BUR COTTON MATERIAL FLOW CHARACTERIZATION AND PARAMETERIZATION ON A WIRE BELT CONVEYOR

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Abstract

The main goal of this study was to characterize and parameterize bur cotton flow on a wire belt conveyor. This was accomplished using fiber quality and foreign matter data collected from previously determined belt configurations. Three typical yields common to the Southern High Plains (428.6, 642.9, and 857.1 kg ha^{-1}, which are equivalent to 1, 1.5, and 2 bale per acre yields), a one meter row width, and 5.6 km h-1 ground speed were used to determine three material flow rates. Four wire belt conveyor widths (0.18, 0.36, 0.53, and 0.69 m) and four material depths (0.025, 0.05, 0.10, 0.18 m) were chosen. Belt speed was determined for each of the 16 width/depth combinations to achieve the three material flow rates. Fiber quality, percent foreign matter removal, and foreign matter data were collected from the extreme high and low velocities as determined by each belt width and greatest and least material flow rates and shallowest and deepest material depths (0.025 and 0.18 m) within each of the wire belt widths to determine the wire belt configuration effects on fiber quality and foreign matter content.

Introduction

Material conveyance can produce many unique challenges, especially when it comes to agricultural products. Harvesters are expected to perform at an utmost level of field efficiency during the harvest season. Baumgarten et al. (2009) investigated an assistance system for optimization of the grain combine harvest process and many of the principles can be transferred to cotton harvesters. Proper parameterization and characterization of harvesting equipment should start with individual component investigation. Studies by Porter et al. (2012, 2013) investigated consecutive conveying/cleaning components on a cotton stripper harvester and identified and tested a redesign of the cross auger for bur cotton conveyance. Rademacher (2009) explored the harvesting and processing efficiency of a combine as related to the optimization of the machine settings. Benefits such as an increased quality of canola and wheat were observed during harvest by Rademacher (2009) using the Claas electronic machine optimization service (CEMOS), the same system used in the Baumgarten et al. (2009) study. There are two other main parameters, independent of conveyance ability, that are the central focus for stripper harvested cotton– foreign matter content and fiber quality. Brashears and Ulich (1986) investigated pneumatic removal of fine material from bur cotton. Exhaust hoods were mounted over the stripper rolls and succeeded in removing up to 70 kg ha^{-1}, but the fine material was not significantly reduced over a standard stripper harvester. Laird and Baker (1985) investigated conveying cotton on an inclined wire belt. They reported that the physical forces that control conveying of a material such as cotton on an inclined belt are frictional forces between the material and the conveying surface, flow characteristics of the conveyed material, and inertial and other forces resulting from the non-uniform flow situation. Laird and Baker reported that the rigorous mathematical theory describing the interactions of all these forces in a belt conveyor has not been developed and was beyond the scope of their study. They reported that the angle of slide, or the angle at which the cotton began to slide back down the surface, was 60°; however with a compressible material such as cotton, the angle of slide may vary considerably with depth, density, trash, and moisture content, and other properties of the cotton. Also, the angle of slide under non-uniform flow conditions may be less than the angle determined under static conditions. The angle of slide is directly related to static and dynamic friction. Similar to the Laird and Baker, the bur cotton in this study has non-uniform material composition and the flow characteristics can change based on material properties. The non-uniform characteristics of the bur cotton make it hard to predict the actual velocity and flow characteristics since the frictional forces are so variable. The principles investigated during the Brashears and Ulich (1986) study could be applied to a wire belt conveyor to employ an additional method of cleaning. Thus, this portion of the study not only investigates bur cotton conveyance on a wire belt but works towards characterizing foreign matter content and fiber quality associated with various belt widths, speeds and depths.

Materials and Methods

This section expands on Porter et al. (2013) and explores various speeds, depths, and widths on a wire belt conveyor. Data from Porter et al. (2013) supported the idea that a wire belt conveyor can be used as a viable replacement for a cross auger on a cotton stripper. A FiberMax 9170 B2F cultivar was used for this study.

