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ENGINEERING AND GINNING

Lint Cleaning with Two Air-jet Cleaners in Series

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ABSTRACT

The performance of two air-jet cleaners connected in series was evaluated. The air-jet cleaners were connected so that the fiber stream could be cleaned on one side or both sides. The effect of flow velocity on cleaning performance was also tested. In comparison to the baseline saw-type lint cleaner, which was the most efficient cleaner, the air-jet cleaners plus a special saw-type cleaner with only one cleaning point ranked second in cleaning performance. The air-jet cleaners were the least efficient cleaners, however, this cleaner configuration was the least aggressive; it generated the fewest neps and produced slightly longer fiber. Compared to cleaning only one side of the fiber stream, cleaning both sides at a higher flow velocity could gain 8% in cleaning efficiency.

Saw-type lint cleaners are the most common and effective cleaners employed in the ginning industry today. Their performance and deficiencies are well documented (Baker, 1978, Mangialardi, 1991). Saw-type lint cleaners are known for their aggressive cleaning; they cause fiber damage and increase neps (Mangialardi, 1985). An air-jet lint cleaner invented by Van Doorn (1954) claimed to provide gentle and effective lint cleaning. This type of cleaner has no moving parts, consumes little additional power, and utilizes the abrupt change in flow direction to eject detached trash particles through an adjustable ejection slot at the bend of a fiber-conveying flow passage. The flow passage has the shape of a converging-diverging nozzle. The 90° bend occurs at the throat (the smallest cross-sectional area of the flow passage), which causes acceleration and deceleration of fiber tufts just before and after the throat and the bend. The combination of acceleration and change in flow direction causes high-momentum trash particles to be ejected through the slot. Recent high-speed photography showed that some scrubbing of the fiber was occurring at the top edge of the ejection slot, but the action was much gentler than that occurring at the saw and grid-bar interface of a saw-type lint cleaner.

In 1961, researchers at the US Cotton Ginning Research Laboratory at Stoneville, MS, designed and built a serpentine air-jet cleaner based on the same principle (Fig. 1). Its flow path formed an S-shaped design. The outside wall (concave portion) was enclosed at the turns of the flow passage by triangular grid bars that could be rotated to adjust the gap between bars (Franks and Shaw, 1964). The patented serpentine cleaner was applied to clean cotton in during the ginning process. When compared to a 7-cylinder cleaner, this air-jet cleaner provided better grade and cleaning in three to five passes. Mangialardi (1990) and Mangialardi and Anthony (1998) conducted studies at commercial gins equipped with an air-jet cleaner. The air-jet cleaner was usually installed behind the gin stand and before a saw-type lint cleaner. Mangialardi and Anthony (1998) found that by varying the opening of the air-jet cleaner from 1.6 to 4.1 cm, waste ejected by the cleaner increased from 0.6 to 2.5 kg/bale. Mangialardi (1990) found that the average cleaning efficiency of an air-jet cleaner was 9% as compared to 36% of a saw-type cleaner. Although the cleaning efficiency of an air-jet cleaner was low and did not significantly improve color grade of fiber, it was a gentler cleaner. It did not cause any fiber damage that decreased fiber length, increased neps, short fiber content, and seed coat fragments. The opposite was true for a saw-type lint cleaner. The serpentine air-jet seed cotton cleaner designed by Franks and Shaw (1964) provided multiple cleaning points and the S shape facilitated cleaning on both sides of the seed cotton stream. Motivated by the operation of the serpentine design, this study was conducted to evaluate the performance of two air-jet lint cleaners connected in series with the ability of cleaning on both sides of a fiber stream.

