on plastic removal was not consistent between the two parts of the study, although higher seed cotton processing rates reduced fiber loss.

ACKNOWLEDGMENTS

The authors wish to thank Cotton Incorporated for their financial support of this project under Cooperative Agreements No. 14-489, Evaluation of Opportunities to Remove Plastic During the Ginning Process, and No. 09-952, Fractionation of Lint Cleaner Waste and Processed Fibers for Ginning Research Support.

DISCLAIMER

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