To properly design and optimize a wire belt for conveying bur cotton, multiple material conveyance parameters need to be tested and quantified. A standard field harvest speed of 5.6 km h^{-1} (3.5 m h^{-1}) was used in combination with three estimated common bur cotton yields observed in the Southern High Plains: 429, 643, and 857 kg lint ha^{-1} (1, 1.5 and 2 bale ac^{-1} yields). The speed and yields in combination with a one row (1 m) harvest width equate to 0.30, 0.45, and 0.60 kg s^{-1} of material flow, respectively. A 0.69-m wide wire belt conveyor was built. The wire belt had rectangular slots that were 1.27 cm by 2.54 cm (Figure 1). The belt conveyor was driven by a single v-belt using a 110 V electric motor with a variable frequency drive (Figure 2).

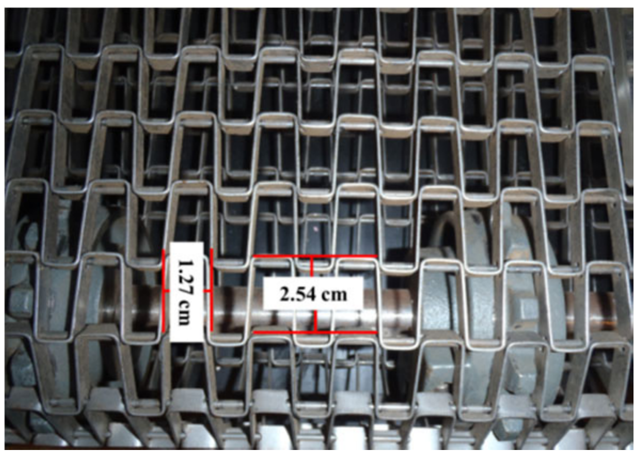

Figure 1. The dimensions of the wire belt that was used for the wire belt conveyance of bur cotton.

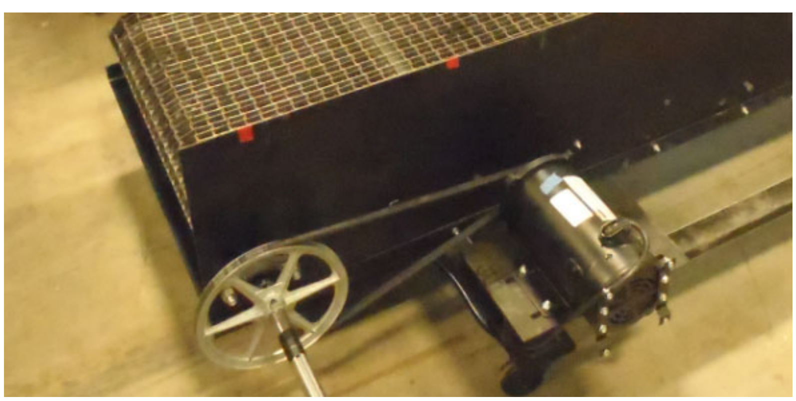
Figure 2. The motor and drive belt that operated the wire belt conveyor.

Four belt widths were tested: 0.18 m, 0.36 m, 0.53 m and 0.69 m. The minimum and maximum widths were determined based on the width of the current auger trough on a cotton stripper. The minimum width was half and the maximum width was double that of the current width of the auger trough on a John Deere 7460 cotton stripper. The width of the belt conveyor was made adjustable by a divider (Figure 3) that was designed to fit over the top of the wire belt conveyor. The divider had slotted rails so it could be set to any width. Four depths were chosen, 0.03 m, 0.05 m, 0.10 m, and 0.18 m. Belt speeds were calculated based on these depths. As with any material conveyance, there is a minimum and maximum speed that would be feasible for field operation. Thus the calculated belt speed was set throughout the tests based on the width and depth settings. Belt speed was controlled by a variable frequency drive on the drive motor and an optical tachometer was used to measure the speed of the belt head-shaft. The test matrix represents the test combinations that were used for the fiber quality data collection (Table 1). The red highlighted fields represent velocities deemed non practical because they were either too slow or too fast for the electric motor. The eliminated speeds are not practical from a field harvesting standpoint as these extreme velocities would be either much slower or faster than bur cotton would be introduced into the machine. Slower velocities could lead to greater material depths and potential clogging within the wire belt conveyance trough slowing and even disrupting harvest in certain cases. Extremely fast velocities would never allow the wire belt to be fully loaded and perform under full load. The fast velocities could also introduce other issues such as high power requirements and potential for increased wear to moving parts on the wire belt conveyor.