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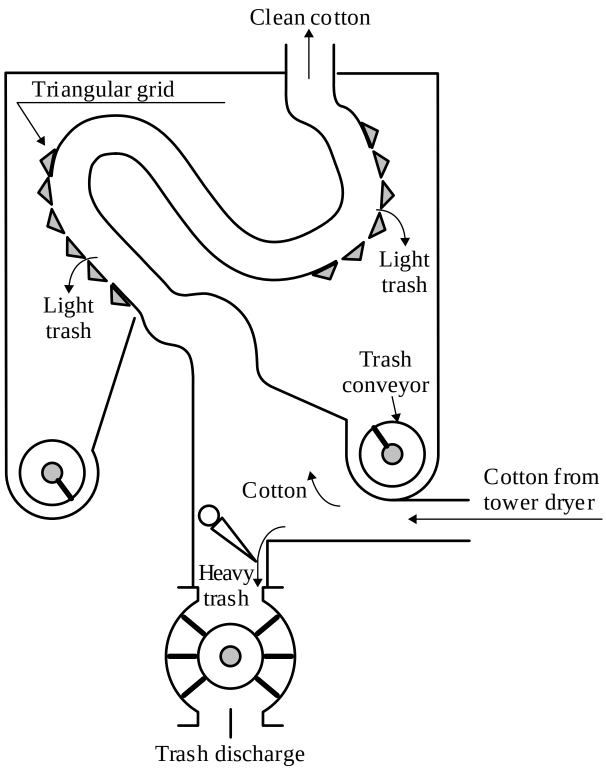

Figure 1. A serpentine air-jet cleaner designed by Franks and Shaw.

MATERIALS AND METHODS

Two reduced-width air-jet lint cleaners were specially fabricated for the Cotton Ginning Research Unit at Stoneville, MS, by Lummus Corporation (Savannah, GA). These air-jet cleaners are scaled-down versions of the Super Jet™ model by Lummus (Fig. 2). Both the inlet and outlet ports of the air-jet cleaners in the lab are 7.6 cm high. From the entrance, the height of the flow passage narrows gradually to 2.54 cm at the throat. The distance from the entrance to the throat is 71.1 cm. At the throat, the flow passage makes a 90° turn and exits at the outlet port. This diverging passage is 55.9 cm long. The constant width of the air jets is 45.7 cm. At the outside corner of the turn, there is an adjustable open slot for the ejection of trash particles. To evaluate the cleaning performance of the air-jet cleaners, three tests were formulated and the air-jet cleaners' performance was compared to a 5-grid-bar saw-type lint cleaner (SLC) as a baseline.

Ginning sequence and sampling procedures were identical for all three tests. The ginning sequence for the tests consisted of a shelf dryer set at 38 °C (100 °F), 6-cylinder cleaner, stick machine, 6-cylinder cleaner, extractor-feeder, 20-saw (40.6 cm diameter) gin stand followed by the lint cleaner treatments described above. For every extended downtime for configuration changes, 18.1 kg (40 lb) of seed cotton was run through the system to warm up the machinery before resuming the test. The average seed cotton flow rate for the tests was set to a nominal rate of 500 kg/hr/m. For each test, three samples were collected at the feeder apron for the fractionation test (Shepherd,1972), before and after the cleaner treatments for High Volume Instrument (HVI), Advanced Fiber Information System (AFIS), and Shirley Analyzer (Shirley Limited, Liverpool, England; ASTM, 2004) tests. Three lint moisture samples were collected at the battery condenser. The positive static pressure before the air-jet cleaners made collecting samples before the air-jet cleaners difficult. To collect these samples, ginned lint was routed to bypass the air-jet cleaners for a short period of time and collected at the condenser. The test resumed with the air jets put back inline and after-cleaner samples were collected.

Test 1. The two air-jet cleaners were connected in series such that both sides of a fiber stream would be

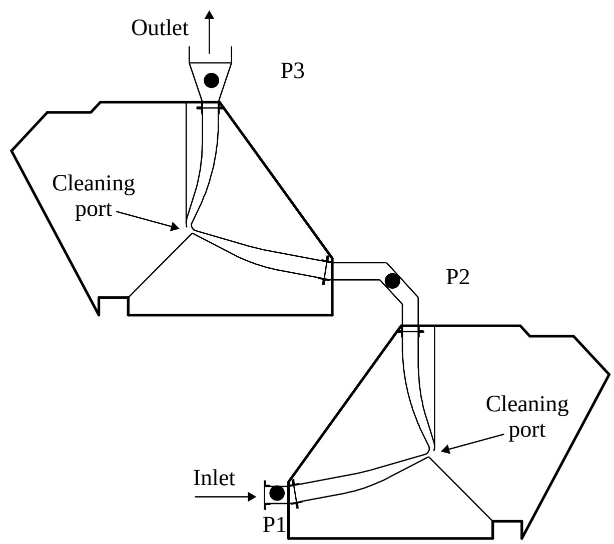

Figure 2. A schematic of two air-jet cleaners connected in series cleaning two sides of a fiber stream.

