2005 Beltwide Cotton Conferences, New Orleans, Louisiana - January 4 - 7, 2005

LINT CLEANING PERFORMANCE OF MODIFIED CYLINDER CLEANERS

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Abstract

Lint cleaning performance of a cylinder cleaner equipped with six different grid bar configurations were evaluated. The configurations varied depending on cylinder positions, grid bar geometries--flat squares or diamonds, and gaps between grid bars--narrow 6.4 mm (0.25 in.) or wide 9.6 mm (0.375 in.). A baseline saw-type lint cleaner was also included in the experiment. Results indicated that all but one cylinder cleaner configuration (number 7, a six cylinder cleaner with a special saw-type lint cleaner connected in tandem), yielded higher turnouts than that of the saw-type lint cleaner. The saw-type lint cleaner and configuration 7 cleaned most efficiently and provided the best reflectance (Rd) values. Configuration 1 was the best overall performer among the cylinder cleaner configurations in the study. This configuration is composed of cradles of flat, square grid bars with both wide and narrow gaps depending on cylinder position. This cylinder cleaner configuration provided an adequate reflectance value and cleaning performance, a high turnout, and a moderate fiber loss to waste.

Introduction

Saw-type lint cleaners are considered the most popular and efficient cleaners in the ginning industry. Cleaning efficiencies in the range of 45-54% are achievable, depending on cotton varieties, harvesting seasons, methods of harvesting and other growing conditions (Mangialardi and Anthony 2003; and Mangialardi and McCaskill, 1967). In another comprehensive study of the performance characteristics of a saw-type lint cleaner, Baker (1978) reported cleaning efficiency as high as 79.7% was achievable. Along with its efficiency as a result of combing fibers aggressively, the saw-type lint cleaner also causes fiber damage and increased short fiber content (Anthony et al., 1986). The trade offs between quality, fiber grade, bale value and profit to the cotton producers are well documented. (Looney et al., 1963; Mangialardi 1972, 1988; Barker and Baker, 1986; Columbus, 1990; and Anthony et al., 2001). Columbus and Anthony (1991) found that the same color grade and higher market prices could be obtained by substituting the second saw-type lint cleaner with 3 additional cylinder cleaners before ginning. To develop a gentler cleaner, Mangialardi (1994) described a concept that included a flow-through air cleaner after the gin stand, followed by a revolving screen/inclined cylinder cleaner and one stage of saw-cylinder cleaner. Not less than 30 different types of lint cleaners were reviewed by Mangialardi and Anthony (2003A and 2003B). The efficiency of the saw-type lint cleaner was recognized and various means were explored to overcome many of its shortcomings, namely fiber damage, increased nep counts, fiber loss to wastage and over-cleaning. Many of these efforts showed that the remedy usually compromised the performance of the cleaner in one way or another. Notably, in addressing the issues of over-cleaning, Anthony (1999) devised a louver arrangement in-between grid bars to selectively shunt the grid bar from the cleaning action. Anthony (2000) reported such a device could reduce fiber loss to wastage up to 75%.

Inclined cylinder cleaners are customarily deployed early in the ginning machinery sequence for seed cotton cleaning. In 1972, Cocke (1972) investigated the effectiveness of a cylinder cleaner in terms of its operating speeds and processing rates. He concluded that a cylinder cleaner used for seed cotton cleaning could operate in a wide range of speeds (350-650 rpm) and processing rates of up to 10 bales per hour without significant effect on lint color, fiber length and fiber fineness. However, Cocke’s finding was contradicted by Read’s research (1972) which showed that higher cleaning efficiency could be obtained at higher cylinder speed for cleaning seed cotton.

Columbus and Mayfield (1995) verified that cylinder cleaners were gentler in cleaning and caused less damage to fiber than saw-type lint cleaners, but the grade improvement of two cylinder cleaners in series was inferior to a single saw-type lint cleaner.

Anthony (1997) studied the effectiveness of a cylinder cleaner in cleaning ginned lint and lint cleaner waste. His results encouraged Whitelock and Anthony (2003) to follow up with another study to further explore the potential of cylinder cleaners. In that study, the investigators considered four different grid bar designs. The four basic grid bar shapes considered were round, flat and sharp squares, and a perforated screen. The spacing between adjacent bars was 9.5 mm (0.375 in.) or 6.4 mm (0.25 in.). The width of the grid bars also varied from 9.5 mm to 6.4 mm. The study was comprehensive. The cylinder cleaner was used to clean seed cotton, ginned lint and lint cleaner waste. Of the grid bar configurations studied, the sharp square at high speed (1100 rpm) was the most efficient in cleaning, but had excessive lint wastage. It was 27% (29.7% versus 56.8% efficiency for visible waste) less effective than a saw-type lint cleaner operated in comparable conditions. The flat squares had the best performance overall both in terms of cleaning efficiency and low fiber wastage. Recall from the same study that although the sharp square (now referred to as diamond in this study) grid bars were the most efficient in cleaning, they also lost more fiber to wastage than the flat, square grid bars. The authors attributed the higher fiber loss to the wide spacing between bars (9.5 mm). The study concluded that cylinder cleaners with flat, square and diamond shaped grid bars are potential gentler efficient cleaners. In this study an experiment was designed to further the goal of finding an efficient and gentler lint cleaner than the saw-type cleaner based on variations of the grid bar designs explored in Whitelock and Anthony's study (2003). The experiment included cleaner configurations with narrow grid bar spacings so as to test the hypothesis that narrow spacing between grid bars would lose less fiber to waste. To examine effects of cleaners on fiber loss, turnout and cleaning efficiency, HVI properties were measured and classing grade information was also included in the cleaner performance evaluation.

