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TEXTILE TECHNOLOGY

Mid-infrared Spectroscopy of Trash in Cotton Rotor Dust

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ABSTRACT

Cotton always has trash associated with its fibers, which is known to affect processing efficiency. Rotor spinning is more sensitive to trash levels in cotton compared with ring spinning, the other major spinning system. Trash trapped in the rotor grove is typically pulverized cotton fiber and trash particles whose origins cannot be visually determined (e.g. leaf, fiber, bark, seed coat, etc.). New techniques or instruments are necessary to reliably provide rapid, consistent, and quantitative identification of cotton trash sources. The goal of this research was to identify the origins and to understand the impact of each type of pulverized substance on textile processing. Research has been done with infrared microscopy in order to confirm the utility of infrared mapping of cotton biological components. The mid-infrared region is between the wave numbers 4000 and 650 cm^{-1} and can be evaluated with Fourier-transform infrared (FT-IR) as a qualitative and quantitative analytical tool for organic substances. This study demonstrated the utility mid-infrared "fingerprinting" for qualitative identification of cotton contaminants. Mid-infrared spectroscopy was used to compare fiber and trash particles or dust with a spectral database of authentic samples to more accurately determine the source of spinning problems. Mid-infrared spectroscopy was able to predict the type of trash and demonstrated that the rotor dust accumulating in open-end spinning rotors appears to be hull and shale rather than seed coat fragments. This technique offers potential to study the influence of various types of trash on spinning efficiency.

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Textile processing is influenced by trash components found in all cotton bales. Cottons and their trash components are diverse in nature and respond differently to textile cleaning and processing. A better understanding of cotton trash chemistry is needed to improve textile processing efficiency. The USDA/ARS Cotton Quality Research Station (CQRS) is committed to exploring improvements in cotton harvesting, ginning, and processing that could result in an improved return for the farmer, gin, or mill through improved products and efficiency. This project is part of a program to identify and quantify cotton trash levels, because trash is known to affect textile-processing efficiency (Bargeron et al., 1988; Verschraege, 1989).

Considerable research has been conducted on the assessment and measurement of cotton trash, and various methods have been suggested for improvement (Siddaiah et al., 2000; Xu et al., 1999). Since cotton is produced in the field rather than at a manufacturing facility, it is difficult to control all trash generated in harvesting. The type, size, and amount of trash, fiber-to-trash adhesion, and how trash mimics a fiber during processing determine the ease of trash removal. The unlimited sizes of trash with different buoyancies, diverse binding forces between fibers, and degrees of fiber entanglement affect fiber processing. Different cultivars of cotton will vary in the nature of trash due to diverse genetic, growing, harvesting, and ginning conditions. Trash maintains its level of moisture differently than cotton fibers and consists of a unique molecular composition.

The classification of cotton trash into various categories may provide information regarding problematic types. These trash particles originate either from the cotton plant (various parts of the leaf, stem, bark, seed, and hull) or from the local environment (grass, sand, dust, and other foreign contamination). Cotton contamination, including large and small pepper trash, is commonly referred to as visible foreign matter. Pepper trash is defined as having a size around 0.51 mm (0.02 in), and seed coat fragments typically range from 0.43 to 0.64 mm (0.017 to 0.025 in). Respirable dust, micro-dust, dust, and trash are commonly defined to fall between 0 to15 μ (0 to 0.0006 in), 15 to50 μ (0 to 0.002 in), <500 μ (<0.02 in), and >500 μ (>0.02 in), respectively (H. Ghorashi, personal communication, 2000). Ginners perform a number of sequential cleaning steps on both seed cotton and ginned lint to extract trash and improve the cotton leaf grade. Consequently, during these sequential cleaning steps, trash particles decrease in size (Baker et al., 1992), which has often been thought to have a detrimental influence on the spinning process and on the finished goods.

Open-end spinning, which is the desired spinning system to evaluate the impact of trash on textile processing, is more sensitive to trash content than ring spinning (Baker et al., 1994). The opening roller in open-end spinning is very efficient at cleaning cotton due to the large number of wire points passing over a small amount of cotton with centrifugal forces that effectively eject small fragments (Verschraege, 1989). Although this mechanical process is effective at removing a significant portion of the trash, further fragmentation of the trash particles occurs. Cottons with larger particles are considered easier to clean than cottons containing many small particles that lack particle mass for optimal centrifugal force extraction (Farber et al., 1990). Low efficiency rates during open-end spinning are often the result of various types and sizes of trash particles, including dust and micro-dust, that become trapped in the rotor and form a full ring of debris in the rotor groove (Furter and Schneiter, 1993). Continual buildup of impurities within this groove interferes with yarn formation (Vaughn and Rhodes, 1977) and results in a gradual deterioration of the yarn that produces neps, thick places in the yarn, or ends-down (yarn breakage) (Thibodeaux and Baril, 1981; McCreight et al., 1997). The effects of trash accumulation have only been considered in connection with yarn properties and end breaks without sufficient consideration for the type of trash that collects within the groove.