exposed to the scrubbing action of the open slots (Figs. 2 and 3). Because of the low cleaning efficiency of the air-jet cleaners, the fiber stream was also cleaned by a special saw-type lint cleaner that had only one cleaning point in a second cleaner treatment. Thus, there were three cleaner treatments for this test: air-jet cleaners, air-jet cleaners plus a saw-type cleaner with one cleaning point, and the baseline SLC. Two cotton cultivars were used in the experiment. The hairy-leaf cultivar (STV 4892, Monsanto Company, St Louis, MO) and the smooth-leaf cultivar (DPL555, Delta Pine and Land Co., Scott, MS) were harvested in the 2006 season. With three blocked replications and randomized orders in cleaner treatment and cultivar combinations, the experiment required 18 runs.

Figure 3. A photograph of the actual setup for Test 1 and Test 3.

Test 2. The two air-jet cleaners in Test 2 were connected in series such that only one side of the fiber stream was exposed to the scrubbing action of the open slots (Figs. 4 and 5). In Test 2, the flow passage external to the jets was shortened and enlarged; the speed of the exhaust fan was increased to increase air flow through the air jets by 38%. Flow measurements for the air-jet cleaners are presented in Table 1. Cleaner treatments and cultivars were the same as used in Test 1 and another 18 runs of a randomized complete block experiment were executed for Test 2.

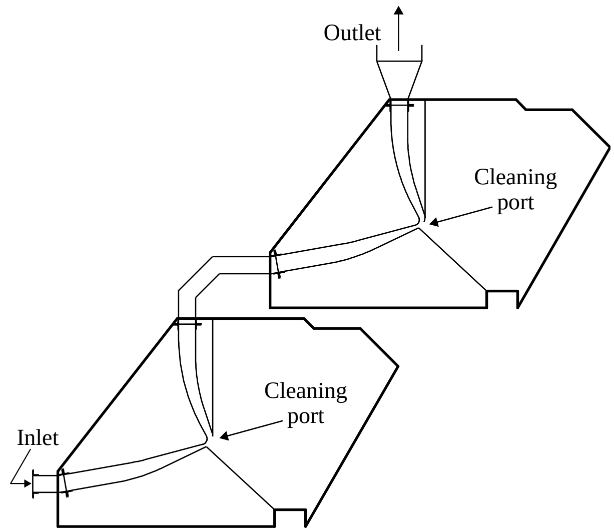

Figure 4. A schematic of two air-jet cleaners connected in series cleaning one side of a fiber stream.

Figure 5. A photograph of the actual set up for Test 2.

Test 3. The test setup for Test 3 was identical to Test 1, except the test was conducted at a higher flow rate.

Table 1. Air-jet flow velocity measurements[z, y]

	Pressure, mm H_2O	Jet 1 inlet @ P1[x]	Jet 2 inlet @ P2[x]	Jet 2 outlet @ P3[x]	Flow rate, m^3 / min
Test 1	p_v	**1.3**	**1.3**	**2.9**	**12.2**
	p_s	**8.9**	**-6.4**	**-31.8**	
Test 2	p_v	**3.8**	**3.8**	**5.1**	**16.1**
	p_s	**-11.4**	**-11.4**	**-41.9**	
Test 3	p_v	**0.8**	**5.1**	**5.1**	**16.1**
	p_s	**-21.6**	**-25.4**	**-49.5**	

[z] P_v = velocity pressure, P_T = total pressure, P_s = static pressure

[y] Ambient conditions: 18 ºC, 77% relative humidity, 100.8 kPa barometric pressure

[x] Locations of measurement ports in Fig. 2.

Analytical methods. Analysis of variance of the data was conducted using mixed models according to Littell et al. (1996) with the SAS software (Version 9.1, Cary, NC). Tests for the difference in the means were based on least significant difference (LSD) calculations with probability level of 5%. Data from each test were analyzed separately. Because all three tests used a randomized complete block design, the mixed models for the tests included the main effects of the cleaner treatments, cultivars, and their first-order interactions. The random effects included the replications and the interaction between replications and cleaner treatments. Because all three tests used the same SLC as the baseline treatment, differences in performance between a cleaner treatment and that of the baseline treatment in each test could provide an assessment of the relative performance of the individual cleaner treatment in different tests.

Test Results. Lint moisture means (Shepherd, 1972) for samples in all three tests varied from 4.4 to 5.7% with standard deviations in the range of 0.26 to 0.63% (Table 2). The moisture variations did not significantly affect results of the tests.

