# 2247 Review of Fiber Quality Effects of Seed Cotton Moisture Restoration in Ginning

## Discipline: Engineering and Ginning


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**Abbreviations:** AFIS (Advanced Fiber Information System), AMS (Agricultural Marketing Service), HVI (high volume instrument), mc (moisture content), RH (relative humidity).

## ABSTRACT

Historical data, mostly collected prior to 1980, has shown that the drying of seed cotton often correlates with reduced lint quality, especially fiber length, and yarn strength. This report discusses several studies conducted since 2003 which have examined in more detail the possibility of adding moisture to seed cotton. The emphasis was to improve cotton fiber properties, especially fiber length and fiber length coefficient of variation. These recent studies have consistently shown that ginning at a higher moisture content improved the fiber properties (length, length uniformity, and strength) as measured by the Advanced Fiber Information System and the High Volume Instrument and that the method of achieving that moisture content, whether by less drying or by moisture restoration, had no statistically significant effect. In some cases the cotton ginned at higher moisture content also had somewhat more non-lint content.

Keywords: Fiber, Gin, Length, Moisture, Quality, Restoration, Seed Cotton.

## INTRODUCTION

The moisture content (mc) of upland cotton fiber affects many of its properties and how it responds to processing in the gin plant. Excessive mc of seed cotton has been a problem, especially in the more humid growth areas. Almost since the initial adoption of the cotton gin dryer in the 1940's scientists have documented the decrease in fiber length quality with excessive drying (Gerdes et al., 1941; Byler, 2006) with gins using up to three dryers at air temperatures as high as 177 °C (350 °F) (Gerdes, 1950). Moore and Griffin (1964) presented an explanation: cotton fiber strength increases over the range 3 to 15% while the attachment of the fiber to the seed is relatively constant from 3 to 11% and then decreases up to 15%. Thus, the ratio of the force required to remove the fiber from the seed to the strength of the fiber decreases with increasing mc.

Cotton fiber is often at a mc below 5% when harvested, without additional drying even in humid growth regions (Mangialardi, G. J. and A. C. Griffin, 1977). The fiber length property for the cotton pricing structure was staple length, determined by visual inspection by human classers, until the HVI fiber length was adopted. Generally the difference in staple length due to the ginning moisture level has not been statistically significant but the negative impact on mills of ginning at lower mc has been consistently documented (Byler, 2006).

Griffin and Merkel, 1953; Leonard et al., 1970; and Lafferty, 1971 added moisture to increase the lint mc after seed cotton cleaning but before ginning, either by spraying water on the seed cotton or by exposing the seed cotton to moist air. Mangialardi et al. (1965) ginned one cultivar with various drying procedures and with moisture added before ginning using vapor or spray methods for some treatments. They measured the fiber length quality with the Suter-Webb array and the Fibrograph. They reported no statistical difference in staple length but most of the other fiber length properties, such as Suter-Webb mean length and Fibrograph upper half mean and mean length, had significant differences related to the treatments. The higher mc cottons tended to have higher trash content but also had significantly higher Pressley fiber strength (P=0.01). Data were also presented linking lower mc fiber at ginning to lower yarn break factor (P=0.01). When moisture was added to the seed cotton after drying and cleaning, but before ginning, the fiber and yarn properties improved. For their "heavy drying" they included two 24 shelf tower dryers both set at 121 °C (250 °F). The heavy drying performed in 1962 resulted in fiber mc of 2.7% and Fibrograph upper half mean length of 26.7 mm (1.05 in) while heavy drying followed by spray type moisture restoration prior to ginning resulted in fiber mc of 8.1% and upper half mean length of 27.7 mm (1.09 in).

Several studies have shown improved spinning properties of cotton associated with moisture restoration done before ginning (Mangialardi et al., 1965; Leonard et al., 1970; Childers and Baker, 1977). But, the measures of fiber length quality which have been used in cotton marketing, especially staple length, have not shown consistent improvement either when ginning at various mc levels or with moisture restoration before the gin stand (Byler, 2006). At the same time, additional drying has consistently resulted in better cleaning efficiency and thus better leaf grades. Therefore, the marketing system has not provided an incentive to producers and ginners to concentrate on the problem of fiber length quality reduction due to ginning at low seed cotton mc. Many of the Suter-Webb, Fibrograph, and Advanced Fiber Information System (AFIS) length and yarn strength measurements made in different studies were improved when ginning after adding moisture to the seed cotton relative to ginning at lower mc. Ginning affects the fiber length quality and it is important for ginning researchers to better understand this problem so that higher quality fiber can be produced for the mills.

In 2002 and 2003 Anthony (2003, 2004) collected samples and analyzed them for mc at 18 and 20 gins respectively in the midsouth. He found that the average mc of all lint samples at individual gins of samples taken from the lint slide before lint moisture restoration varied between 3.7 and 6.2% and 3.0 to 5.8% wet basis (wb) respectively. The overall mean mc for all gins was 5.1% in 2002 and was 4.4% in 2003. These data show that despite years of emphasis that ginning not be done below 5% mc the problem of ginning at lower mc is common. This results from farmers harvesting during good weather and storing the seed cotton in modules which often results in seed cotton drier than ideal for ginning. Other contributors include use of gin dryers for smoother operation and the improvement to cotton value because of better cleaning efficiency resulting from ginning at lower mc. At the present time the grading system has limited ability to detect the fiber damage done by ginning at lower mc.