Materials and Procedures

The study considered three different grid bar configurations (cleaner treatments). Configuration 1 consisted of three cradles of flat, square (6.4 mm wide) grid bars with 9.5 mm spacing between bars (Figure 1) followed by another three cradles of flat, square (9.5 mm wide) grid bars with 6.4 mm spacing (Figure 2); configuration 2 consisted of six cradles of diamond shaped (9.5 mm wide) grid bars with 6.4 mm spacing (Figure 3); and configuration 3 comprised of 6 alternating flat, square and diamond shaped grid bar cradles with narrow (6.4 mm) spacings as used in configurations 1 and 2. Additionally, two baseline configurations were included in the treatments for comparison. They were the (40.6 mm or 16 in. diameter) saw-type lint cleaner (configuration 4) and a cylinder cleaner (configuration 5) comprised of six cradles of flat, square (6.4 mm wide) grid bars with 9.5 mm spacing between bars. Table 1 shows the cleaner treatment configurations studied in this experiment.

In addition to cleaner treatments and seed cotton varieties, other factors considered in this study included cylinder speed and moisture. Cylinder speed variations were accomplished by changing the drive ratio between the motor and the driven cylinders. Different moisture was achieved by conditioning the seed cotton in a controlled environment 3 days before testing and then drying the cotton to different levels to obtain the desired seed cotton moisture during ginning. For the first three configurations, because of the time involved in attaining speed and grid bar configuration changes, the experiment was arranged in a split-split plot design where cleaner treatment corresponded to whole plots within each replicate (block), speed formed subplots, and 2 varieties and 2 moisture contents randomized within subplots formed sub-subplots. Two baseline cleaner treatments (configurations 4 and 5) were also included among the whole plots of cleaner treatment in a random order. The 2 baseline configurations were run at only one speed (980 rpm), a low moisture (targeted 4.0%) and 2 varieties. Thus within a replicate block, the experiment required a total of 28 runs, 24 runs (3*2*2*2) for the first three configurations and 2 runs (2 varieties) for each baseline configuration. With 3 replicates for each run, the number of runs for the experiment was 84 runs (3*24 runs).

Seed cotton used in this study was harvested in the 2003 season. The two seed cotton varieties Stoneville 4892 (STV4892) and Delta and Pine Land 555 (DPL555) were harvested by spindle pickers in September and October of 2003, respectively. Though the two varieties were harvested from two different fields, it was assumed no significant field effect was observed in the varieties. Approximately 50 lots of nominal 40 lbs of seed cotton were prepared from each cotton variety. They were stored in mesh bags and allowed to condition over 72 hours at 50% relative humidity and 75 ^{o}F. Seed cotton was ginned in the microgin at the Stoneville Cotton Ginning Laboratory, MS. The ginning sequence consisted of a shelf dryer 1, six-cylinder cleaner, stick machine, shelf dryer 2, six-cylinder cleaner, extractor-feeder, 20-saw (40.6 cm diameter) gin stand followed by an experimental six-cylinder cleaner subjected to various grid bar configurations. The experimental cylinder cleaner was used in place of the saw-type lint cleaner to clean lint in this study. Dryer 1 was set to low heat (38 ^{o}C or 100 ^{o}F), and dryer 2 was set to high heat (93 ^{o}C or 200 ^{o}F). For high moisture runs, seed cotton was routed to dryer 1 only. For low moisture runs, seed cotton was routed through both dryers to remove moisture. For every extended downtime due to speed or configuration changes, 40 pounds of seed cotton was run through the system to warm up the machinery. The experimental cylinder cleaner was installed in parallel with a saw-type lint cleaner (Figure 4).

As the experiment was carried out, preliminary results indicated a potential efficient cleaning grid bar configuration. Two new cylinder cleaner configurations (configuration 6 and 7, Table 1) were then added. Configuration 6 is composed of 3 flat, square grid bar cradles followed by 3 diamond shaped grid bar cradles. Both grid bar types have narrow 6.4 mm spacings. Configuration 7 is a hybrid cylinder cleaner. It is composed of cylinder cleaner, configuration 6, with a special one cleaning grid bar saw-type cleaner connected in tandem. Together with 2 varieties, 1 moisture (6%), 1 speed (980 rpm) and 3 replications, a total of 12 (2*2*3) runs were added to the experiment.

For the lot ginned, three seed cotton samples were collected at the feeder apron for foreign matter and three each of lint samples were collected before and after the experimental cylinder cleaner for High Volume Instrument (HVI) and Advanced Fiber Information System (AFIS) analyses. Three moisture samples were also collected after the cylinder or saw-type lint cleaner. The six cylinders of the cleaner were divided into two sections of three cylinders each; each was equipped with a trash pan to collect trash separately. Equipment deployed in the ginning sequence of the experiment is summarized in Table 2.

Results and Discussion

Moisture analysis

Moisture results from the standard oven test method (Shepherd, 1972) showed that the dryer strategy used to effect seed cotton moisture was partially successful when the laboratory was air conditioned on the first day. Low and high moisture levels achieved varied from 4 to 5%. To obtain high moisture levels, the air conditioner was turned off and doors were open to expose the seed cotton to the outside air temperature and humidity. While the treatment called for a difference of 2% moisture (from a low level of 4% to a high level of 6%), the method of controlling moisture described above could effectuate only a 1% difference. Variability (standard deviation of 3 samples) of moistures within a treatment was generally less than 0.5%. The actual level of moisture content was taken into account when analyzing moisture effects on cleaning efficiency and other process responses.

Analysis of Variance (ANOVA) procedure

Fixed effects of the experiments were analyzed exclusively using Analysis of Variance (Littell et al, 1996). The random effects are replication, replication by cleaner treatment, and replication by speed (rep, rep*Ct, rep*sp (Ct)). Because of the imbalance in the designed experiment (the first three configurations included both low and high moisture and speed runs; the two baseline configurations included only one low moisture and high speed runs), results of the experiments were best sorted then analyzed by speed, so that means of the first 5 cleaner treatments could be compared at the high speed of 980 rpm and separately, only the means of the first 3 cleaner treatments could be compared at the low speed of 680 rpm. Also by segmenting the data by moisture, the cleaner treatments could be compared at low and high moistures separately. Since runs for cleaner treatments 6 and 7 were added at the tail end of the experiment, results from these runs were analyzed as a separate experiment. Direct and rigorous statistical comparison between the two experiments was not performed. Results from the second experiment were compared to the former five cleaner treatments solely by inferences with the understanding that there were no significant observable changes in the environment or process that could bias the results from these experiments due to time. The adjusted means of the properties in each experiment were compared based on their Least Squares Differences (LSD) at a test significance level of $p=0.05$. Results of the low speed runs (680 rpm) involved only the first 3 configurations. Their performance is found to be similar to that in the high speed runs, and for the most part, there are no significant performance differences among these 3 configurations. Therefore, results presented in the following discussion concentrate on the results and analyses of the high speed runs (980 rpm).