Trash in the sliver can be further divided into particles of high density (large particles), particles of low density (small particles), and seed coat fragments (Farber et al., 1990). Different views exist regarding which trash particles (fine or coarse) cause rotor buildup (Simpson, 1980). Due to high tangential acceleration forces at the combing zone of the opening roller, large particles are centrifuged away from the fiber into the trash disposal system (Farber et al., 1990). Particles of low density remain lodged in the combing roller teeth or are ejected but, due to buoyancy aerodynamics, go to the rotor and become lodged in the rotor dust (Farber et al., 1990). Seed coat fragments are removed by the opening roller, but the fibers attached to the seed fragment act like a parachute inserting the seed coats into the rotor (Farber et al., 1990). Fiber fragments are rarely removed by the opening roller. Some fiber fragments are removed at the rotor rim, but the smallest fiber fragments become bound in the rotor dust (Farber et al., 1990). Unfortunately, very little information is available to textile mills regarding dust levels in cotton. Trash separation is only capable of a limited degree of dust separation. Dust becomes trapped in the rotor groove, and only a small portion is removed from the rotor rim or through combing (Farber et al., 1990). Rotor dust likely consists of low-density particles, seed coat fragments, small fiber fragments, or dust.

Although spinning machines are equipped with rotor cleaning features, dust accumulation remains a major problem in rotor spinning (Farber et al., 1990). Rotor dust accumulation increases with higher levels of residual dust in the sliver, with higher rotor speeds, and with smaller roller diameters (Farber et al., 1990). A reduction of trash in the card sliver reduces the number of ends-down during processing, which confirms that rotor groove accumulation hinders yarn production (Arzt et al., 1990). Reducing the rotor diameter and increasing production rates by 10% produces a disproportionate 17% increase in the maximum theoretical accumulation of fine dust per mm of the rotor groove (Farber et al., 1990). Increased cleaning steps are required for rotor spinning dusty cotton and preventing large levels of rotor deposits. Trash trapped in the rotor grove is typically pulverized trash particles, and its origin (leaf, bark, seed coat, etc.) is impossible to visually identify.

Chemical techniques or instruments are necessary to reliably provide rapid, consistent, and quantitative cotton trash data. A method for measuring flax fiber trash (non-fiber) content based on near infrared spectroscopy is being refined by the Russell Research Center, ARS-USDA. This method is a nondestructive, chemometric method to evaluate flax fiber quality. Spectroscopy and spectral imaging of flax stems have been conducted by infrared (Himmelsbach et al., 1998; Himmelsbach et al., 1999) and Raman spectroscopy (Himmelsbach and Akin, 1998) to characterize the physicochemical structure and distribution of components to support basic research on the physiology and processing of flax. Work has progressed with infrared microscopy to confirm the utility of infrared mapping of cotton biological components (Himmelsbach, 2003). The infrared region of the electromagnetic spectrum exists between the wave numbers 14,000 and 20 cm^{-1} (Dean, 1995) and has been used for many years in textile analysis (Morris et al., 1984). The mid-infrared region is between the wave numbers 4,000 and 650 cm^{-1} and can be evaluated via Fourier-transform infrared (FT-IR), which provides fast results with high resolution and sensitivity (Dean, 1995).

FT-IR can be a qualitative and quantitative analytical tool for organic substances (Kim and Yun, 1986; Morris et al., 1984; Himmelsbach et al., 2002a). In order to evaluate organic substances, an enhanced understanding of molecules is required, because these particles have specific frequencies that are directly associated with their rotational and vibrational motions. Research with flax fibers has identified differences between various plant components including the fiber, wax, core, and cuticle (Himmelsbach et al., 2002b). The inner and outer surfaces of nutshells have also demonstrated distinct differences (Stewart, 1996). Trash and other visible foreign matter in cotton consist of various types of plant components each with different molecular structure that can be quickly evaluated using FT-IR (Himmelsbach, D., Foulk, J, McAlister, D, unpublished data). The range of simultaneous vibrations produces a highly complex absorption spectrum that is distinctive of the functional groups that create the molecule and their configuration, and have the potential to identify substances from their infrared absorption spectrum (Dean, 1995). FT-IR has been used to describe and differentiate cotton fiber and seed interactions for potential ginning purposes (Himmelsbach et al., 2003). The goal is to use FT-IR to identify the type of pulverized cotton fiber or trash that accumulates in the rotor groove and impacts rotor spinning.

MATERIALS AND METHODS

Cotton ginning. Sample bales of cotton (upland and pima) were selected because of their wide range of trash levels due to different ginning procedures. An assortment of ginning equipment was included in this study to incorporate diverse levels of processing, cleaning, and trash. Some bales are representative of a typical harvest at any one location, and some bales were spiked with 16.3 kg (30 lb) of mostly whole hulls at the gin stand just prior to ginning to represent potential harvests. Moisture restoration was included in ginning to evaluate differences in fiber quality due to moisture addition. Bales were all harvested, ginned, and baled by commercial methods, except where noted.

The first group of cotton bales consisted of pima cotton with three replications and four treatments. These bales of cotton contained different levels of trash and dust. Ginning treatment 1 consisted of a one cylinder cleaner, roller-gin stand, and zero lint cleaning. Ginning treatment 2 consisted of a sequential series of a cylinder cleaner, a stick machine, a cylinder cleaner, a roller-gin stand, and an Aldrich beater-super jet lint cleaner (Lummus Corp.; Savannah, GA). Ginning treatment 3 consisted of one cylinder cleaner, a saw-gin stand, and zero lint cleaning. Ginning treatment 4 consisted of cylinder cleaner-stick machine-cylinder cleaner, saw gin stand, and one saw-type lint cleaner. Treatments 3 and 4 were spiked with hulls at the saw-gin stand (Foulk et al., 2003).