Table 1. Test matrix that was used for testing the wire belt conveyor for high speed camera and fiber quality work (velocities highlighted in red were not performed due to being impractical).

Width (m)	**0.03 m Material Depth**	**0.05 m Material Depth**	**0.10 m Material Depth**	**0.18 m Material Depth**
Velocities (m/s) for 0.30 kg s^{-1} of Material Flow				
0.18	2.05	1.03	0.51	0.29
0.36	1.03	0.51	0.26	0.15
0.53	0.68	0.34	0.17	0.10
0.69	0.53	0.27	0.13	0.08
Velocities (m/s) for 0.45 kg s^{-1} of Material Flow				
0.18	3.08	1.54	0.77	0.44
0.36	1.54	0.77	0.38	0.22
0.53	1.03	0.51	0.26	0.15
0.69	0.80	0.40	0.20	0.11
Velocities (m/s) for 0.60 kg s^{-1} of Material Flow				
0.18	4.11	2.05	1.03	0.59
0.36	2.05	1.03	0.51	0.29
0.53	1.37	0.68	0.34	0.20
0.69	1.06	0.53	0.27	0.15

The wire belt speeds were calculated and followed the material flow rates as they relate to the estimated common selected yields. Table 1 contains 48 tests, but due to the impractical speeds, only 43 tests were actually completed. The wire belt velocities ranged from 0.08 m s^{-1} to 4.10 m s^{-1} or 14 rpm to 770 rpm on the shaft attached to the drive pulleys on the wire belt conveyor. The current auger design on the cotton stripper moves material laterally at approximately 2.0 m s-1. The current auger design is rated much faster than required for the material flow rates selected for this test. Thus the velocity ranges selected for this test covered a full range of speeds to adequately evaluate a wire belt conveyor.

A bur cotton batt (Figure 3) was placed on the wire belt conveyor equivalent to one row in width or 1.0 m. The bur cotton batt was placed at the appropriate depth on the wire belt conveyor. Guide marks (Figure 3) were placed on the divider to ensure the appropriate depth was matched. The conveyor apparatus and high-speed camera is shown in figure 4.

Figure 3. The guide marks on the divider were used to ensure the bur cotton bat was placed at the appropriate depth and can be seen on the right to the far end of the wire belt conveyor.

Figure 4. The high speed camera and the belt conveyor with the plexiglass side installed.

To aid with the characterization and parameterization process, fiber quality samples were collected from the lowest and highest material flow rate and minimum and maximum depths of the belt conveyance tests for all four belt widths for a total of four replications. The data from Porter et al. (2013) showed that a belt conveyor did not have a significant impact on foreign matter content or fiber quality when compared to the standard auger conveyance method. Due to the low impact on evaluated fiber quality parameters from Porter et al. (2013), only select tests were used to collect foreign matter content and fiber quality samples. It was decided to select extreme testing parameters to aid in discovering differences between wire belt configurations. Thus the 0.45 kg s^{-1} material flow rate was eliminated from this test, leaving only the remaining 0.30 and 0.60 kg s^{-1} material flow rates. Thus not collecting all of the wire belt conveyor configurations was justified. Potential optimization work could be performed on a belt conveyance system to aid in foreign matter removal and further preservation of fiber quality. Table 2 represents the test matrix that was used to determine the testing parameters for this study. The use of the extreme wire belt parameters should show relationships, if they exist, without the testing of every belt configuration necessary.