HVI data

To examine effects of the cleaner and its treatment factors, samples collected after the cleaner were submitted for an HVI analysis. The resultant data was subjected to an ANOVA analysis as described above. Analysis results are presented in Tables 3a and 3b. Adjusted treatment means of properties measured after the cleaner were compared based on their Least Squares Differences (LSD). The tables show that cleaner treatment 4 (saw-type lint cleaner) and 7 (hybrid cylinder cleaner) have the best average values for reflectance (Rd), and lower leaf, and % area. Their performances in properties of micronaire, strength, length and uniformity are not distinguishable from those of other cylinder cleaners (configurations 1,2,3,5 and 6). Variety DPL555 seems to be easier to clean than the hairy leaf, STV4892 variety; DPL555 has a higher Rd, and lower % area and leaf values. Its micronaire is higher, but its strength and uniformity are lower.

AFIS data

An analysis of variance as described above was performed on the AFIS measured properties for samples collected after the cleaner. Properties that were effected by the treatment factors are listed in Tables 4a to 4d. The tables show that configuration 4 (saw-type lint cleaner) is consistently the more efficient cleaner. Its values for total trash, dust, and visible foreign matter are significantly lower than other cylinder cleaner arrangements. Its higher neps also reveal the aggressiveness of the saw-type lint cleaner. Properties produced by configuration 7 (hybrid cylinder cleaner) are indistinguishable from its cylinder cleaner counter part (configuration 6) in all properties except neps. Properties of configuration 7 are nevertheless aligned with values produced by the saw type lint cleaner (configuration 4). These observations agree with the conclusion that saw-type cleaners are more efficient in cleaning based on HVI properties discussed above. Variety DPL555 is again observed to be easier to clean as it has the lower particle count in total trash, dust and visible foreign matter. Its neps, seed coat neps and length are also lower in values; however, its short fiber content, upper quartile length and maturity ratio are significantly higher.

Lint turnout analysis

Output of the ANOVA procedure for turnouts is listed in Tables 5a and 5b. The LSD method was used to compare the adjusted means of turnouts. Comparison results are also listed in the same tables. The fixed effect model for turnout is comprised of three main effects: cleaner treatment (Ct), variety (Var), and moisture (Mc). Compared to the saw-type lint cleaner, the six cylinder cleaner configurations studied, in general, provide slightly higher turnouts. Cylinder cleaner configuration 1 has the highest turnout (40.40%) and the saw-type lint cleaner has the lowest (38.92%). Configuration 1 is composed of flat, square grid bars, its first 3 positions have wide gaps (9.4 mm) and the next 3 positions have narrow gaps (6.4 mm). However, there is no significant difference in turnout among all cylinder cleaners. Turnouts of configurations 6 and 7 are also in the range of the high turnout group led by configuration 1. Yet their values are in the low range of the high turnout group and come closest to that of the saw-type lint cleaner. Cylinder cleaner configuration 6 is comprised of 3 flat grid bar followed by 3 diamond grid bar cradles, both with narrow spacings. The hybrid cylinder cleaner of configuration 7 is exactly as configuration 6 with the addition of a special saw-type lint cleaner connected in tandem. The special saw-type lint cleaner used in this configuration has only one cleaning grid bar. These results show that a range of turnout performance options is achievable. Cylinder cleaner configurations included in this study all yielded higher turnouts than that from a saw-type lint cleaner.

Tables 5a and 5b also indicate higher turnouts for the variety DPL555. It is 42.59% in the first 5 cleaner treatments and 42.38% in cleaner treatments 6 and 7.

Lint wastage

Another aspect of the study in cleaner performance is to examine the trash collected in each test. Pictures of typical trash collected from the various grid bar configurations and independent factor treatments are also shown in Figures 5 to 10.

The same ANOVA procedure described before was used to analyze the variance of total lint cleaner waste (LWT). These measurements were normalized to the amount of ginned lint and scaled to a 500-pound bale to account for variability in the amount of input seed cotton. Output of the analysis is also listed in Tables 5a and 5b. The fixed effect model for the normalized total lint waste (NLWT) is comprised of two significant main effects: cleaner treatment (Ct), and variety (Var). The LSD method was used to compare the adjusted means of the normalized cleaner wastes (at a test level p=0.05, Tables 5a and 5b). The test separates wastes produced by the saw-type lint cleaner (configuration 4) from the group of cylinder cleaners (configurations 1, 2, 3 and 6). Saw-type lint cleaner incurs the most lint waste (6.6 lbs/bale), and cylinder cleaner configurations 3 and 6 the least (2.46 and 2.27 lbs/bale, respectively). Configuration 3 contains alternating flat and diamond grid bar cradles with narrow spacings. Configuration 6 uses the same cradles but with a different arrangement (See Table 1). This result is further supported by the turnout conclusion drawn above, that is, configuration 3, which loses the least fiber to waste due to its narrow gaps, has the highest turnout. This is encouraging, since the purpose of the experiment is to verify the hypothesis that grid bars with narrow spacings will lose less fiber to waste. It is interesting to note that configurations 5 and 7 lose similar amounts of fiber to waste. It implies that configuration 5 with wide grid bar spacings loses as much fiber to waste as that of configuration 7, which is a hybrid cylinder cleaner with narrow grid bar spacings plus a special saw-type lint cleaner with only one cleaning grid bar.