The second group of cotton bales consisted of upland cotton with three replications each of a standard and small seed cotton cultivar (Foulk et al., 2003). These bales of cotton contained different levels of trash and dust. Typical ginning equipment was used to gin the cotton, and all lots were passed through two 6-cylinder cleaners and one stick machine for seed cotton cleaning. Half of the lots were ginned on an experimental saw gin stand designed to minimize seed loss and the other half were processed through a standard saw gin stand. All lots were processed through a one saw-type lint cleaner.

The third group of cotton bales consisted of upland cotton from two cotton modules. The first cotton module was harvested using a field cleaning unit on a stripper with two replications. The second cotton module was harvested using a conventional brush stripper with two replications. Field cleaners can remove 60 to 70% of foreign matter prior to ginning (Anthony and Mayfield, 1994). Due to harvesting differences, these bales of cotton contained different levels of trash and dust. At the gin, all seed cotton was given conventional double overhead cleaning consisting of an inclined cleaner and stick machine and second incline cleaner and stick machine. The different gin treatments included the Continental 93-saw Double Eagle gin stand (Continental Eagle Corp.; Prattville, AL) as a control along with ten different experimental gin test treatments (Laird et al., 2001; Laird et al., 2002) followed by one lint cleaner. These treatments included the experimental gin settings as follows: saw rotating at 900 rpm with the paddle roll rotating at 180 and 140 rpm, saw rotating at 810 rpm with the paddle roll rotating at 160 rpm, saw rotating at 720 rpm with the paddle roll rotating at 180 or 140 rpm, saw rotating at 630 rpm with the paddle roll rotating at 180 or 100 rpm, saw rotating at 540 rpm with paddle roll rotating at 140 and 180 rpm, and saw rotating at 450 rpm and paddle roll rotating at 100 rpm.

The fourth group of cotton bales consisted of upland cotton with two replications. These bales of cotton contained different levels of moisture, trash, and dust. Typical ginning equipment was used to gin the cotton, and all lots were passed through three incline cleaners, Continental Eagle impact cleaner (Continental Eagle Corp.), Continental Golden Eagle Super 96-gin stand (Continental Eagle Corp.), and two lint cleaners. After ginning and before baling, water was added to the bales, and the bales were wrapped in a single polyethylene sheet wrap and stored for one year. Target moisture levels were no moisture and 6, 8, and 10% moisture added based on the oven dry method. After storage, the moisture content of the bales was 5.73, 6.03, 6.79, and 7.19% for the 0, 6, 8 and 10% levels of added moisture, respectively (Chun et al., 2003).

The fiber properties (see Table 1 for official classification) for all ginned cotton were determined by high volume instrumentation (HVI). The HVI allows cotton fibers to be tested for length, strength, fineness, color, and trash according to established standards (ASTM, 1993).

Textile processing. Cotton was processed through the same modern Truetzschler opening and cleaning line and card (American Truetzschler Inc.; Charlotte, NC) to produce a 60 grain sliver at 43.6 kg/h (100 lb/h). All cotton was processed in the sequence that follows: blending hoppers in a Fiber Controls Synchromatic Blending System (M&M Electric Service Inc.; Gastonia, NC), Axi-Flo cleaner (American Truetzschler Inc.), GBRA blending hopper (American Truetzschler Inc.), a RN cleaner (American Truetzschler Inc.), RST cleaner (American Truetzschler Inc.), DUSTEX fine dust remover (American Truetzschler Inc.), chute fed DK803 card (American Truetzschler Inc.), Rieter RSB draw frame (Rieter Corp.; Spartanburg,SC), and SE-11 open-end spinning (Sauer Inc.; Charlotte, NC). Pima sliver was run on open-end spinning frame into 20/1's yarn at 80,000 rotor speed with a 3.75 TM and a comber roll of 8,000 using a T40 mm rotor. Upland cotton was spun at 100,000 rotor speed under the same conditions. In spinning, visible cotton fibers were physically removed and only the fine brown/gray rotor dust was scraped from the rotor groove, collected, and ends-down recorded.

Spectroscopy. Authentic and identified cotton fiber and trash samples had previously been obtained, analyzed, and sequentially added to an index to create a spectral database for future trash assessment (Himmelsbach, D., Foulk, J, McAlister, D, unpublished data). Trash identification for known authentic samples was based upon color differences as follows: hull vein (edge of hull section), hull outside (outside surface), hull stem (tip of hull), hull inside (interior portion of hull), shale (entirely internal portion of the hull), and shale vein (vein located within shale). Raw dust was collected from the rotor groove, analyzed by mid-infrared spectroscopy, and compared with a database of spectra of authentic samples. Fourier-transform infrared (FT-IR) spectra in the database and of dust samples were collected using Nicolet Magna 850 FT-IR bench (Thermo Electron Corporation; Madison, WI) employing a DuraScope (SensIR Technologies; Danbury, CT) single-contact ATR sampling device equipped with a round (2 mm diameter) diamond crystal and video imaging. The IR spectrometer (Thermo Electron Corp.; Madison, WI) was equipped with a globar source, KBr beamsplitter, and deuterated triglycine sulfate (DTGS) detector. A background scan of the clean diamond crystal with no sample and no pressure was obtained. The rotor dust mixture was placed on the surface of the diamond ATR crystal and pressure applied using a metal rod until "wetting" of the sample on the crystal was observed (rating load of 5.0). Three separate spectra were collected at a resolution of 8 cm^{-1} with 128 scans for each spectra. All three were then averaged to give one file per sample. The individual spectra were from three different rotor dust sample readings. OMNIC software (version 5.2; Thermo Electron Corporation; Madison, WI) was used in data collection. Data manipulation, such as smoothing, region blanking, or baseline removal was not conducted. Analysis and classification of the complex trash mixture was performed using the search routine found in OMNI software, using Euclidean distances (the industry standard algorithm for performing library data searches) and involved matching trash within its known database.