Table 2. Test matrix that was used for testing the wire belt conveyor for fiber quality work (velocities highlighted in red were not performed due to being impractical).

Width (m)	0.03 m Material Depth	0.18 m Material Depth
Velocities (m/s) for 0.30 kg s^{-1} of Material Flow		
0.18	2.5	0.29
0.36	1.03	0.15
0.53	0.68	0.10
0.69	0.53	0.08
Velocities (m/s) for 0.60 kg s^{-1} of Material Flow		
0.18	4.11	0.59
0.36	2.05	0.29
0.53	1.37	0.20
0.69	1.06	0.15

A total of four replications were conducted for each belt configuration from Table 2. Separated foreign matter was collected and weighed after each run from the bottom of the conveyance trough for all samples including those performed during the high-speed camera analysis. The bur cotton samples were collected at the end of the conveyor belt into a container, weighed on an Electroscale (Model LC2424), and then transferred to be prepared for ginning. Since this was bur cotton, all samples were processed through an extractor feeder prior to ginning to ensure the ginning process was consistent. A fractionation sample was collected from each bur cotton sample prior to passing through the extractor feeder and was processed as outlined by USDA (Shepherd 1972). An A&D Company Ltd. (Model HP 20K) scale was used for weight collection of the fractionation data. Due to the small sample size (usually <4.5 kg), the samples were ginned on a 10-saw gin. Due to the differences in sample sizes and potential time requirements for ginning large samples on a small gin, sub-sample sizes were limited to 1.5 kg. If the sample was smaller than 1.5 kg then the entire sample was ginned, if larger than 1.5 kg then only 1.5 kg was ginned. The clean lint was collected and weighed along with the trash and seeds to obtain lint turnout and a lint sample was taken and sent to the Texas Tech University, Fiber and Biopolymer Research Institute in Lubbock, TX for HVI (Uster Technologies HVI 1000) and AFIS (Uster Technologies AFIS Pro 2) fiber analysis. Analysis of Variance (ANOVA) was performed using the Minitab Statistical Software version 16 (Minitab Inc. State College, PA). Tukey's Studentized Range test was used to declare differences among treatment means ($\alpha = 0.10$). An alpha level of 0.10 was used since this was preliminary and exploratory work.

Results and Discussion

Results from the foreign matter content and cotton fiber quality analysis provided insight into speed, width, depth, and material flow rate effects on foreign matter content and fiber quality. Figure 5 shows the percent of foreign matter removed from each sample as it passed across the wire belt conveyor. As the material depth increased, the velocities were reduced. A lower material depth required a higher velocity to transport the same amount of material than a greater depth. The data showed that a lower material depth promoted an increase in foreign matter removal. There was not a statistical relationship but there appeared to be an optimal speed at each of the material depths that also promoted an increase in foreign matter removal (Figure 5). The highest levels of foreign matter removal occurred at the 0.03 and 0.05 m material depths. The optimal velocity for the 0.03 m depth ranged from approximately 0.5 to 1.5 m s^{-1}, and the optimal velocity for the 0.05 m depth ranged from approximately 0.35 to 1.00 m s^{-1}. There appeared to be a few points that had much higher than average foreign matter removal percentages, but since this particular test was not replicated, firm conclusions cannot be drawn. On a percent removal basis, greater material depths removed less material than the lower material depths.