Fiber properties. Results of the analysis of variance for the HVI properties are summarized in Table 3. Reflectance values for the treatments with air-jet cleaners and with air-jet cleaners plus a special SLC with one grid bar were not significantly

Table 2. Lint moisture content of the tests

	Test 1	Test 2	Test 3
Mean, %	5.7	4.4	5.0
Standard deviation, %	0.46	0.26	0.63

Table 3. Anova summary of HVI properties means after cleaner treatment[z]

Source of variance	Micronaire	Reflectance	Yellowness	Leaf grade	Trash area, %	Length, cm	Uniformity, %
Cleaner treatment[y]	Test 1: cleaned on two sides						
Air jets	4.6	78.6b	8.1	3.5ab	0.52a	2.83	82.2
Air jets + saw	4.7	79.3b	8.1	3.6a	0.50a	2.84	82.1
SLC	4.6	80.1a	8.3	2.9b	0.36b	2.82	82.1
Cultivar							
STV4892	4.7	78.5	8.7	3.8a	0.56a	2.83	82.6a
DPL555	4.6	80.2	7.7	2.9b	0.36b	2.83	82.6b
Cleaner treatment	Test 2: cleaned on one side						
Air jets	4.6	78.8b	8.0b	3.5a	0.47a	2.82	82.3
Air jets + saw	4.6	79.3b	8.2a	3.2b	0.34b	2.82	81.9
SLC	4.6	80.3a	8.0b	3.0b	0.28b	2.81	81.9
Cultivar							
STV4892	4.7	77.5b	8.8a	3.3	0.42a	2.82	82.9a
DPL555	4.5	81.4a	7.4b	3.2	0.30b	2.81	81.2b
Cleaner treatment	Test 3: cleaned on two sides						
Air jets	4.6	78.2c	7.8	3.5a	0.50a	2.81	82.0
Air jets + saw	4.6	79.0b	7.7	3.4a	0.42b	2.79	81.9
SLC	4.6	79.6a	7.9	2.9b	0.32c	2.80	81.8
Cultivar							
STV4892	4.7a	78.8	8.1	3.6a	0.53a	2.81a	82.5a
DPL555	4.5b	79.1	7.5	2.9b	0.29b	2.79b	80.3b

[z] Means followed by the same letter within a property were not significantly different. Means where letters are not shown were not significantly different; LSD calculated at appropriate degrees of freedom and $p = 0.05$.

[y] Air jets = two air-jet cleaners connected in series, Air jets + saw = two air-jet cleaners connected in series plus a saw-type cleaner with only one cleaning point, SLC = saw-type lint cleaner.

different, but the values were lower than that of the baseline SLC. In Test 3, in which both sides of the fiber stream were cleaned by the jets as in Test 1 but at a higher flow velocity, reflectance values for all three cleaner treatments were significantly different: reflectance of the SLC was the highest, followed by that of the air-jet cleaners plus saw treatment, and then the air-jet cleaners. Fiber yellowness values for the air-jet configuration and SLC were not different and were lower than that of the air-jet cleaners plus saw (Table 3, Test 2). The air-jet cleaners generally did not clean as well as the other two treatments in Test 2 and Test 3 according to trash area measurements. Cleaner treatments 1 and 2 had significantly different and higher values in leaf grade and trash area than the baseline SLC. Overall, the baseline SLC was a more efficient cleaner than the both air-jet treatments. There were minor differences between the air-jet cleaners and air-jet cleaners plus saw treatments in other fiber properties; the latter treatment was generally a more effective cleaner because of the added cleaning by the saw-type cleaner with one grid bar. All lint cleaner treatments, including the baseline SLC, did not significantly affect micronaire, fiber yellowness (except Test 2), fiber length, and fiber uniformity.