Interest exists in including an additional appropriate measurement of fiber length which better predicts fiber-processing at the mill in official USDA Agricultural Marketing Service (AMS) classing (Bradow and Davidonis, 2000; Cui et al., 2004; Krifa, 2004; and Knowlton, 2004). Researchers are interested in ginning methods which improve the fiber length properties that affect price and mill processing. Additions to the mc of the lint before the gin stand would be limited under commercial ginning conditions due to the short time the seed cotton is available for treatment in the gin plant and the mass flow rate of material through the plant.

## OBJECTIVE

The objective of this multi-year project was to examine ways to improve fiber length and strength and lint spinning quality which are related to ginning mc by repeating some of the approaches found in the literature and examining additional approaches to restore moisture to seed cotton. Modern fiber measurements, including HVI and AFIS, will be used to judge the effect on fiber quality of the moisture restoration.

## RECENT RESEARCH

Work was begun to increase the mc of lint in the gin stand by adding humidified air in the second drier then that approach was compared with using humidified air with a hopper above the gin stand. The next approach was to spray atomized water into the seed cotton stream entering the conveyer-distributor. All of these tests showed that the fiber quality improved when the fiber was ginned at higher mc. Two surfactants were then added to the water being sprayed on the seed cotton in an attempt to further increase the lint mc.

Tests were performed and samples collected while ginning in the Cotton Ginning Research Unit in Stoneville, MS USA. The cotton was dried in the first tower dryer, cleaned with a cylinder cleaner and a stick machine, dried in the second stage of drying, then cleaned in the second cylinder cleaner in the normal sequence for spindle picked cotton. All of the cotton used in the testing was grown in the Stoneville, MS area and spindle picked. The Continental gin stand (Continental Eagle Corporation, Prattville AL) was used with a single saw-type lint cleaner.

The data from these tests were analyzed with SAS procedures MEANS and MIXED to determine what mc was achieved by the moisture control system and what effect ginning at those mc levels had on fiber properties. For the MIXED procedure analysis of mc, the means were taken by bale of the mc readings. Then the MIXED procedure used the module within variety for the random factor and the RH, variety, drying level, spray water level, and humidaire fixed effects. In many cases several of the fixed effects did not affect the dependent variable significantly. The Type III sums of squares were used in the evaluation of the importance of the fixed effects. Type III sum of squares for a particular effect is the amount of variation in the dependent variable due to that effect after correcting for all other terms in the model. Type III sums of squares, therefore, do not depend on the order in which the effects are specified in the model (SAS, 2003). The LSMEANS statement of the MIXED procedure calculated the means reported.

**Moisture addition in the second stage of drying (Byler 2005).** A commercially available device, a Humidaire unit (Samuel Jackson Inc.; Lubbock, TX), was reconfigured so that it would produce either warm dry air for drying, or warm moist air for moisture restoration. The air from the Humidaire unit was used to pick up the cotton after the stick machine, Figure 1, after which it went through a tower dryer and was separated from the seed cotton in a cylinder cleaner. Adding moisture to the seed cotton at this location would be expected to reduce the seed cotton cleaning efficiency somewhat, but the system design would not require much remodeling in most gins.

Tests were run at two periods in 2000, Part I on April 13 and 18 and Part II on July 27 and 28. In Part I 12 bales were ginned and in Part II 14 bales were ginned. The cotton variety ginned in Part I was BXN 47 (Stoneville Pedigreed Seed Company; Memphis, TN) and was DPL 5409 (Delta and Pine Land Seed; Scott, MS) for Part II. The cotton had been harvested during the fall of 1999 and stored dry on trailers until ginned.

Tests were run on two separate days for each part with two moisture treatments each day. The treatments were applied to full bale units based on approximately 640 kg (1400 lb.) of seed cotton. Each day, half of the bales were ginned while conditioning the seed cotton in the second tower dryer with warm dry air and the other half were ginned while conditioning the cotton in the second tower dryer with moist warm air. On one day one bale was ginned with drying then two bales were ginned with each treatment alternatively. On the next day one bale was ginned with moisture addition then two bales were ginned with each treatment alternatively. This was a randomized complete block design repeated for four days with a pair of bales, one with drying only and the other with moisture addition, as the block. Sub-samples were collected for each bale by treatment combination. The seed cotton ginned during each day was believed to be uniform because it had been all planted on the same day, grown on uniform soil at Stoneville, MS, harvested on the same day, and stored under similar conditions until used.

Table 1 shows the lint mc means by testing day and location, before the lint cleaner or after the lint cleaner. The treatment with moisture restoration was higher than without moisture restoration in every case with a mean difference of 0.82 percentage points before the lint cleaner. Table 2 shows the mean AFIS fiber length data of samples which were improved significantly for every measure for samples collected before the lint cleaner as well as after the lint cleaner although the magnitude of the differences were small.