Tables 5a and 5b also show less fiber loss to waste for the smooth leaf variety, DPL555. The loss is 3.0 lbs/bale for the first 5 cleaner treatments and 2.61 lbs/bale for cleaner treatments 6 and 7.

Cleaning efficiency model based on AFIS-VFM (visible foreign matter)

Samples collected before and after the cleaner in each treatment were submitted for AFIS analysis, which measured VFM and other properties. The difference in VFM measured before and after the saw-type or cylinder cleaner divided by the VFM measured before the cleaner is defined as the cleaning efficiency for the cleaner (Tables 5a and 5c). Tables 5a and 5b includes the cleaning efficiency model based on VFM measured before and after the cylinder cleaner.

In comparing treatment means for cleaning efficiency, significant differences can be found only in the cleaner treatments. They are differentiated into 3 overlapping groups. Group A includes configuration 4, a saw-type lint cleaner. Group B contains configurations 2 and 5. These are cylinder cleaners with narrow and wide gaps between grid bars, respectively. Group C is composed of configurations 1 and 3, which are also cylinder cleaners. Configuration 1 is made up of flat, square grid bars with both wide and narrow grid bar gaps depending on the cylinder position. Configurations 2, 3, 6 have narrow grid bar spacings. Considerable overlaps exist among the groups. Group A has the highest cleaning efficiency means (35.85%) and group C has the lowest (4.22%). This analysis shows that the saw-type lint cleaner cleans most efficiently and cylinder cleaners with narrow gaps clean poorly, because they lose less fiber and trash particles to waste. Performance of the hybrid cylinder cleaner of configuration 7 falls in between the groups of the saw-type and cylinder cleaners. Thus, a saw-type lint cleaner is the best in cleaning, but it also loses the most fiber to waste and has the lowest lint turnout. A cylinder cleaner with narrowly spaced grid bars is less efficient in cleaning, but loses less fiber to waste and yields a higher lint turnout (Tables 5a and 5b). Finally, performance of configuration 7 due to its hybrid nature falls in between the two cleaner groups. Although not statistically significant, AFIS-VEM cleaning efficiency was substantially different for varieties.

Cleaning efficiency model based on visible waste from the Shirley Analysis

The Shirley Analyzer was used to process samples returned from HVI tests. Cleaned lint and visible waste were recorded for these samples. The visible waste data were used to calculate the cleaning efficiencies of treatments. An ANOVA was performed on the data and a cleaning efficiency model was analyzed. Its significant fixed effect is cleaner treatment. Tables 5a and 5b show a comparison in cleaning efficiencies among treatment means of different cleaner treatments. Again, cleaning efficiencies are separated into two groups: saw-type and cylinder cleaners, with the former possessing the higher efficiency. Configuration 7 behaves similarly to the saw-type cleaner and configuration 6 resembles configuration 3 in cleaning efficiency. Among cylinder cleaners, although their cleaning performance is distinguishable statistically, it is seen that both configurations 1 and 5 are leaders in the cylinder cleaner group. Grid bars in these two configurations are flat and square. Spacings between grid bars in configuration 5 are 9.4 mm wide and uniform in all six positions. In configuration 1, spacings between grid bars in the first three positions are wide (9.4 mm), and in the last three positions are narrow (6.4 mm). The saw-type lint cleaner and hybrid cleaner configuration 7 are still the best lint cleaners. Variety plays little role in terms of cleaning efficiency based on visible waste measured by a Shirley Analyzer.

Optimal configurations

Effects of cleaner treatments on HVI properties were evaluated using analysis of variance. Of special interest is the color grade classing performance of the treatments. Reflectance (Rd) was found to be the dominant classing property and was most effected by cleaner treatments. Treatment means comparison for reflectance is recaptured in Table 6 together with other performance parameters of interest, namely, cleaning efficiency, lint cleaner waste, and lint turnout. The table shows the consistency in the results and also provides a comprehensive picture of cleaner performances. The saw-type lint cleaner and configuration 7 clean most efficiently and provide the best color, but lose more fiber to waste and yield lower turnouts. Since fiber loss is a cost and turnout directly effects profits, these measurements must be balanced by the marginal gain in cleaning efficiency and classing grade. Results summarized in Table 6 group performance of the first four cylinder cleaner configurations (configurations 1, 2, 3, and 5) the same in all properties, and the first among the equals is led by configuration 1. From inspection, configuration 1 emerges as the best all around performer for the parameters considered. Its reflectance is next to the best of the saw-type and configuration 7 cleaners (0.8 unit from the saw-type and 0.7 unit from configuration 7) and its cleaning efficiency also ranked third after the saw-type cleaner and configuration 7. Its turnout is the best among all cleaners.

Its turnout is 1.48 to 0.51% higher than the saw-type and configuration 7 cleaners. Lastly, its "penalty" in terms of lint wastage is 3.75 to 1.14 lbs/bale lower than the saw-type and configuration 7 cleaners.

Summary and Conclusions

Fixed effects for turnout in various configurations can be modeled by three main effects: cleaner treatment (Ct), variety (Var) and moisture content (Mc). Turnouts produced by configurations 6 and 7 are similar to that of a saw-type lint cleaner (configuration 4). Generally, the different cylinder cleaner configurations included in this study produce higher turnouts than that of a saw-type lint cleaner.

The fixed effect model for the total lint waste, after normalization, contains two main effects, cleaner treatment (Ct), and variety (Var). The model verifies the hypothesis that cylinder cleaners with narrow grid bar spacings lose less fiber to waste. Cylinder cleaners equipped with narrowly spaced grid bars lose less fiber to waste, clean less efficiently and yield higher turnout.

The cleaning efficiency analyses show that the saw-type lint cleaner is still the most efficient cleaner and also yields the best color fiber. However in considering other performance of interest such as lint cleaner waste, lint turnout and reflectance for color grade, cylinder cleaner configuration 1 is considered the best all around performer in this experiment. Grid bars used in this configuration are flat, square grid bars; spacings between grid bars are both wide and narrow depending on the position of the cylinders. This cylinder configuration provides the best balanced performance in lint turnout, cleaning efficiency, lint wastage, and classing grade.