Results of the variance analysis for the AFIS properties are summarized in Table 4. In general, the cleaner treatments did not affect AFIS properties in seed-coat neps, upper quartile length, and fiber length (except in Test 1 where the air-jet cleaners produced slightly longer fiber). For all three tests, the air-jet configuration generated the fewest neps and indicated gentler cleaning; the air-jet cleaners plus saw and the baseline SLC treatments were the more aggressive cleaners and produced more neps. Their cleaning effectiveness was demonstrated by lower values in dust and visible foreign matter (VFM). In

Table 4. Anova summary of AFIS properties means after cleaner treatment[z]

Source of variance	Neps/g	Seed coat neps/g	Dust/g	Visible foreign matter, %	Length (w), cm	Upper quartile length (w), cm	Short fiber content (w), %
Cleaner treatment[y]	**Test 1: cleaned on two sides**						
Air jets	**149.3b**	**10.2**	**330.2a**	**1.93a**	**2.52a**	**2.98**	**6.29b**
Air jets + saw	**182.5a**	**10.1**	**283.0a**	**1.78a**	**2.51a**	**2.99**	**6.89a**
SLC	**185.8a**	**9.0**	**218.9b**	**1.30b**	**2.49b**	**2.97**	**7.07a**
Cultivar							
STV4892	**148.5b**	**12.3a**	**304.3**	**1.94**	**2.52**	**2.98**	**6.06**
DPL555	**196.5a**	**7.2b**	**250.5**	**1.40**	**2.50**	**2.99**	**7.44**
Cleaner treatment	**Test 2: cleaned on one side**						
Air jets	**165.8b**	**9.8**	**364.5a**	**1.42**	**2.44**	**2.93**	**7.97**
Air jets + saw	**202.3a**	**11.1**	**287.5ab**	**1.52**	**2.43**	**2.93**	**8.21**
SLC	**181.1ab**	**10.3**	**202.1b**	**1.17**	**2.44**	**2.92**	**7.96**
Cultivar							
STV4892	**153.3b**	**13.9a**	**349.8a**	**2.09a**	**2.50a**	**2.94**	**6.27b**
DPL555	**212.8a**	**6.9b**	**153.0b**	**0.64b**	**2.38b**	**2.91**	**9.82a**
Cleaner treatment	**Test 3: cleaned on two sides**						
Air jets	**165.8b**	**9.4**	**309.2a**	**1.89a**	**2.46**	**2.94**	**7.36b**
Air jets + saw	**196.9a**	**10.3**	**239.2b**	**1.52ab**	**2.45**	**2.93**	**7.60ab**
SLC	**196.1a**	**11.6**	**200.0b**	**1.17b**	**2.44**	**2.93**	**8.02a**
Cultivar							
STV4892	**173.8**	**13.2a**	**306.7a**	**1.84**	**2.48a**	**2.95**	**6.68b**
DPL555	**198.7**	**7.6b**	**192.2b**	**1.22**	**2.42b**	**2.93**	**8.65a**

[z] Means followed by the same letter within a property were not significantly different. Means where letters are not shown were not significantly different; LSD calculated at appropriate degrees of freedom and *p* = 0.05.

[y] Air jets = two air-jet cleaners connected in series, Air jets + saw = two air-jet cleaners connected in series plus a saw-type cleaner with only one cleaning point, SLC = saw-type lint cleaner.

this experiment, dust was a more consistent indicator of cleaning efficiency: its presence showed that the air-jet cleaners in series were the least efficient in cleaning (309 dust/g), followed by the air-jet cleaners plus saw configuration (239 dust/g), and the SLC cleaner (200 dust/g). From the inspection of dust and VFM in Test 2 and Test 3, one might infer that the air-jet cleaners cleaning on both sides of the fiber stream (Test 3) cleaned slightly better than air-jet cleaners cleaning on only one side of the fiber stream (Test 2). Cleaning efficiency results (Table 5) show that the former was roughly 8% higher with an adjustment for the difference in baseline values. Test 1 operating at a lower flow velocity also cleaned less efficiently. From the property of short fiber content (SFC) measured by weight, Test 1 operating at lower flow velocity cleaned less efficiently but caused less fiber damage with lower SFC compared to the other two tests at higher flow velocity. Besides cleaning more effectively by cleaning on both sides of the fiber stream, Test 3 might also cause less fiber damage than cleaning only one side of the fiber stream (Test 2) based on its lower SFC (Table 4). The saw-type cleaner caused more fiber damage than the air-jet configurations, except in Test 2, where the differences among treatments were insignificant.