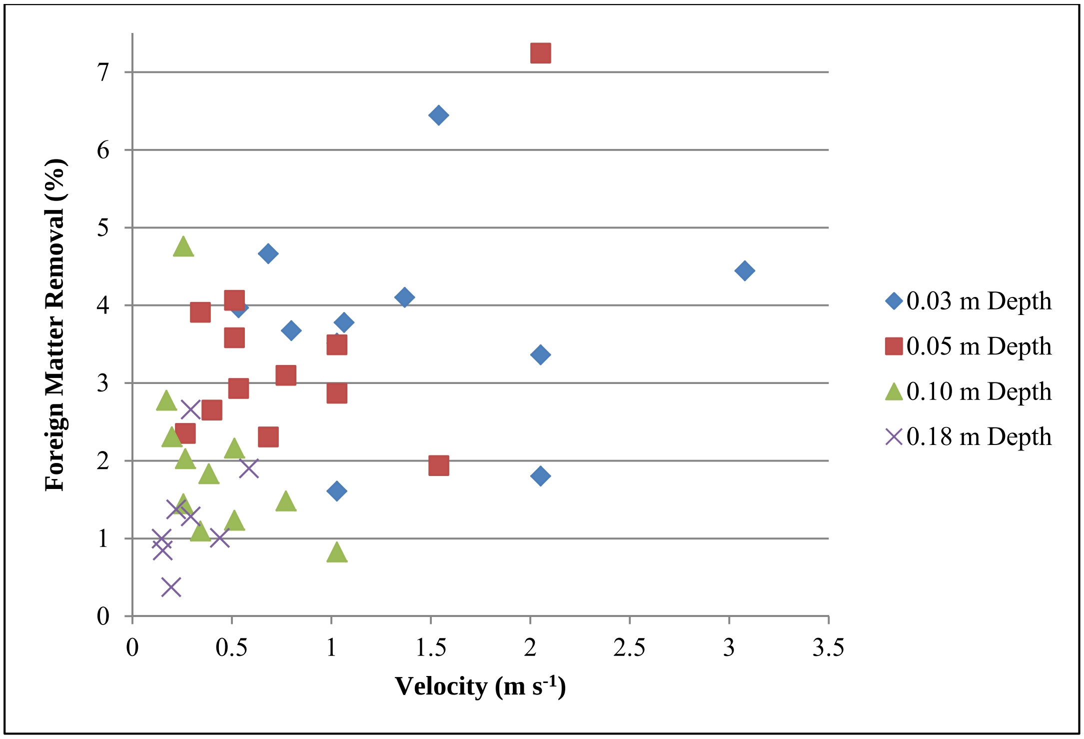

Figure 1. Percentage of foreign matter removed from the bur cotton by the wire belt conveyor based on bur cotton material depth.

The data represented in Figure 5 was collected from material pneumatically removed from the bottom of the wire belt conveyor and collected from the floor. The faster velocity could introduce a higher rate of vibration that accounted for a higher amount of material removal. As would be expected, a deeper depth did not result in a higher amount of foreign material removal. The same surface area of material was allowed to touch the wire belt independent of the material depth, verifying that foreign matter is only being removed from the portion of the bur cotton that is allowed to touch the belt. Approximately the same amount of foreign matter was collected from each sample, thus the data is presented as percent removal of foreign matter from each sample to normalize this data by sample weight. The sample size varied with each wire belt conveyor configuration such that smaller samples had the same amount of foreign matter collected as did the larger samples; however, in terms of percent removal the smaller samples had higher values since the weight of the foreign matter comprised a higher amount of the total sample weight. Thus, typically a shallower depth had a higher percent removal per sample size than did the deeper material depths. The mixing action of a cross auger aids in inverting and mixing the bur cotton allowing for foreign material to not only be removed from the bottom of the material flow, but from the entire material flow stream. However, the mixing action of a cross auger could also intermix foreign material making it more difficult to remove during later processes. The non-mixing flow action of a wire belt conveyor may make it easier to remove foreign material within the field cleaner and perhaps at the gin level because it prevents foreign matter from being further incorporated into the bur cotton.

Figure 6 shows the percent removal of foreign matter based on the width of the wire belt conveyor. According to this data, the 0.36 m wide belt performed best at removing foreign matter, while the 0.69 m wide belt removed approximately 0.1% less. However, it is important to note that there was only about a 0.3% difference between the highest and lowest foreign matter removals. After pairing this data with the depth and speed data, optimal ranges and widths can be determined and appear to range from 0.36 to 0.69 m in width, 0.5 to 1.5 m s^{-1} in velocities and the material depth should stay at or below 0.05 m.