The cleaning efficiency of seed cotton cleaning after moisture restoration would be expected to be lower. The system with moisture restoration in the second tower dryer has a considerable portion of the cleaning after moisture restoration. Table 3 shows the means of the AFIS trash measurements, and in many cases the trash levels were higher with moisture restoration, but differences of this magnitude would rarely make any difference in the market value of the lint. Table 4 shows the AFIS nep and seed coat data. The AFIS nep count was significantly lower with moisture restoration but most of the remaining measurements were not significantly different.

**Moisture restoration in the tower dryer or above the gin stand (Byler 2003).** The equipment design again used a commercially available device, a Samuel Jackson Humidaire unit, which was reconfigured so that it would produce either warm dry air for drying, or warm moist air for moisture restoration. The air from the Humidaire unit was used to pick up the cotton after the stick machine, following the first tower dryer, after which it went through a tower dryer and was separated from the seed cotton in a cylinder cleaner.

A thermocouple-based temperature indicator was installed at the exhaust of the cylinder cleaner after the second tower dryer to better monitor conditions. Control of the air temperature produced by the moisture-conditioning unit was based on a thermocouple located in the duct ahead of the air-cotton mix point under the stick machine. Control of the stage one drying was based on a thermocouple located in the top of the tower dryer.

The second equipment design used an additional Humidaire unit to add moisture to the seed cotton in a hopper (Samuel Jackson, Inc., Lubbock TX) immediately above the gin stand. The hopper had ducts for moist air application from both sides. The ducts each had a valve controlled by the gin stand so that moist air would not be applied when the gin stand breast was not "in."

The three treatments were 1) using heated air in the stage two drying system and no air with the hopper, 2) using humidified air in the stage two drying system and no air with the hopper, 3) using heated air in the stage two drying system and humidified air in the hopper. The stage 1 drying air control was set to 93 °C (200 °F) at all times. When the heated air was used in the stage two dryer the temperature setting was 49 °C (120 °F). When humid air was used in the stage two dryer the water temperature was 40 °C (104 °F) and the air temperature setting was 43 °C (110°F). The water temperature setting was 44 °C (112 °F) and the air temperature setting was 49 °C (120 °F) for the air for the hopper above the gin stand. The humidaire settings were lower than normally used in conditioning lint and the resulting air carried much less moisture than could be carried with higher settings. The treatments were meant to produce different lint mc levels but not to necessarily achieve a certain final mc.

The mc differences achieved by the treatments were not large, the mean was 0.45 percentage points before the lint cleaner, but were statistically significant, Table 5. The AFIS trash and nep count means by treatment were not significantly different. Some of the means of the AFIS length data are shown in Table 6. Each of the two moisture restoration treatments were compared with the fiber with no moisture restoration. In many cases the fiber length was improved with the moisture restoration, even though the mc differences were small. The AFIS fiber length data was analyzed with mc and treatment both in the model. It was found that the mc explained much more of the length variation than the treatment. Even with cotton with no moisture restoration variation in mc of the fiber measured before the lint cleaner correlated significantly with the AFIS length measurements.

**Moisture restoration with atomized spray above conveyer-distributor (Byler and Boykin, 2006).** For this experiment one trailer of each of three varieties of seed cotton were used: Delta Pine DP444BR, Delta Pine DP5415BR, and Stoneville ST4892BR. These cottons had been harvested in late Sept. or early Oct. 2004 and ginned on Aug. 16 and 17, 2005. They had been stored on trailers under roof to protect them from rain but were exposed to ambient conditions. The weather during the ginning varied from 28 °C (82 °F) and 80% RH to 34 °C (94 °F) and 45% RH. One atomizing nozzle, 1/4J+SU2 with model 2850 fluid cap (Spraying Systems, Wheaton IL) was installed to spray water into the seed cotton. Water spray rate vs. water pressure data were collected and analyzed. Eight treatments were used, half with low drying level and the other half with high drying level. The low drying treatments the temperature at the second shelf of the first tower dryer was controlled at 49 °C (120 °F) and the second stage burner was off (ambient air was used). For the high drying the first stage of drying was set at 93 °C (200 °F) and the second stage was set at 68 °C (155 °F). The water spray treatments consisted of: none, 41 kPa (6 psi) and 83 kPa (12 psi) water pressure. The atomizing air pressure was kept constant at 414 kPa (60 psi). A Humidaire Unit was used in conjunction with a conditioning hopper (Samuel Jackson, Inc., Lubbock TX) to add moisture to the seed cotton by the vapor method for certain bales. Two treatments included the use of moist air from the Humidaire applied above the gin stand. Because limited material was available not all treatments were applied to the same number of lots. The basic treatment unit was one bale of cotton. There were seven bales of the variety 444, six bales of the variety 5415, and five bales of the variety 4892 in the experiment.

Five lint samples per bale were taken between the gin stand and the lint cleaners for mc determination plus five samples for AFIS measurements. Nine lint samples per bale were taken at the lint slide for mc determination with two or three sub-samples analyzed for each sample. In addition, five samples were obtained for AFIS measurement and five samples for HVI evaluation were taken per bale.