Table 1. Official cotton bale classification data[x]

Gin[y] trmt.	Cotton cultivar	Harvesting	Mic	Strength (cN/tex)	Reflect. (Rd)	Yellowness (+b)	Trash (%)	UHM (mm)	UF (%)	Leaf
1	Pima	Spindle picker	4.26	37.72	64.67	12.94	11.7	33.78	84.33	4.1
2	Pima	Spindle picker	4.14	38.64	65.75	13.38	5.4	34.04	84.33	3.0
3	Pima	Spindle picker	4.42	38.29	63.08	12.93	10.8	33.27	83.33	4.6
4	Pima	Spindle picker	4.12	39.10	66.75	13.53	3.2	33.02	82.83	3.0
5	Upland (small seed)	Cotton stripper	3.80	27.44	76.50	8.77	4.1	28.96	79.83	4.4
6	Upland (standard seed)	Cotton stripper	4.59	26.70	74.17	8.66	4.3	28.96	81.17	4.6
7	Upland (small seed)	Cotton stripper	3.85	27.26	75.08	8.95	4.4	28.70	79.50	4.6
8	Upland (standard seed)	Cotton stripper	4.64	27.41	73.53	8.72	4.0	28.96	81.25	4.2
9[z]	Upland (standard seed)	Cotton stripper	3.67	28.77	76.70	9.60	5.0	26.75	80.53	4.0
9	Upland (standard seed)	Cotton stripper	3.37	28.74	77.00	9.90	6.0	26.34	80.0	4.0
10[z]	Upland (standard seed)	Cotton stripper	3.33	28.15	77.7	9.50	6.0	26.42	79.3	4.0
10	Upland (standard seed)	Cotton stripper	3.13	28.15	77.3	9.63	6.0	26.42	79.7	4.0
11[z]	Upland (standard seed)	Cotton stripper	3.83	28.71	76.0	9.83	5.0	26.42	79.7	4.0
11	Upland (standard seed)	Cotton stripper	3.73	28.87	74.3	10.20	7.0	26.24	80.3	4.0
12[z]	Upland (standard seed)	Cotton stripper	3.27	28.81	77.7	9.67	5.0	26.59	79.7	4.0
12	Upland (standard seed)	Cotton stripper	3.23	28.77	76.0	9.80	8.0	26.59	80	5.0
13[z]	Upland (standard seed)	Cotton stripper	3.23	28.28	77.3	9.57	6.0	26.34	79.3	4.0
13	Upland (standard seed)	Cotton stripper	4.03	28.74	75.0	10.03	8.0	26.59	80.3	5.0
14[z]	Upland (standard seed)	Cotton stripper	3.50	28.52	77.3	9.83	4.0	26.09	79.3	4.0
14	Upland (standard seed)	Cotton stripper	3.27	28.52	76.7	9.87	6.0	26.59	79.3	5.0
15[z]	Upland (standard seed)	Cotton stripper	3.50	28.32	77.7	9.60	5.0	26.42	80.0	5.0
15	Upland (standard seed)	Cotton stripper	3.13	28.62	77.3	9.40	6.0	26.34	79.7	4.0
16[z]	Upland (standard seed)	Cotton stripper	3.30	28.48	78.0	9.50	5.0	26.09	79.3	4.0
16	Upland (standard seed)	Cotton stripper	3.50	28.22	76.3	9.97	6.0	26.24	79.7	4.0
17[z]	Upland (standard seed)	Cotton stripper	3.23	28.35	78.3	9.47	5.0	26.24	80.3	4.0
17	Upland (standard seed)	Cotton stripper	3.23	28.94	77.0	9.83	6.0	26.24	79.3	4.0
18[z]	Upland (standard seed)	Cotton stripper	3.47	28.18	77.3	9.57	5.0	26.24	79.7	4.0
18	Upland (standard seed)	Cotton stripper	3.10	28.97	77.0	9.73	6.0	26.42	79.3	4.0
19[z]	Upland (standard seed)	Cotton stripper	3.17	29.04	78.7	9.37	6.0	26.49	80.3	4.0
19	Upland (standard seed)	Cotton stripper	3.43	29.60	76.7	9.90	7.0	26.49	80.3	4.0
20	Upland (standard seed)	Spindle picker	5.28	27.66	76.00	9.03	3.3	26.42	82.00	3.0
21	Upland (standard seed)	Spindle picker	5.30	27.42	76.00	9.30	3.3	26.16	82.00	3.0
22	Upland (standard seed)	Spindle picker	5.30	27.66	75.80	9.23	3.3	26.42	82.00	3.0
23	Upland (standard seed)	Spindle picker	5.33	27.66	74.80	9.60	3.5	26.42	81.80	3.0

[x] USDA, ARS, AMS; Memphis, TN.