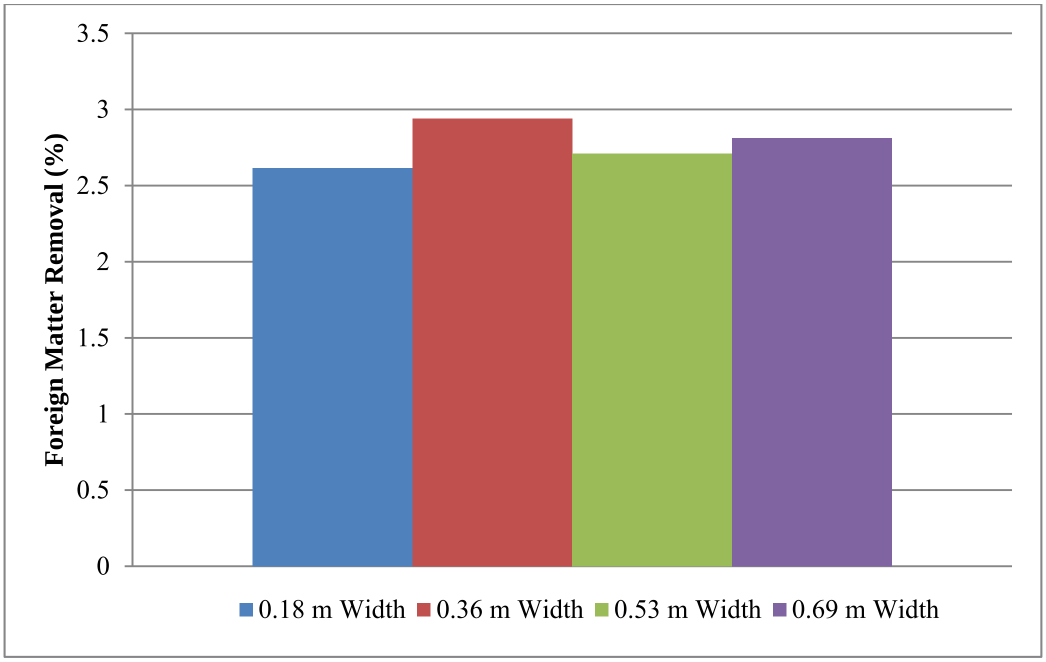

Figure 2. Percentage of foreign matter removed from the bur cotton by the wire belt conveyor based on wire belt width.

There were no statistically significant differences among the widths for lint turnout. Table 3 represents the mean groupings of the lint turnout data grouped by width.

Table 3. Lint turnout grouped by width of the wire belt conveyor.

Width (m)	Lint turnout % Lint
Untreated	37
0.18	38
0.36	38
0.53	36
0.69	36
P-Value	0.066

Greater belt widths had slightly lower lint turnouts than did the narrower belt widths. This could potentially be attributed to sample size, because typically the narrower widths were comprised of smaller samples, or natural variations in the cotton samples. All of the lint turnout numbers are high based on typical turnouts from stripper harvested bur cotton. However, the use of a small-scale gin can sometimes increase the lint turnout and have other adverse effects on fiber quality parameters due differences in gin stand design and environmental conditions during ginning (Boykin et. al 2008). Since less material is processed, the gin may perform better at retaining more lint. Conversely, the smaller gin may not perform as well at removing foreign material thus increasing the lint weight and consequently lint turnout.

Slight variations were observed in lint turnout when velocity was used as a factor. Table 4 presents the lint turnout divided by both width and material conveyance. Turnout tended to be slightly higher at low flow rates and minimum material depths. This could be attributed to more removal of foreign material occurring during the conveyance process of the bur cotton. However, the differences are slight and may not mean there is much difference between the material conveyance rates and depths.

Table 4. Percentage of foreign material removed from the bur cotton ginning based on material flow rate.

Width (m)	Lint turnout (%)	
	0.30 kg s^{-1} of Material Flow	0.60 kg s^{-1} of Material Flow
Untreated	37.1^{BC}	
0.18	41.0^{A}	36.2^{C}
0.36	38.5^{B}	36.2^{C}
0.53	36.2^{C}	36.5^{C}
0.69	36.6^{C}	35.6^{C}
P-Value	<0.0001	
Means followed by the same letter do not differ significantly at the 10% level of probability.		