Table 7 shows the least squares means of the mc data. The mc of the seed cotton before drying varied by variety but not with any of the other factors used in the analysis. After drying the mc varied with the cotton variety and the drying level, as expected. The mc of the lint for samples taken before the lint cleaner varied due to the variety, the drying level, and the spray level. The difference in least squares mean mc due to the high spray application vs. none was 0.79 percentage points. The Humidaire had been used with the hopper above the gin stand but because of the settings under which it was operated no significant moisture was added (Prob>F: >0.4). When the mc means at the bale were examined the mc range was found to vary from 3.7 to 6.9% due to a combination of the treatments. The effect on the mc of the lint samples obtained after the lint cleaner was reduced but all of the effects which had been significant before the lint cleaner were significant after it.

The results of analyzing the AFIS data for samples taken after the lint cleaner are shown in Table 8. The variety affected the AFIS length data significantly and the slope due to the change in mc was significant in every case with improved lint properties resulting from ginning at higher mc. All treatments which affected the lint mc affected the AFIS length measurements as expected so the moisture restoration using the spray technique significantly improved the AFIS length data. The AFIS short fiber content calculated by weight was decreased by about 6% (or half an SFC percentage point) for each percentage point increase in lint mc for samples obtained before the lint cleaner.

The least square means resulting from the analysis of the HVI samples obtained after the lint cleaners are shown in Table 9. The mc effect on the Rd color component was not statistically significant. The HVI +b and micronaire did not vary significantly due to the mc. The HVI length uniformity was not statistically significant. Lint mc significantly affected HVI trash and length measurements. The increase in HVI trash was mostly due to the drying treatment, which occurs before the seed cotton cleaning and would be expected to affect the trash level. The estimate of the effect of mc on the HVI length was not significantly different for the two experiments considering that the standard error of the estimate was about 0.04 mm and the difference was only 0.015 mm.

This study involved the addition of moisture to seed cotton and the amount of moisture which could be added was limited. When higher levels of moisture addition were attempted the gin stand would choke. This problem would automatically limit the amount of moisture added commercially. The addition of moisture to seed cotton, as studied here, resulted in lint mc in the range 5 to 6 percent, a level never considered to be excessive.

**Atomized spray moisture restoration with surfactants.** Two surfactants were used in the study which were already in use in the cotton industry, Dyne-Amic® (Helena Chemical Co.; Collierville, TN), called surfactant 1 in this study, which is used with chemical application during cotton production and AN114022 spindle cleaner (John Deere; Moline, IL) that is widely used during cotton harvesting, called surfactant 2. In initial testing clumps of approximately 16 g of seed cotton were loosely confined within cotton gauze then submerged in water, water with 0.1% by weight of surfactant 1 or water with 1.56% by weight of surfactant 2 for 5 s. The gauze and seed cotton were then reweighed. The seed cotton in water increased in weight by about 80%, in surfactant 1 the weight increased by about 200% and in surfactant 2 the weight increased by about 175%. Thus it was clear that the surfactants were effective in wetting the seed cotton.

Three drums were used to hold the three fluids applied to the seed cotton under the dropper above the conveyer-distributor. A separate pump was used to deliver the fluid to the atomizing spray nozzle (model SUQR-300, Spraying Systems Co.; Wheaton, IL) located above the conveyer-distributor. The atomizing air pressure was kept constant at 552 kPa (80 psi) and three spray application levels were used: zero; low, 138 kPa (20 psi); and high, 276 kPa (40 psi).

The seed cotton was grown commercially south of Leland, MS. Two modules of cultivar DP444 BG/RR (444) and two modules of cultivar DP434 RR (434) (Delta and Pine Land; Scott, MS) were ginned. In addition to the moisture addition by the atomizing spray nozzles some additional moisture was added using a Humidaire with Conditioning Hopper (Samuel Jackson Inc.; Lubbock, TX) above the gin stand for selected bales.

The basic treatment unit was the bale produced from 660 kg (1450 lb) of seed cotton. A total of 54 bales were ginned in the test. For each bale 5 lint samples were obtained for mc wb analysis by the oven method (Shepherd, 1972) before the lint cleaner and 5 additional after the lint cleaner. Three seed cotton samples were obtained per bale as the cotton entered the gin and 3 additional samples at the gin stand feeder apron after moisture treatment for mc determination. Five lint samples were obtained before and five others after the lint cleaner for fiber quality determination AFIS.

Seven of the bales were shipped to the ARS Cotton Quality Research Station in Clemson, SC (CQRS). The work at the CQRS was intended to detect any fiber quality and spinning problems related to the surfactant application. Each of the bales had three repeat lots processed and examined for opening and cleaning waste, card waste, spinning performance, single end strength, strength CV and elongation, yarn evenness data and long term yarn data. Each lot consisting of 45 kg (100 lb) of lint was processed on the Truezschler Opening line and 803 Card (Truetzschler: Monchengladbach, Germany). Card sliver was produced at 4.5 g/m processed at the rate 68 kg/h (150 lb/h). First and second finisher drawings were performed, and roving was produced with a 1.3 twist multiplier at a spindle speed of 1200 rpm. The lots were ring spun into 22-Tex yarn with a 3.5 twist multiplier. Stops were recorded. The Statimat-M (Textechno, Monchengladbach, Germany) was used for yarn measurements including strength, strength CV, and elongation. The ILE DS-65 Evenness Tester (Industrial Laboratory Equipment, Charlotte, NC) was used to measure thick places and thin places. Long term defects were measured using the Classimat II (Uster Technologies Inc., Knoxville, TN).