[y] Gin treatment 1 consisted of one cylinder cleaner, roller-gin stand, and zero lint cleaning; gin treatment 2 consisted of cylinder cleaner-stick machine-cylinder cleaner, roller-gin, and Aldrich beater-super jet lint cleaner; gin treatment 3 was spiked with 13.6 kg of mostly whole hulls at the gin stand just prior to ginning to represent potential harvests, and consisted of one cylinder cleaner, saw-gin stand, and zero lint cleaning; gin treatment 4 was spiked with 13.6 kg of mostly whole hulls at the gin stand just prior to ginning to represent potential harvests, and consisted of cylinder cleaner-stick machine-cylinder cleaner, saw gin stand, and one saw-type lint cleaner; gin treatments 5 & 6 consisted of a cylinder cleaner-stick machine-cylinder cleaner and gin stand with experimental saw guides; gin treatments 7 & 8 consisted of a cylinder cleaner-stick machine-cylinder cleaner and saw-gin stand without guides; gin treatment 9 consisted of standard Continental 93 saw Double Eagle gin stand; gin treatment 10 consisted of an experimental gin stand with the saw rotating at 900 rpm and paddle roll rotating at 180 rpm; gin treatment 11 consisted of an experimental gin stand with the saw rotating at 900 rpm and paddle roll rotating at 140 rpm; gin treatment 12 consisted of an experimental gin stand with the saw rotating at 810 rpm and paddle roll rotating at 160 rpm; gin treatment 13 consisted of an experimental gin stand with the saw rotating at 720 rpm and paddle roll rotating at 180 rpm; gin treatment 14 consisted of an experimental gin stand with the saw rotating at 720 rpm and paddle roll rotating at 140 rpm; gin treatment 15 consisted of an experimental gin stand with the saw rotating at 630 rpm and paddle roll rotating at 180 rpm; gin treatment 16 consisted of an experimental gin stand with the saw rotating at 630 rpm and paddle roll rotating at 100 rpm; gin treatment 17 consisted of an experimental gin stand with the saw rotating at 540 rpm and paddle roll rotating at 140 rpm; gin treatment 18 consisted of an experimental gin stand with the saw rotating at 450 rpm and paddle roll rotating at 180 rpm; gin treatment 19 consisted of an experimental gin stand with the saw rotating at 450 rpm and paddle roll rotating at 100 rpm; gin treatment 20 consisted of three incline cleaners, impact cleaner, gin stand, and two lint cleaners with no moisture added; gin treatment 21 consisted of three incline cleaners, impact cleaner, gin stand, and two lint cleaners with a target cotton moisture level of 6%; gin treatment 22 consisted of three incline cleaners, impact cleaner, gin stand, and two lint cleaners with a target cotton moisture level of 8%; gin treatment 23 consisted of three incline cleaners, impact cleaner, gin stand, and two lint cleaners with a target cotton moisture level of 10%.

[z] Harvested using a field cleaning unit on a stripper.

RESULTS AND DISCUSSION

It is important to evaluate and attempt to determine the source of rotor dust buildup, because the majority of ends-down in open-end spinning are related to dust and trash deposits. Farber et al. (1990) indicate that sliver trash consists of dust (respirable dust, micro-dust, and dust), trash (particles that best mimic a fiber), and fiber fragments (1 to 8 mm in length). Raw trash changes during processing so that a large portion of this trash is removed and has neither the same shape nor form as trash found in processed sliver. This complex problem is coupled with a reduction in trash size that results in the generation of a multitude of trash particulates. These residual trash particles remain in the sliver despite continued attempts to remove them through processing. It would be very tedious and time consuming to remove the remaining trash from the sliver (Thibodeaux and Baril, 1981). This study has determined that buildup in the rotor groove is an excellent trash collection point for analysis that impacts open-end spinning efficiency.

Residual trash that has not been detached in cleaning or with the opening roller just prior to spinning is transported to the rotor for spinning and possibly further reduced in size. This trash will either be incorporated into the yarn or accumulate in the rotor groove. Opto-electronic testing equipment can further detect the trash particles that remain on the surface of yarns (Uster Technologies AG, 2003), but this technology can only detect trash and dust, and determine their relative size. It does not have the ability to verify the origins of trash and dust within the cotton sample. It would be a difficult task to follow a single large plant particle (e.g. leaf) from the field, through ginning, and all the way through spinning to identify problematic trash types. Rotor dust was collected and evaluated using FT-IR to attempt to determine the plant source. This study determined that this fine powder residue can easily be removed from the rotor's groove for FT-IR evaluation.

While FT-IR has been used to map chemical components involved with the base of cotton fibers and their associated seed coat (Himmelsbach et al., 2003), it has not been used to evaluate cotton trash and its relation to open-end spinning. Rotor residue has been effectively collected and analyzed using mid-infrared spectroscopy from upland and pima cotton with a wide range of trash levels due to various ginning procedures, including trash and moisture augmentation. Collected dust was likely a mixture of cotton fiber and/or residue ground to a fine powder. An example spectrum of a rotor dust sample is shown in Figure 1 with the most significant band positions annotated. The bands in the 3600-2700 cm^{-1} region, due to O-H and C-H stretch are common to all of the samples and are different mainly in band intensity. The "fingerprint" region of the spectrum, 1800-650 cm^{-1}, provides the most essential information for the specific identification of the particular trash components. Bands from about 1800-1650 cm^{-1} involve carbonyl functionality. Bands from 1600-1420 cm^{-1} have overlapping contributions from many different C-H vibrations and specific assignments in complex matrices are difficult to separate without further data treatments or physical extraction of specific components. Bands in the 1160-1000 cm^{-1} region primarily involve C-O stretch and C-O-H and C-O-C groups that are associated with carbohydrates.