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Table 1. Treatment configurations.

Cleaner treatment	Cylinder position number (lower to higher)[1]					
	1	2	3	4	5	6
1	A	A	A	B	B	B
2	C	C	C	C	C	C
3	B	C	B	C	B	C
4	Saw-type lint cleaner					
5	A	A	A	A	A	A
6	B	B	B	C	C	C
7[2]	B	B	B	C	C	C

[1]Nomenclature for Table 1:
A: 6.4 mm key stock turned flat surface to face the spiked cylinder with 9.6 mm spacing between grid bars
B: 9.6 mm key stock turned flat surface to face the spiked cylinder with 6.4 mm spacing between grid bars

C: 9.6 mm key stock turned a sharp edge to face the spiked cylinder (diamond) with 6.4 mm spacing between grid bars
[2] Treatment 6 (cylinder cleaner) + a special saw-type lint cleaner with only one active grid bar.

Table 2. Equipment list and description.

Manufacturer	Description
Lummus cylinder cleaner	6 spiked cylinders, 25.4 cm (10 in.) wide, 30° incline
Continental stick machine	3 channel-saw cylinders, 30.5 cm (12 in.) wide
Continental extractor feeder	4 channel-saw cylinder, 34.3 cm (13.5 in.) diameter, 35.6 cm (14 in.) wide
Continental gin stand	20 saws, 8 teeth/linear in., 40.6 cm (16 in.) diameter
Condenser and feed works	Condenser diameter: 61.0 cm (24 in.), (Continental), feed rolls diameter: 11.3 cm (4.4375 in.)
Continental model 16D lint cleaner	8 saw wraps/in., 8 teeth/linear in., 40.6 cm (16 in.) diameter. 38.1 cm (15 in.) wide, 5 grid bars, one 18 in. diameter doffing solid brush

Table 3a. ANOVA of HVI properties measured after the cleaner -- fixed effects, analyzed by speed at 980 rpm. [1,2]

Source of variance	Mic	Str. g/tex	Length in.	LUI %	Rd	Plus b	% area	Leaf
Cleaner treatment (Ct)	ns	ns	ns	ns	ns	ns	*	**
Variety (Var)	**	**	ns	**	**	**	**	**
Moisture (Mc)	ns	**	*	ns	ns	*	*	ns
Ct*Mc	ns	ns	ns	ns	ns	ns	ns	ns
Var*Mc	ns	ns	ns	ns	ns	ns	ns	ns
Ct*Var*Mc	ns	ns	*	ns	ns	ns	ns	ns
Cleaner treatment	Means							
1	4.47 a	27.9 a	1.071 a	80.5 a	79.0 ab	7.56 a	0.0361 ab	3.17 a
2	4.47 a	27.3 a	1.072 a	80.8 a	78.3 b	7.59 a	0.0444 a	3.50 a
3	4.41 a	27.5 a	1.058 a	81.3 a	78.2 b	7.64 a	0.0433 a	3.39 a
4	4.32 a	26.8 a	1.052 a	80.7 a	79.8 a	7.66 a	0.0256 b	2.67 b
5	4.44 a	27.4 a	1.068 a	80.6 a	78.7 b	7.58 a	0.0389 a	3.28 a
LSD	0.190	1.54	0.0257	0.86	1.05	0.20	0.0144	0.338
Variety	Means							
STV4892	4.10 a	27.9 a	1.064 a	81.6 a	77.6 a	8.38 a	0.0462 a	3.53 a
DPL 555	4.75 b	26.9 b	1.065 a	79.9 b	80.0 b	6.84 b	0.0291 b	2.87 b
LSD	0.094	0.38	0.0087	0.54	0.66	0.120	0.0723	0.214

[1]Means followed by the same letter within a property are not significantly different based on Least Squares differences (LSD) calculated at appropriate degrees of freedom and 0.05 level of probability.
[2] * indicates significance at probability p<0.05, ** indicates significance at probability p<0.01, 'ns' denotes not significant.

Table 3b. ANOVA of HVI properties measured after the cleaner-- fixed effects, analyzed by speed at 980 rpm.[1,2]

Source of variance	Mic	Str. g/tex	Length in.	LUI %	Rd	Plus b	% area	Leaf
Cleaner treatment (Ct)	ns	ns	*	*	ns	ns	ns	ns
Variety (Var)	**	ns	ns	**	*	**	**	**
Moisture (Mc)	na	na	na	na	na	na	na	na
Ct*Mc	na	na	na	na	na	na	na	na
Var*Mc	na	na	na	na	na	na	na	na
Ct*Var*Mc	ns	ns	ns	ns	ns	ns	ns	ns
Cleaner treatment	Means							
6	4.49 a	28.1 a	1.069 a	80.8 a	78.5 a	7.52 a	0.0361 a	3.22 a
7	4.42 a	27.6 a	1.058 b	80.4 a	79.1 a	7.56 a	0.0344 b	3.27 a
LSD	0.463	0.66	0.0103	0.46	4.84	0.116	0.0537	0.362
Variety	Means							
STV4892	4.14 a	28.1 a	1.064 a	81.7 a	77.9 a	8.33 a	0.0424 a	3.56 a
DPL 555	4.77 b	27.6 a	1.063 a	79.6 b	79.7 b	6.74 b	0.0282 b	2.94 b
LSD	0.066	0.66	0.0103	0.46	0.86	0.132	0.0852	0.362

[1]Means followed by the same letter within a property are not significantly different based on Least Squares differences (LSD) calculated at appropriate degrees of freedom and 0.05 level of probability.
[2] * indicates significance at probability p<0.05, ** indicates significance at probability p<0.01, 'ns' = not significant, 'na' = not applicable.