To determine if the different combinations of speed, depth, and material flow rate had any effects on the type of foreign material being removed, the fractionation samples were collected and analyzed by all of the wire belt configurations. Differences were only significant for a few of the wire belt configurations tested. Leaf trash did have a significant relationship with width (Table 5).

Table 5. Leaf trash grouped by width for the wire belt conveyor reported from fractionation results.

Width (m)	Leaf Trash % of Sample
Untreated	3.0^{A}
0.18	2.9^{AB}
0.36	2.5^{AB}
0.53	2.7^{AB}
0.69	2.4^{B}
P-Value	0.042
Means followed by the same letter do not differ significantly at the 10% level of probability.	

An increase in belt width seemed to reduce the total amount of leaf trash present in the samples. However, there was not a statistically significant difference between the samples. This is potentially due to more surface area of the bur cotton being allowed to touch the wire belt conveyor. The area touching the belt allowed more of the leaf trash to be removed from the sample as it passed along the conveyor than did the reduced areas of the narrower widths. The only other significant interaction occurred between leaf trash as analyzed by depth and material flow rate (Table 6).

Table 6. Percentage of leaf trash present measured by fractionation procedures.

Width (m)	0.03 m Depth % Leaf Trash	0.18 m Depth % Leaf Trash
Untreated	3.02^{A}	
0.30 kg/s Material Flow		
0.18	2.6^{AB}	3.2^{A}
0.36	2.2^{AB}	2.8^{AB}
0.53	2.7^{AB}	Not Collected
0.69	2.3^{AB}	Not Collected
0.60 kg/s of Material Flow		
0.18	Not Collected	2.8^{AB}
0.36	2.3^{AB}	3.0^{AB}
0.53	2.8^{AB}	2.6^{AB}
0.69	2.1^{B}	2.9^{AB}
P-Value	0.012	
Means followed by the same letter do not differ significantly at the 10% level of probability.		

Again, the differences were minor, but the lower percentages of leaf trash tended to occur at the lowest depths and the greatest widths. This again supports that a faster velocity could introduce more vibration, aiding in foreign material removal, especially leaf trash. The greater widths are allowing for more surface area of the conveyed bur cotton to be exposed to the open wire belt. The increase in exposure to the belt provides both an open area for the leaf trash to fall out and introduces more vibration to the material touching the wire belt. The increase in vibration at this point aid in removing foreign material from the bur cotton.

Larger trash such as burs, sticks, and stems may not be able to fall through the belt since typically they are larger than the openings of the belt. More research into belt design could aid in increasing the amount of larger sized trash that is removed from the bur cotton. However, this process must be taken with care to ensure that the bur cotton is not allowed to fall out of the material stream, effectively reducing yield and decreasing harvest efficiency.

Both HVI and AFIS results, similar to the turnout and fractionation results, did not show significant differences between treatments for many of the HVI parameters including micronaire, strength, reflectiveness, and yellowness. Minor significant differences were present for HVI length, uniformity, elongation, and leaf. The HVI parameters with differences are presented in Table 7 below.

Table 7. HVI parameters containing statistically significant differences based on treatment.