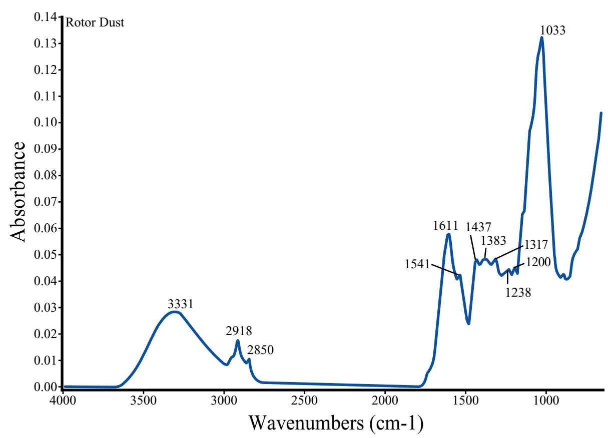

Figure 1. Example of a FT-IR/ATR spectrum of a rotor dust sample showing the positions of the major bands.

The spectra in the database, which cannot be shown here because they are part of a patent consideration, often show only subtle differences. These differences are often just barely visible to the eye, but spectral subtraction of spectra that represent materials that are very close anatomically can reveal these differences. Figure 2 shows the subtraction of a spectrum of the shale from a spectrum of the inside of the hull. That subtraction is compared with an authentic sample of cottonwood lignin (Himmelsbach et al., 2002b). Essentially every band in the lignin spectrum matches that of the difference spectrum. This permits the conclusion that the samples differ by the greater amount of lignin in the hull component. These demonstrate that computer searching is an integral part of the analysis to classify the trash mixture using an industry standard algorithm.

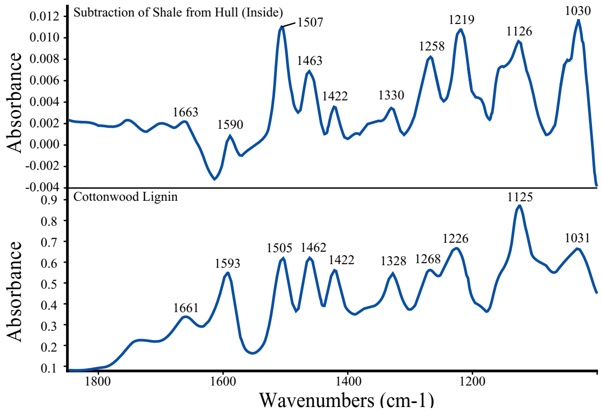

Figure 2. Difference spectrum from the subtraction of a FT-IR/ATR spectrum of an authentic sample of shale from that of the inside of hull from an upland cotton plant (top) compared with that from a sample of cottonwood lignin (bottom) with band positions annotated.

This spectral matching is not exact, so a list of 5 possible qualitative matches from the spectral database is provided for each sample (Table 2). These virtually equivalent matches have probabilities, but the lists of 5 trash types refers to a general category. These categories characterize the quality of the trash but do not provide sufficient evidence that by weight these trash types are the main organic constituents. These qualitative results are promising, and future studies could address quantitative IR analysis. For improved results, this database will require frequent updating with new cotton cultivar fiber and trash samples. Further database refinements will include grinding, analyzing, and sequentially adding to the spectral database the results from authentic and identified cotton fiber and trash samples. Results were evaluated by 1) counting the number of spectra matches for a particular defined trash (Fig. 3), or 2) counting the number of spectra matches for a particular defined trash and weighting the value of the matches from 5 to 1 for matched locations 1 thru 5, respectively, to give more accounting more for the higher ranked hits (Fig. 4). For example, shale inside (SI) weighted matches were calculated as follows: (5) × (0; the number of first location matches) + (4) × (5; second location matches) + (3) × (2; third location matches) + (2) × (0; fourth location matches) + (1) × (2; fifth location matches) = 28. Analysis of rotor dust with mid-IR indicates that rotor dust consists mainly of hull and shale (Fig. 3 and 4), and seed coat fragments are not matched within the top 5 matches.

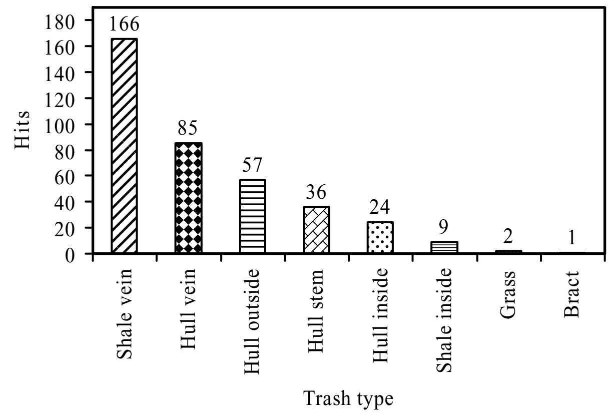

Figure 3. FT-IR spectra matched hits for open end spinning rotor dust.