Selected AFIS measurements of samples taken in the gin were complemented by AFIS measurements obtained from samples obtained at the CQRS (AFIS Version 4). The data for bales with Humidaire moisture application and low level spray were eliminated from the data for samples from the gin to produce a compatible data set. The data from the gin included five lots from each of 24 bales and the data from the spinning lab included three lots from each of seven bales, so there were many more measurements included in the data from the gin than from the spinning lab.

Table 10 shows the results from the analysis of the fiber moisture data. There were statistically significant differences in the mc of the lint related to the module it had come from, the Humidaire moisture treatment and the spray water treatment but the differences related to the material within a spray level were not significant. The surfactants used at the levels used did not result in significantly more moisture in the fiber. The mc data from before the lint cleaner, the best indicator of the mc in the gin stand, showed that the Humidaire added 0.28 percentage points and the low and high spray settings added 0.62 and 1.12 percentage points respectively. In Table 11 the AFIS upper quartile length calculated by weight was greater in every case for samples with atomized spray moisture restoration but in the finisher sliver the difference was not considered to be statistically significant. In none of the five sampling locations did the use of a surfactant significantly affect the length differently than water. One cultivar had greater fiber length in every measurement location but the difference was statistically significant only with the samples obtained in the gin. The data for AFIS short fiber content was less consistent, Table 12. The short fiber content for the samples with spray moisture restoration were significantly lower for samples obtained in the gin but the differences, while still lower for lint ginned with moisture restoration, were not considered to be significant for the card and finisher sliver. The short fiber content was higher with no moisture restoration than with it in all cases. The CQRS processed all fiber at about the same mc so any additional short fiber created at the CQRS would experience much smaller differences due to the treatments at the gin. In addition there were many fewer AFIS measurements at the CQRS. These two factors may have combined to make the observed differences in short fiber not statistically significant. For two of the locations in the spinning process the spray materials affected the short fiber content differently. In Table 13 the opening and cleaning waste was shown to be higher for the samples with moisture restoration by spray with no additional significant differences. The total card waste showed differences related to cultivar, spray moisture restoration, and the spray material with somewhat higher waste from the samples with moisture restoration and the highest with moisture restoration with water.

The single strand strength was significantly greater when made after moisture restoration, 15.3 compared to 15.7 g/tex, while the single strand elongation, strength CV, and yarn appearance differences were not statistically significant, although the means were better for the fiber with moisture restoration in every case. The data from the evenness tester of neps, thick places, thin places did not show any significant differences related to moisture restoration.

## CONCLUSIONS

A review of data published before 2000 generally showed that moisture restoration of seed cotton resulted in better yarn properties but generally did not result in measurable improvement in fiber properties. Tests performed since 2000 with AFIS testing of fiber showed significant improvement of fiber properties when ginned with moisture restoration, even with small differences in lint mc. The moisture restoration was achieved through the use of humid air applied in the second dryer, in a hopper above the gin stand, by spraying atomized water above the conveyer-distributor, by decreased drying, and even from variation in mc of the seed cotton not controlled by the test design. The factor which was important was the mc of the fiber when ginned, not the method of arriving at that mc. Ginning at higher lint mc results in better quality fiber and gins need to be attentive to this issue. Gin managers should consider the improved value of the lint when moisture is restored to seed cotton.

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Table 1. Lint moisture content, percent wet basis, calculated by day, sampling location, and treatment determined by the oven method.

| Test day | Sampling before lint cleaner[z] | | Sampling at lint slide[z] | |
|---|---|---|---|---|
| | Drying only | Moisture restoration | Drying only | Moisture restoration |
| First | 4.84 | 5.84 | 5.46 | 6.10 |
| Second | 4.62 | 5.61 | 4.93 | 5.68 |
| Third | 4.54 | 5.52 | 4.64 | 5.36 |
| Fourth | 5.04 | 5.34 | 5.18 | 5.58 |
| Mean | 4.76 | 5.58 | 5.05 | 5.68 |

[z]All differences between treatments at a location were significant ($P \leq 0.01$).

Table 2. Means and statistical significance of fiber length-related AFIS data calculated by sampling location and treatment.

| | Sampled before lint cleaner[z] | | | Sampled at lint slide[z] | | |
|---|---|---|---|---|---|---|
| | Drying only | | Moisture restoration | Drying only | | Moisture restoration |
| Fiber length averaged by number (mm) | 19.8 | ** | 20.2 | 19.1 | ** | 19.6 |
| Fiber length averaged by number (%CV) | 48.1 | ** | 47.2 | 49.8 | ** | 48.8 |
| Short fiber content calculated by number (%) | 25.2 | ** | 23.9 | 27.5 | ** | 26.0 |
| 2.5% length by number(mm) | 35.2 | ** | 35.6 | 34.8 | ** | 35.1 |
| 5.0% length by number (mm) | 33.1 | ** | 33.4 | 32.7 | ** | 33.0 |
| Fiber length averaged by weight (mm) | 24.3 | ** | 24.7 | 23.8 | ** | 24.2 |
| Fiber length averaged by weight (%CV) | 32.9 | * | 32.5 | 33.8 | ** | 33.2 |
| Short fiber content calculated by weight (%) | 8.7 | ** | 8.0 | 9.6 | ** | 8.9 |
| Upper quartile length calculated by weight (mm) | 29.3 | ** | 29.6 | 28.9 | ** | 29.2 |