Turnout, cleaner waste, and cleaning efficiency. Waste generated by the cleaner treatments in all three tests was processed through a Shirley Analyzer; the results were consistent. The air-jet cleaners generated the least waste, which was one third of the waste produced by the air-jet cleaners plus saw, which in turn was also roughly one third of the waste generated by the baseline SLC. However, turnout yielded by the cleaner treatments in these tests were not distinguishable, except in Test 1, where the air-jet

Table 5. Anova summary of turnout, cleaning efficiency and waste characteristics[z]

Source of variance	Turnout, %	Cleaning efficiency, %	Cleaner waste, kg/bale
Cleaner treatment[y]		**Test 1: cleaned on two sides**	
Air jets	39.42a	1.94c	1.6c
Air jets + saw	39.14ab	26.85b	7.0b
SLC	38.18b	45.13a	32.6a
Cultivar			
STV4892	37.22b	22.15	13.8
DPL555	40.60a	27.14	13.7
Cleaner treatment		**Test 2: cleaned on one side**	
Air jets	39.27	2.27c	2.7c
Air jet s+ saw	39.72	27.96b	8.9b
SLC	38.57	51.35a	28.9a
Cultivar			
STV4892	37.85	22.19	12.4b
DPL555	40.53	29.17	14.6a
Cleaner treatment		**Test 3: cleaned on two sides**	
Air jets	38.78	8.84c	3.78c
Air jets + saw	38.57	34.66b	9.75b
SLC	38.34	49.32a	31.1a
Cultivar			
STV4892	38.05	28.86	14.6
DPL555	39.08	33.02	15.2

[z] Means followed by the same letter within a property were not significantly different. Means where letters are not shown were not significantly different; LSD calculated at appropriate degrees of freedom and $p = 0.05$.

[y] Air jets = two air-jet cleaners connected in series, Air jets + saw = two air-jet cleaners connected in series plus a saw-type cleaner with only one cleaning point, SLC = saw-type lint cleaner.

cleaners had the highest turnout, followed by the air-jet cleaners plus saw and the baseline SLC (Table 5). The 1.24% gain in turnout for the air-jet cleaners over the baseline SLC is a gain of $2.78 per bale for a nominal 200 kg bale at $0.50 per 454 g of lint.

To calculate the cleaning efficiency of a cleaner treatment, the before and after cleaner samples were processed through the Shirley analyzer to measure the amount of visible waste in the samples. The difference in visible wastes between the before and after samples divided by that of the before sample is the cleaning efficiency for the cleaner treatment. Table 5 shows that SLC had the highest cleaning efficiency, followed by the air-jet cleaners plus saw, and then the air-jet cleaners. The results show that it was up to 8% more efficient to clean on both sides of the fiber stream than to clean on only one side (Table 5). The air-jet cleaners also had lower cleaning efficiency at low flow velocity (Test 1).

There was no significant interaction between cleaner treatments and cultivars; cultivar data were included in the tables for information only.

SUMMARY AND CONCLUSION

Three separate tests were conducted for this study. In the first test, the three cleaner treatments were: two air-jet cleaners connected in series, two air-jet cleaners in series plus an SLC with one cleaning point, and the baseline SLC. The air-jet cleaners were connected such that both sides of the fiber stream were cleaned at the ejection ports. Test 2 was set up so that only one side of the fiber stream was cleaned at an increased flow velocity. Test 3 was a repeat of Test 1 at the higher flow velocity. In general, the three cleaner treatments did not cause significantly different values in micronaire, fiber yellowness, length, and length uniformity. HVI and AFIS properties clearly showed that the SLC was the most efficient cleaner followed by the air-jet cleaners plus saw and the air-jet cleaners. The SLC and air-jet cleaners plus saw configuration were more aggressive in cleaning than the air-jet cleaners as they generated more neps. Comparing to cleaning only one side of the fiber stream, the air-jet cleaners gained 8% in cleaning efficiency when cleaning both sides of the fiber stream. The air-jet cleaners cleaned less efficiently but less aggressively at low flow velocity (Test 1).

The air-jet cleaners generated the least amount of waste, which was one third of that generated by the air-jet cleaners plus saw configuration; this waste in turn was roughly one-third the waste generated by the SLC. However, turnout from the three cleaner treatments was not significantly different at high flow velocity. At low flow velocity, the air-jet cleaners had the highest turnout which was 1.24% higher than the lowest turnout produced by the SLC (38.18%) and a gain of $2.73 per bale.

DISCLAIMER

Mention of a trademark, warranty, proprietary product or vendor does not constitute a guarantee by the U. S. Department of Agriculture and does not imply approval or recommendation of the product to the exclusion of others that may be suitable.

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