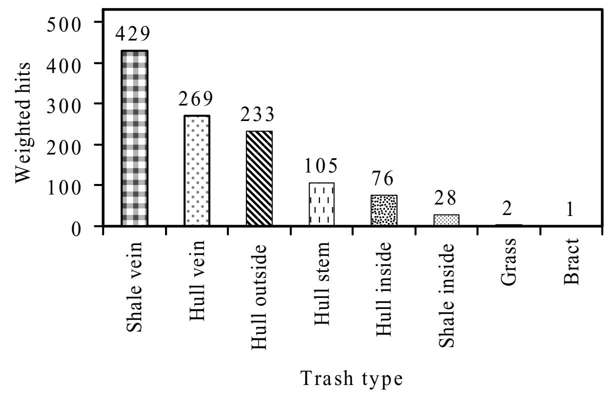

Figure 4. FT-IR spectra weighted match hits for open end spinning rotor dust.

Trash in the rotor grove is typically pulverized trash particles, and it is impossible to visually detect its origin. It is acknowledged that rotor buildup may not directly be causing the ends-down. Ends-down, however, may be a combination of events with a seed coat or other type of trash particle inundating the rotor groove with residue that exacerbates the problem. Qualitative analysis characterizes the trash, but it does not predict ends-down, as verified in plotting the number of ends-down against the number FTIR matches ($R^2 = 0.15$). In this study, there is no relationship between recorded ends-down and the top 5 FTIR matches. Identifying the type of trash producing this rotor buildup could improve textile mill efficiency with anticipation that a gin or textile mill could better remove a known form of trash. In the interest of cost savings, gins may try to save operational and power costs by bypassing certain processing steps or machines (e.g. stick machines that typically remove hull and shale). This ginning

Table 2. Cotton rotor dust mid-infrared spectroscopy database classification

Gin treatment[x]	Replication	Top 5 matches [y]					Ends-down [z]
		1	2	3	4	5	
1	1	HSP	HIP	HVP	HIP	HOP	497
1	2	HSP	HIP	HVP	HIP	HS	465
1	3	HSP	HIP	HVP	HIP	BR	445
2	1	HSP	HIP	HVP	HIP	HV	794
2	2	HSP	HIP	HVP	HIP	HV	883
2	3	HSP	HIP	HVP	HIP	HV	861
3	1	HSP	HIP	HVP	HIP	HV	304
3	2	HSP	HIP	HIP	HVP	HVP	301
3	3	HSP	HIP	HVP	HIP	HV	309
4	1	HSP	HIP	HVP	HIP	HV	704
4	2	HSP	HIP	HVP	HIP	GR	734
4	3	HSP	HIP	HVP	HIP	GR	787
5	1	HVP	SI	SV	SV	HO	167
5	2	HVP	SI	SV	SV	HV	431
5	3	HVP	SI	SV	SV	HO	300
6	1	HO	HVP	SV	SV	SV	106
6	2	HO	SV	SV	SV	SV	97
6	3	HO	SV	SV	SV	HVP	69
7	1	HVP	SI	SV	SV	HO	128
7	2	HVP	SI	SV	SV	HO	167
7	3	HVP	SV	SI	SV	SV	83
8	1	HVP	SV	SV	HO	SV	139
8	2	HVP	HO	SV	SV	SV	153
8	3	HVP	SV	SV	HO	SV	111
9 [z]	1	HO	SV	SV	SV	SV	0
9 [z]	2	HO	HV	SV	SV	SV	0
9	1	HO	HV	SV	SV	SV	52
9	2	HO	HV	SV	SV	HS	42
10 [z]	1	HO	SV	SV	HV	SV	35
10 [z]	2	HO	SV	SV	HS	HV	37
10	1	HO	HV	SV	SV	SV	0
10	2	HO	HV	SV	HS	SV	28
11[z]	1	SV	HO	HV	SV	HV	31
11 [z]	2	HV	HV	SV	SV	HO	21
11	1	SV	HV	HO	HV	SV	31
11	2	SV	HO	HV	HV	SV	39
12 [z]	1	HO	HV	SV	SV	SV	0
12 [z]	2	HV	HO	HV	SV	SV	52
12	1	HO	SV	SV	HV	SV	52
12	2	HV	HO	SV	HS	SV	21
13 [z]	1	HO	HV	SV	SV	HS	53
13 [z]	2	HO	HV	SV	SV	HS	9
13	1	HO	SV	SV	HS	HV	37
13	2	HO	SV	SV	HS	HV	18
14 [z]	1	HO	SV	SV	SV	SV	29
14 [z]	2	HO	SV	HS	SV	HV	19