[z] *, and ** indicate means between treatments within a sampling location were significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Table 3. Means and statistical significance of trash-related AFIS data calculated by sampling location and treatment.

| | Sampled before lint cleaner[z] | | | Sampled at lint slide[z] | | |
|---|---|---|---|---|---|---|
| | Drying only | | Moisture restoration | Drying only | | Moisture restoration |
| Total trash count (per g) | 700 | ** | 780 | 350 | ** | 410 |
| Trash mean size (µm) | 327 | NS | 324 | 450 | NS | 351 |
| Dust count (per g) | 580 | ** | 650 | 290 | ** | 335 |
| Trash count (per g) | 117 | * | 128 | 62 | ** | 74 |
| Visible foreign matter (%) | 2.25 | * | 2.47 | 1.26 | * | 1.45 |

[z]NS, *, and ** indicate means between treatments within a sampling location were not significantly different $P > 0.05$, and significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Table 4. Means and statistical significance of nep-related AFIS data calculated by sampling location and treatment.

| | Sampled before lint cleaner[z] | | | Sampled at lint slide[z] | | |
|---|---|---|---|---|---|---|
| | Drying only | | Moisture restoration | Drying only | | Moisture restoration |
| Nep count (per g) | 220 | ** | 200 | 290 | ** | 270 |
| Nep size (μm) | 714 | NS | 717 | 702 | NS | 706 |
| Seed coat nep count (per g) | 19 | * | 21 | 22 | NS | 23 |
| Seed coat nep size (μm) | 1120 | NS | 1100 | 1120 | NS | 1110 |

[z]NS, *, and ** indicate means between treatments within a sampling location are not significantly different ($P > 0.05$), and significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Table 5. Means of lint moisture content, percent wet basis, by location and moisture restoration treatment.

| Sample location | Moisture restoration | Mean[z] | Standard error |
|---|---|---|---|
| Before lint cleaner | None | 4.34 c | 0.11 |
| | Second dryer | 4.77 a | 0.09 |
| | Above gin stand | 4.80 a | 0.10 |
| After lint cleaner | None | 4.34 c | 0.11 |
| | Second dryer | 4.68 ab | 0.09 |
| | Above gin stand | 4.57 bc | 0.10 |

[z]Means not having the same letter differ ($P < 0.10$).

Table 6. Variations in fiber quality measurement least squares means from AFIS data showing differences due to different moisture restoration, samples taken before the lint cleaners.

| | Moisture restoration | | |
|---|---|---|---|
| | None | Second dryer[z] | Above gin stand[z] |
| Fiber moisture content (%) | 4.34 | 4.77* | 4.80* |
| Fiber length by weight (in) | 0.98 | 1.00** | 0.98NS |
| Fiber length by weight (%CV) | 33.2 | 32.3** | 32.5** |
| Upper quartile length by weight (in) | 1.185 | 1.197NS | 1.180NS |
| Short fiber content by weight | 8.4 | 7.6** | 8.0* |
| Fiber length by number (in) | 0.79 | 0.82** | 0.80NS |
| Fiber length by number (%CV) | 48.87 | 47.67** | 47.73NS |
| Short fiber content by number | 25.4 | 23.8** | 24.3** |

[z]NS, *, and ** indicate means between a moisture restoration treatment and the control were not significantly different ($P > 0.05$), and significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively

Table 7. Least squares means of the moisture content data by relevant effects for the moisture content data of samples obtained at several specified locations during the ginning process and the probability that the observed variation was due to random effects.

| Effect | Level | Feed control seed cotton mc (%) | Feeder seed cotton mc (%) | Before lint cleaner lint mc (%) | After lint cleaner lint mc (%) |
|---|---|---|---|---|---|
| Variety | 444 | 9.27 | 8.48 | 5.80 | 5.92 |
| Variety | 4892 | 8.69 | 7.95 | 5.27 | 5.32 |
| Variety | 5415 | 8.19 | 7.80 | 5.07 | 5.40 |
| Drying | Low | 8.68 | 8.34 | 5.86 | 5.93 |
| Drying | High | 8.76 | 7.82 | 4.90 | 5.16 |
| Spray | Off | 8.77 | 8.11 | 4.93 | 5.21 |
| Spray | Medium | 8.55 | 7.96 | 5.51 | 5.74 |
| Spray | High | 8.84 | 8.15 | 5.72 | 5.70 |
| Probability of greater F value due to random variation | Variety | 0.006 | 0.0043 | <0.0001 | <0.0001 |
| Probability of greater F value due to random variation | Drying | 0.68 | 0.0014 | <0.0001 | <0.0001 |
| Probability of greater F value due to random variation | Spray | 0.50 | 0.55 | <0.0001 | <0.0001 |

Table 8. AFIS length least squares means estimates for samples taken after lint cleaning.