Table 4a. Summary of AFIS properties after processed through the cleaner—fixed effects, analyzed by speed at 980 rpm.[1,2]

Source of variance	Neps/g	Seed coat neps/g	Total/g	Dust/g	Visible foreign matter, %
Cleaner treatment (Ct)	ns	ns	**	**	*
Variety (Var)	*	**	**	**	**
Moisture (Mc)	**	ns	**	**	**
Ct*Mc	ns	*	ns	ns	ns
Var*Mc	ns	*	ns	ns	ns
Ct*Var*Mc	ns	ns	ns	ns	ns
Cleaner treatment					
1	226.6 a	10.6 a	406.1 a	320.3 a	1.67 a
2	219.4 a	10.2 a	431.6 a	341.6 a	1.65 a
3	229.3 a	9.2 a	425.3 a	338.2 a	1.67 a
4	255.6 b	8.7 a	281.2 b	222.2 b	1.05 b
5	228.7 a	10.5 a	457.1 a	366.3 a	1.72 a
LSD	26.18	2.75	80.8	67.0	0.356
Variety					
STV4892	236.3 a	11.0 a	528.5 a	414.9 a	2.00 a
DPL 555	227.5 a	8.6 b	272.0 b	220.5 b	1.10 b
LSD	10.96	1.28	50.3	41.2	0.211

[1]* indicates significance at probability p<0.05, ** indicates significance at probability p<0.01, 'ns' = not significant.
[2]Means followed by the same letter within a property are not significantly different based on Least Squares differences (LSD) calculated at appropriate degrees of freedom and 0.05 level of probability.

Table 4b. Summary of AFIS properties after processed through the cleaner—fixed effects, analyzed by speed at 980 rpm.[1,2]

Source of variance	Length(w), in.	Upper quartile length(w), in.	Short fiber content(w), %	Fineness, mTex	Maturity ratio, %
Cleaner treatment (Ct)	ns	ns	ns	ns	ns
Variety (Var)	**	ns	**	**	**
Moisture (Mc)	**	**	**	*	**
Ct*Mc	ns	ns	ns	ns	ns
Var*Mc	ns	ns	ns	ns	ns
Ct*Var*Mc	ns	ns	ns	ns	ns
Cleaner treatment					
1	0.9617 a	1.1539 a	7.88 a	169.6 a	0.8828 a
2	0.9633 a	1.1500 a	7.81 a	171.3 a	0.8878 a
3	0.9578 a	1.1489 a	8.11 a	169.2 a	0.8800 a
4	0.9489 a	1.1411 a	8.31 a	169.4 a	0.8800 a
5	0.9639 a	1.1544 a	7.64 a	169.8 a	0.8833 a
LSD	0.0193	0.0174	0.906	2.4	0.0054
Variety					
STV4892	0.9738 a	1.1469 a	6.42 a	170.6 a	0.8720 a
DPL 555	0.9444 a	1.1524 a	9.49 b	169.2 a	0.8936 b
LSD	0.0084	0.0069	0.298	1.4	0.0094

[1]* indicates significance at probability p<0.05, ** indicates significance at probability p<0.01, 'ns' = not significant.
[2]Means followed by the same letter within a property are not significantly different based on Least Squares differences (LSD) calculated at appropriate degrees of freedom and 0.05 level of probability.

Table 4c. Summary of AFIS properties after processed through the cleaner—fixed effects, analyzed by speed at 980 rpm.[1,2]

Source of variance	Neps/g	Seed coat neps/g	Total/g	Dust/g	Visible foreign matter, %
Cleaner treatment (Ct)	**	ns	ns	ns	ns
Variety (Var)	ns	**	**	**	**
Moisture (Mc)	na	na	na	na	na
Ct*Mc	na	na	na	na	na
Var*Mc	na	na	na	na	na
Ct*Var*Mc	ns	ns	ns	ns	ns
Cleaner treatment	Means				
6	229.3 a	10.8 a	418.4 a	328.9 a	1.69 a
7	268.1 b	11.7 a	381.7 a	300.5 a	1.44 a
LSD	24.3	5.6	94.1	72.1	0.43
Variety	Means				
STV4892	256.3 a	13.1 a	528.4 a	412.2 a	2.01 a
DPL 555	241.1 a	9.4 b	271.7 b	217.2 b	1.11 b
LSD	24.3	1.8	94.1	72.1	0.35

[1]* indicates significance at probability p<0.05, ** indicates significance at probability p<0.01, 'ns' = not significant, 'na' = not applicable.
[2]Means followed by the same letter within a property are not significantly different based on Least Squares differences (LSD) calculated at appropriate degrees of freedom and 0.05 level of probability.

Table 4d. Summary of AFIS properties after processed through the cleaner—fixed effects, analyzed by speed at 980 rpm.[1,2]

Source of variance	Length(w), in.	Upper quartile length(w), in.	Short fiber content(w), %	Fineness, mTex	Maturity ratio, %
Cleaner treatment (Ct)	ns	ns	ns	ns	ns
Variety (Var)	**	*	**	*	**
Moisture (Mc)	na	na	na	na	na
Ct*Mc	na	na	na	na	na
Var*Mc	na	na	na	na	na
Ct*Var*Mc	ns	ns	ns	ns	ns
Cleaner treatment	Means				
6	0.9594 a	1.1489 a	7.75 a	171.7 a	0.8906 a
7	0.9578 a	1.1511 a	8.05 a	171.4 a	0.8844 a
LSD	0.0076	0.0084	0.45	2.05	0.0085
Variety	Means				
STV4892	0.9728 a	1.1450 a	6.40 a	172.8 a	0.8767 a
DPL 555	0.9444 b	1.1550 b	9.40 b	170.4 b	0.8983 b
LSD	0.0076	0.0084	0.50	2.05	0.0085

[1] * indicates significance at probability p<0.05, ** indicates significance at probability p<0.01, ‘ns’ = not significant, ‘na’ = not applicable.
[2]Means followed by the same letter within a property are not significantly different based on Least Squares differences (LSD) calculated at appropriate degrees of freedom and 0.05 level of probability.