Treatment: Material flow rate (kg s^{-1}), width (m), depth (m)	**Length (cm)**	**Uniformity (%)**	**Elongation**	**Trash (%)**
Untreated	3.0^{AB}	81.9^{AB}	7.6^{A}	67.0^{AB}
0.30, 0.18, 0.03	3.0^{AB}	82.0^{AB}	7.2^{B}	34.5^{B}
0.30, 0.18, 0.18	3.0^{B}	81.0^{B}	7.6^{A}	57.0^{AB}
0.60, 0.18, 0.03	Not Collected	Not Collected	Not Collected	Not Collected
0.60, 0.18, 0.18	3.0^{AB}	82.4^{AB}	7.6^{A}	61.8^{AB}
0.30, 0.36, 0.03	3.1^{AB}	82.5^{AB}	7.7^{A}	50.5^{AB}
0.30, 0.36, 0.18	3.1^{AB}	83.3^{A}	7.6^{A}	84.3^{A}
0.60, 0.36, 0.03	3.0^{B}	81.8^{AB}	7.9^{A}	53.5^{AB}
0.60, 0.36, 0.18	3.0^{AB}	82.3^{AB}	7.6^{A}	72.3^{AB}
0.30, 0.53, 0.03	3.1^{A}	83.2^{A}	7.6^{A}	64.0^{AB}
0.30, 0.53, 0.18	Not Collected	Not Collected	Not Collected	Not Collected
0.60, 0.53, 0.03	3.0^{AB}	82.8^{AB}	7.6^{A}	75.5^{A}
0.60, 0.53, 0.18	3.1^{AB}	82.5^{AB}	7.6^{A}	67.8^{AB}
0.30, 0.69, 0.03	3.1^{AB}	83.1^{A}	7.7^{A}	56.3^{AB}
0.30, 0.69, 0.18	Not Collected	Not Collected	Not Collected	Not Collected
0.60, 0.69, 0.03	3.1^{AB}	82.4^{AB}	7.7^{A}	53.3^{AB}
0.60, 0.69, 0.18	3.1^{A}	83.0^{A}	7.6^{A}	83.8^{A}
P-Value	0.008	0.009	<0.0001	0.012

Means in a column followed by the same letter do not differ significantly at the 10% level of probability.

As presented in Table 7, most of the differences present are slight and even though they are statistically significant at α=0.10 levels, the difference in actual fiber quality is not necessarily practically important. There do not appear to be any trends present that correlate the fiber quality variation to the depth, width, and speed of material conveyance on the wire belt. No statistically significant differences were observed in AFIS fiber quality parameters tested, and variability was noted, just as in the HVI data. The slight variations observed in the fiber quality data can be attributed to natural variation in sampling and ginning methods. The set-up and evaluation of machinery projects often leave no feasible opportunities for treatment randomization. Even when considering the nature of this particular project, the foreign matter and fiber quality data do not seem to follow a trend that would suggest the issues could have been resolved by adjusting the testing procedures. As is often the case when working with natural environments, the variation present shows up in the data as slight differences with little to no pattern. Thus, it appears that various configurations of a wire belt conveyor do not seem to have a significant effect on cotton fiber quality parameters.

Summary and Conclusions

Cotton fiber quality and foreign matter content samples were processed across four widths combined with two depths on a wire belt conveyor to produce two material conveyance rates. The combination of width, depth, and material conveyance rate was used to determine the speed at which the wire belt conveyor should be operated at. The minimum and maximum conditions were tested for this part of the study. It was decided to use two material flow rates that would be considered high and low in the Southern High Plains. The fastest and slowest possible velocities were selected. Fractionation, ginning, HVI, and AFIS data were collected from these testing parameters. There were slight differences present from these processes and fiber quality tests. The various wire belt conveyor configurations did not have significant impacts on lint turnout, HVI and AFIS results. However, percent removal data collected from the wire belt conveyor suggest an optimal belt configuration to ensure higher levels of foreign matter removal. The optimal belt configurations based on the percent foreign matter removal data are velocities ranging from 0.5 to 1.5 m s^{-1}, widths ranging from 0.36 to 0.69 m and material flow depths less than 0.10 m. Since the percent removal data was the only data that show significant differences between wire belt conveyor configurations it was used to determine optimum settings. Designing a belt conveyor to meet these specifications would optimally increase the amount of foreign matter removed from bur cotton as it passes along a wire belt to higher levels than other belt configurations. Most of the differences present in the foreign matter and fiber quality parameters that were statistically significant were not of practical significance. The results of these tests have aided in developing values for fiber quality parameters and foreign matter removal with wire belt conveyance. This foundation can be used to further optimize a wire belt conveyor for conveying bur cotton.

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