| AFIS Measurement | Variety[z] | | | Slope due to moisture content (per percentage point) |
|---|---|---|---|---|
| | 444 | 4892 | 5415 | |
| Lw (mm) | 25.07 a | 25.04 a | 24.71 b | 0.20 [y] |
| LwCV (%) | 34.0 a | 31.3 c | 32.0 b | -0.357 [y] |
| UQLw (mm) | 30.40 a | 29.90 b | 29.77 b | 0.17 [y] |
| SFCw (%) | 8.7 a | 7.2 c | 7.8 b | -0.45 [y] |
| Ln (mm) | 20.04 c | 20.78 a | 20.29 b | 0.30 [y] |
| LnCV (%) | 50.1 a | 45.5 c | 46.9 b | -0.75 [y] |
| SFCn (%) | 26.2 a | 22.1 c | 23.6 b | -1.03 [y] |
| L5%n (in) | 34.29 a | 33.53 b | 33.50 b | 0.20 [y] |
| L2.5%n (in) | 36.58 a | 35.61 b | 35.43 c | 0.16 [y] |

[z] Means followed by different letters within a row varied with significance ($P \leq 0.05$).
[y]This slope was statistically significant ($P \leq 0.05$).

Table 9. Least squares means estimates of HVI properties of samples taken after lint cleaning.

| HVI measurement | Variety [z] | | | Moisture content slope (per percent mc change) |
|---|---|---|---|---|
| | 444 | 4892 | 5415 | |
| Strength (g/Tex) | 30.5 a | 30.5 a | 30.2 a | 0.33 [y] |
| Rd | 71.4 c | 78.0 b | 82.2 a | -0.84 |
| +b | 9.20 c | 10.82 a | 9.48 b | -0.43 |
| Uniformity (%) | 83.0 a | 83.1 a | 82.5 b | 0.11 |
| Micronaire | 3.88 c | 4.66 b | 4.72 a | -0.008 |
| HVI trash (%) | 0.86 a | 0.35 b | 0.21 c | 0.054 [y] |
| HVI length (mm) | 29.06 a | 28.32 b | 28.40 b | 0.165 [y] |

[z] Means followed by different letters within a row ($P \leq 0.05$).
[y] This slope was statistically significant ($P \leq 0.05$).

Table 10. Moisture content, wet basis, least squares means and statistical significance of differences between means.

| | Samples taken before lint cleaner | Samples taken after lint cleaner |
|---|---|---|
| | Module | |
| 101 | 5.11 | 5.26 |
| 3398 | 5.46 | 5.23 |
| 3298 | 5.66 | 5.17 |
| 3299 | 5.93 | 5.49 |
| Average over modules | 5.54 | 5.29 |
| | Change in moisture content due to moisture restoration | |
| With Humidaire | 0.28 | 0.23 |
| With low spray | 0.62 | 0.55 |
| With high spray | 1.12 | 0.80 |
| | Change in moisture content due to surfactant | |
| High water alone | 1.02 | 0.80 |
| High water with surfactant 1 | 0.95 | 0.69 |
| High water with surfactant 2 | 1.41 | 0.66 |
| | Statistical probability > F by chance | |
| Module differences | <0.0001 | 0.011 |
| Humidaire addition | 0.057 | 0.023 |
| Spray addition | <0.0001 | <0.0001 |
| Material within spray | 0.37 | 0.17 |
| Drying level | 0.26 | 0.37 |

Table 11. Least squares means of AFIS upper quartile length (cm) calculated by weight for samples obtained in the gin with data for treatments including low spray level and Humidaire removed and during the spinning process.

| | Gin before lint cleaner | Gin after lint cleaner | Raw stock | Card sliver | Finisher sliver |
|---|---|---|---|---|---|
| | Mean by cultivar | | | | |
| 434 | 3.0694 | 3.0282 | 3.088 | 3.049 | 3.124 |
| 444 | 3.0353 | 2.9946 | 3.075 | 3.026 | 3.106 |
| | Mean by spray moisture restoration | | | | |
| No | 3.0326 | 2.9948 | 3.061 | 3.014 | 3.095 |
| Yes | 3.0721 | 3.0281 | 3.100 | 3.059 | 3.129 |
| | Mean by spray material | | | | |
| Surfactant 1 | 3.0670 | 3.0239 | 3.090 | 3.052 | 3.102 |
| Surfactant 2 | 3.0810 | 3.0388 | 3.099 | 3.061 | 3.133 |
| Water | 3.0683 | 3.0226 | 3.112 | 3.065 | 3.154 |
| | Statistical probability > F by chance | | | | |
| Cultivar | <0.0001 | <0.0001 | 0.21 | 0.12 | 0.16 |
| Spray moisture restoration | <0.0001 | <0.0001 | 0.011 | 0.013 | 0.10 |
| Material within spray | 0.47 | 0.12 | 0.55 | 0.87 | 0.24 |

Table 12. Least squares means and statistical significance of the AFIS measurement of short fiber content calculated by weight (percent) of samples taken at the gin and during the spinning process for the bales tested at the Clemson Quality Research Station.