Table 5a. Analysis of variance for lint turnout, lint cleaner waste and cleaning efficiency, analyzed by speed at 980 rpm.[1, 2]

Source of variance	Lint turnout	Cleaner waste, lb/bale	Cleaning efficiency	
			Based on AFIS visible foreign matter	Based on visible waste (Shirley Analyzer)
Cleaner treatment (Ct)	*	**	ns	**
Variety (Var)	**	**	**	ns
Moisture (Mc)	**	ns	ns	ns
Ct*Mc	ns	ns	ns	ns
Var*Mc	ns	ns	ns	ns
Ct*Var*Mc	ns	ns	ns	ns
Cleaner treatment	Means			
1	0.4040 a	2.85 a	0.0422 b	0.1697 a
2	0.4028 a	2.57 a	0.1667 ab	0.0931 a
3	0.3994 a	2.46 a	0.1291 b	0.0989 a
4	0.3892 b	6.60 c	0.3585 a	0.4710 b
5	0.4023 a	3.82 b	0.1495 ab	0.1592 a
LSD	0.00796	0.886	0.2181	0.0856
Variety	Means			
STV4892	0.3731 a	4.32 a	0.2258 a	0.2081 a
DPL 555	0.4259 b	3.00 b	0.1127 a	0.1887 a
LSD	0.00465	0.327	0.1293	0.0501

[1] * indicates significance at probability p<0.05, ** indicates significance at probability p<0.01, ‘ns’ = not significant.
[2]Means followed by the same letter within a property are not significantly different based on Least Squares differences (LSD) calculated at appropriate degrees of freedom and 0.05 level of probability.

Table 5b. Analysis of variance for lint turnout, lint cleaner waste and cleaning efficiency, analyzed by speed at 980 rpm.[1, 2]

Source of variance	Lint turnout	Cleaner waste, lb/bale	Cleaning efficiency	
			Based on AFIS visible foreign matter	Based on visible waste (Shirley Analyzer)
Cleaner treatment (Ct)	ns	**	**	**
Variety (Var)	**	*	ns	ns
Moisture (Mc)	na	na	na	na
Ct*Mc	na	na	na	na
Var*Mc	na	na	na	na
Ct*Var*Mc	ns	ns	ns	ns
Cleaner treatment			Means	
6	0.3932 a	2.27 a	0.0673 a	0.0962 a
7	0.3989 a	3.99 b	0.2667 b	0.2777 b
LSD	0.0219	0.797	0.2011	0.0627
Variety			Means	
STV4892	0.3684 a	3.65 a	0.2012 a	0.1840 a
DPL 555	0.4238 b	2.61 b	0.1328 a	0.1898 a
LSD	0.0219	0.797	0.2277	0.0627

[1] * indicates significance at probability p<0.05, ** indicates significance at probability p<0.01, 'ns' = not significant, 'na' = not applicable.
[2]Means followed by the same letter within a property are not significantly different based on Least Squares differences (LSD) calculated at appropriate degrees of freedom and 0.05 level of probability.

Table 6. Comparisons of statistically significant responses for the cleaner treatments.[1,2]

Cleaner treatment	Rd	Cleaning efficiency based on Shirley visible waste, %	Lint cleaner waste, (lb/bale)	Lint turnout, %
1[3]	**79.0 ab**	**16.97 ab**	**2.85 a**	**40.40 a**
2	78.3 b	9.31 a	2.57 a	40.28 a
3	78.2 b	9.89 a	2.46 a	39.94 a
4	79.8 a	47.10 b	6.60 c	38.92 b
5	78.7 b	15.92 a	3.82 b	40.23 a
6	78.5 a	9.62 a	2.27 a	39.32 a
7	79.1 a	27.77 b	3.99 b	39.89 a

[1] * indicates significance at probability p<0.05, ** indicates significance at probability p<0.01, 'ns' = not significant.
[2]Means followed by the same letter within a property are not significantly different based on Least Squares differences (LSD) calculated at appropriate degrees of freedom and 0.05 level of probability.
[3]Bold letters indicate an overall best balanced performance.

Figure 1. Flat, square grid bar: 6.4 mm wide and 9.5 mm spacing.

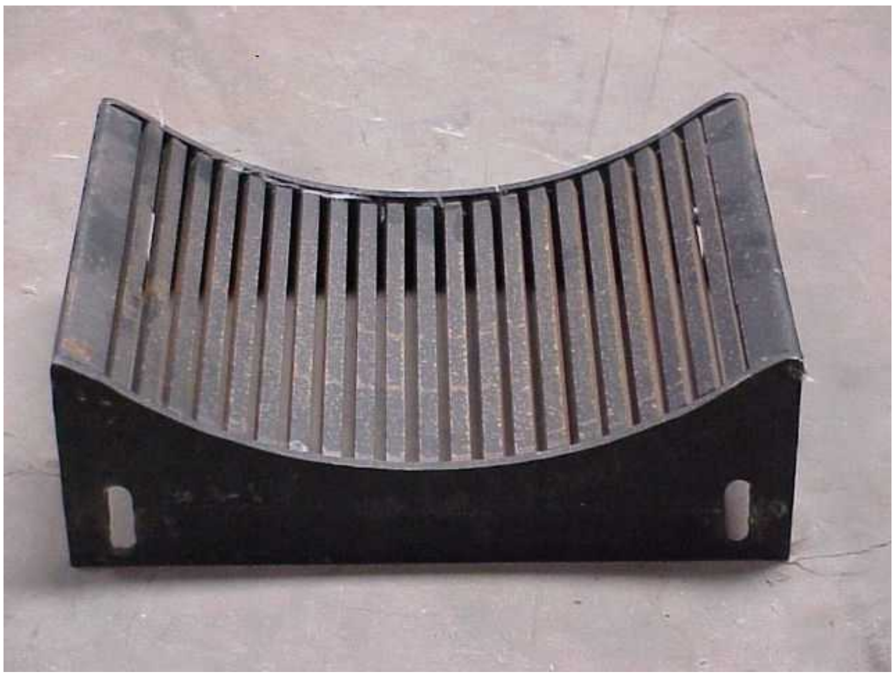

Figure 2. Flat, square grid bar: 9.5 mm wide and 6.4 mm spacing.