Table 2 continued next page

Table 2 continued

Gin treatment[x]	Replication	Top 5 matches [y]					Ends-down [z]
		1	2	3	4	5	
14	1	HO	HV	SV	HS	SV	21
14	2	HO	HV	HS	SV	SV	93
15 [z]	1	HO	HV	SV	SV	SV	83
15 [z]	2	HV	HV	HS	SV	SV	28
15	1	HV	HO	SV	SV	SV	31
15	2	HV	HO	SV	HS	SV	20
16 [z]	1	HO	HV	HS	SV	SV	37
16 [z]	2	HO	SV	SV	SV	SV	10
16	1	HO	HV	SV	SV	HS	0
16	2	HO	HO	HS	SV	SV	0
17 [z]	1	HO	SV	SV	SV	HS	10
17 [z]	2	HO	HV	SV	SV	HS	19
17	1	HO	HV	SV	SV	SV	10
17	2	HO	HV	SV	SV	HS	9
18 [z]	1	HV	HO	SV	HS	SV	14
18 [z]	2	HV	HO	SV	SV	SV	36
18	1	HO	SV	SV	SV	SV	56
18	2	HO	HV	SV	SV	SV	8
19 [z]	1	HV	HO	SV	HS	SV	0
19 [z]	2	HO	HV	SV	HS	SV	21
19	1	HO	HV	SV	SV	SV	52
19	2	HO	HV	SV	HS	SV	21
20	1	SV	SV	SV	HV	SI	208
20	2	SV	SV	SV	HV	HV	139
21	1	SV	SV	SV	HV	SI	97
21	2	SV	SV	SV	HV	HO	153
22	1	SV	SV	SI	SV	HV	111
22	2	SV	SV	SV	HO	HV	125
23	1	SV	SV	SV	HV	HO	167
23	2	SV	SV	SV	HV	HV	181

[w] See Table 1 for ginning treatments and official USDA AMS cotton bale classifications. Treatments 3 and 4 were spiked with 13.6 kg (30 lb) of mostly whole hulls at the gin stand just prior to ginning to represent potential harvests.

[x] Rotor dust was collected and analyzed by mid-infrared spectroscopy and compared with a spectral database of authentic samples abbreviated as follows: HVP = hull vein (pima); HIP = hull inside (pima); HOP = hull outside (pima); SVP = shale vein (pima); SIP = shale inside (pima); HSP = hull stem (pima); HV = hull vein (upland); HO = hull outside (upland); HI = hull inside (upland); SV = shale vein (upland); SI = shale inside (upland); HS = hull stem (upland); BR = bract; and GR = grass.

[y] Ends-down recorded during open-end yarn production on a Schlafhorst SE-11.

[z] Harvested using a field cleaning unit on a stripper.

cost savings may be offset by decreases in fiber quality and spinning efficiency due to residual trash. It appears that a combination of events initiates ends-down as residue accumulates in the rotor groove. The cause of the ends-down may likely be identified at the end of the separated yarn in further studies. Regardless of the type of trash causing ends-down, there appears to be hull and shale accumulating in the rotor's groove. Additional ginning or textile cleaning steps to remove this type of trash could increase open-end processing efficiency.

The authentic cotton trash samples included in the spectral database consist of plant components from upland and pima cotton. Cotton trash consists of various types of plant components each with diverse functions, so different ratios of components are reflected in the FT-IR separation. Only ginning treatments 1 through 4 were performed with pima cotton and these matches typically include the abbreviation for pima (P; Table 2). Evaluation of the ginning treatments for upland cotton demonstrates the lack of the letter P in the FTIR matches. Some upland cotton matches appear in the pima cotton rotor dust and some pima cotton matches appear in the upland cotton rotor dust, but it appears for the most part that FT-IR "fingerprinting" is able to differentiate upland and pima cotton trash (Table 2).

In general, different harvesting techniques, spiking the samples with trash, and ginning treatments do not appear to demonstrate FTIR match differences. Ginning treatments produced lint from various harvesting techniques with different levels of trash that was subsequently removed in processing with few differences seen in the rotor dust. Spectra matching is still not exact and only provides a list of potential trash category matches. Minor differences exist between the top 5 FTIR potential matches and ginning treatments, and there is no identifiable relationship between ginning, ends-down, and trash FTIR matches. From the data presented here, it appears that the hull and shale are brittle trash material that are easily reduced in size, ground into a fine dust, trapped within cotton fibers, embedded in the rotor groove, and matched via FTIR. Currently, the FT-IR system is not entirely able to detect species differences, but with an expanding database of fiber and trash samples from many cultivars and localities this could be possible. These preliminary FT-IR results may prove to be an effective tool to further explore the types of trash causing processing problems in open end spinning.

CONCLUSIONS

Mid-IR appears to be an effective tool able to identify a wide range of cotton trash and contaminants that are commonly found in cotton. This study has determined that buildup in the rotor groove is an excellent trash collection point and the fine powder residue can easily be removed from the rotor's groove for FT-IR evaluation and matched to a spectral database. Analysis of rotor dust with mid-IR indicates that rotor dust consists mainly of hull and shale, and this "fingerprinting" is generally able to differentiate upland and pima cotton trash. It appears that a combination of events cause ends-down while the rotor groove develops residue. Future studies may attempt to determine the exact cause of each spinning interruption through inspection of the broken yarn for trash material (e.g. seed coat, bark, trash, nep, or slub) and later inspected by Mid-IR. In this study, regardless of the type of trash causing ends-down, there appears to be hull and shale accumulating in the rotor's groove. Qualitative analysis characterizes the trash but does not provide sufficient evidence that these trash types are the main organic constituents by weight. These qualitative results are promising and future studies could address quantitative IR analysis. Additional harvesting, ginning, or textile cleaning steps to remove the type of trash accumulating in rotor grooves could increase open-end processing efficiency.

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DISCLAIMER

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