| | Gin before lint cleaner | Gin after lint cleaner | Raw stock | Card sliver | Finisher sliver |
|---|---|---|---|---|---|
| | | | Mean by cultivar | | |
| 434 | 8.421 | 8.916 | 7.34 | 10.35 | 8.81 |
| 444 | 8.178 | 8.729 | 7.48 | 9.89 | 8.74 |
| | | | Mean by spray moisture restoration | | |
| No | 8.641 | 9.219 | 7.65 | 10.40 | 9.13 |
| Yes | 7.958 | 8.425 | 7.35 | 9.81 | 8.57 |
| | | | Mean by spray material | | |
| Surfactant 1 | 8.09 | 8.40 | 8.10 | 9.68 | 9.21 |
| Surfactant 2 | 7.94 | 8.40 | 7.25 | 10.47 | 8.28 |
| Water | 7.86 | 8.48 | 6.70 | 9.30 | 8.22 |
| | | | Statistical probability > F by chance | | |
| Cultivar | 0.040 | 0.13 | 0.025 | 0.20 | 0.72 |
| Spray | <0.0001 | <0.0001 | 0.098 | 0.16 | 0.23 |
| Material | 0.53 | 0.92 | 0.0002 | 0.068 | 0.33 |

Table 13. Least squares means and statistical significance of spinning waste measurements (percent).

| | Opening and cleaning waste | Total card waste |
|---|---|---|
| | Mean by cultivar | |
| 434 | 1.512 | 4.396 |
| 444 | 1.509 | 4.206 |
| | Mean by spray moisture restoration | |
| No | 1.410 | 4.272 |
| Yes | 1.614 | 4.319 |
| | Mean by spray material | |
| Surfactant 1 | 1.627 | 4.273 |
| Surfactant 2 | 1.567 | 4.277 |
| Water | 1.648 | 4.408 |
| | Statistical probability > F | |
| Cultivar | 0.98 | <0.0001 |
| Moisture restoration with spray | 0.0001 | 0.093 |
| Material within spray | 0.22 | 0.001 |

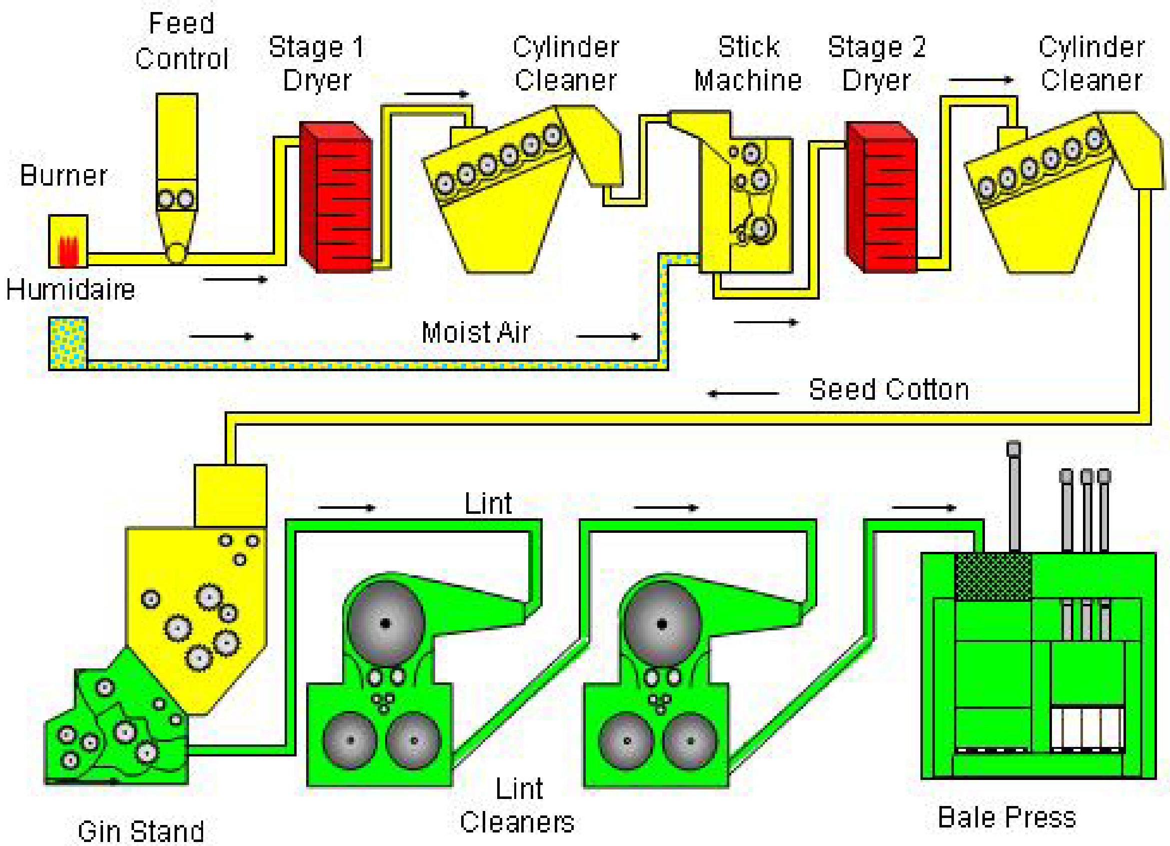


Figure 1. Schematic of the cotton ginning system with moisture addition in the second stage of drying.