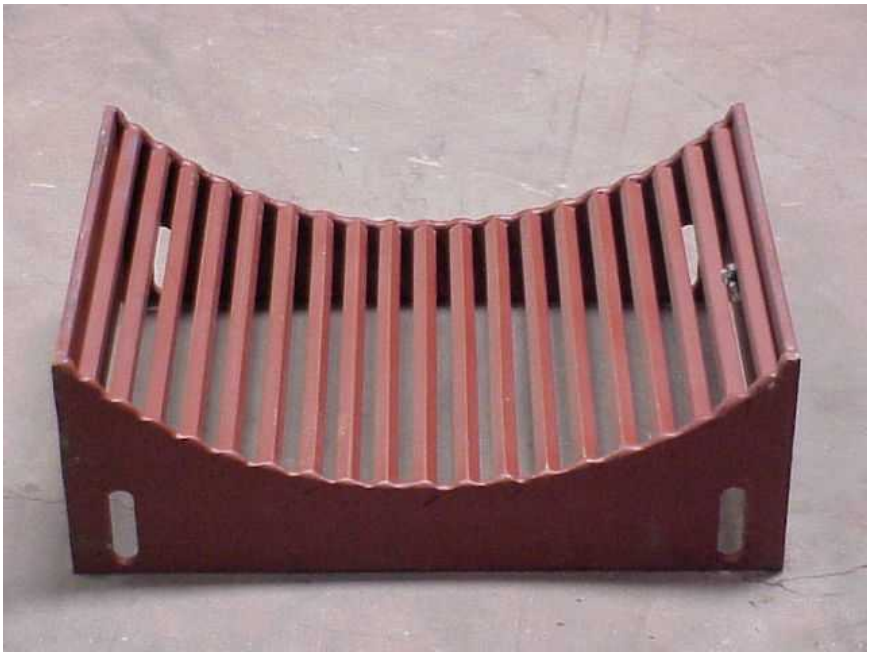

Figure 3. Diamond shaped grid bar: 9.5 mm wide and 6.4 mm spacing.

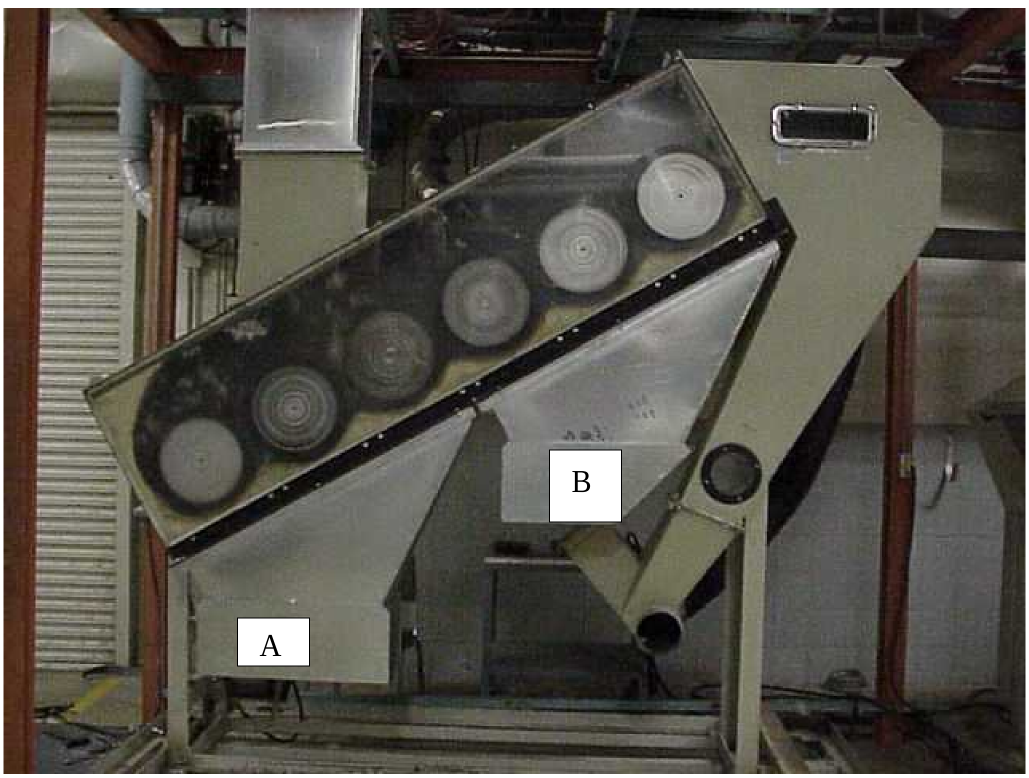

Figure 4. Experimental inclined six cylinder cleaner with trash hopper A and B.

Figure 5. Trash collected from configuration 2, 980 rpm, variety DPL555 and 6% moisture. Pan A (left) showing trash collected from the lower 3 cylinders, Pan B (right) showing trash collected from the upper 3 cylinders.

Figure 6. Trash collected from configuration 3, 980 rpm, variety DPL555 and 4 % moisture. Pan A (left), Pan B (right).

Figure 7. Trash collected from configuration 5, 980 rpm, variety DPL555and 4% moisture. Pan A (left), Pan B (right).

Figure 8. Trash collected from configuration 1, 980 rpm, variety STV4892 and 4% moisture. Pan A (left), Pan B (right).

Figure 9. Trash collected from configuration 4 (saw-type lint cleaner), 980 rpm, variety DPL555 and 4 % moisture.

Figure 10. Trash collected from configuration 7 (cylinder cleaner +special saw-type lint cleaner), 980 rpm, variety DPL555 and 6% moisture. Pan A (top left), Pan B (top right), Pan C (bottom center) showing trash collected from the special saw-type cleaner.