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ENGINEERING & GINNING

Moisture Measurement

Mathew G. Pelletier* and Rick K. Byler

ABSTRACT

Proper measurement of moisture content (MC) during the ginning process is crucial for proper management of a cotton gin. It is important to avoid producing wet cotton lint for the benefit of textile mills and because wet cotton is damaged in storage and degrades the value of cotton leading to a USDA-AMS classing color-grade that is no longer reflective of the actual color of cotton, which in turn is damaging to U.S. cotton commodity markets. Cotton stored at too high MC is unacceptable for marketing and is ineligible for placement into the Commodity Credit Corporation Marketing Assistance Loan Program. Additional problems occur with improper cotton moisture when ginning at excessively low MC, which results in cotton lint of lower quality with shorter fiber length and lower fiber length uniformity. Thus, use of moisture sensors are critical to ensure cotton gins produce bales at a MC that is safe for long term storage and transport. To assess cotton moisture, several meters are available from different manufacturers for the measurement of seed cotton and cotton lint MC. Some of these meters are portable and can be used with seed cotton or lint, whereas others are permanently installed. Some meters are suitable for automated moisture control in the gin.

The quality of lint produced by a cotton gin is dependent on the initial quality of the seed cotton and on the type and degree of drying and cleaning performed at the gin. Both cleaning efficiency and damage done to fibers during ginning and cleaning are controlled, in large part, by the moisture content (MC) of the fiber as it is being processed (Hughs et al., 1994). Current recommendations are to run pre-cleaning machines with cotton MC ranging from 5 to 6%, to gin with fiber MC at the gin stand in the range of 6 to 7% wet basis (WB)(Mayfield et al., 1994), and drop to 5 to 6% MC for lint cleaning. Gins should not process cotton at MC below 5% and should not bale cotton at MC above 9% due to cotton color degradation in storage. Figure 1 shows the change in the Rd and +b values as moisture content increases (Anthony, 2003, 2005; Chun et al., 2007; Gamble 2008). Note that more damage occurs when MC exceeds 10%, where mold can begin to grow on the fibers, which leads to significant discoloration and fiber decomposition (Fig. 2). Given these two acceptable MC boundaries, the appropriate range is a narrow 4% range, with the preferred range an even narrower 1% span about the optimum. Because of the importance of MC to processing and quality preservation in the gin, adjusting and monitoring the operating MC is crucial for proper management. To adjust MC, seed cotton driers are used to remove moisture and moisture restoration systems are used to add moisture above the gin stand at just before the bale press (Fig. 3). To aid in this management, many different systems have been used for measuring seed cotton and lint MC in the gin. Figure 4 details several of the commercially available hand-held moisture meters.

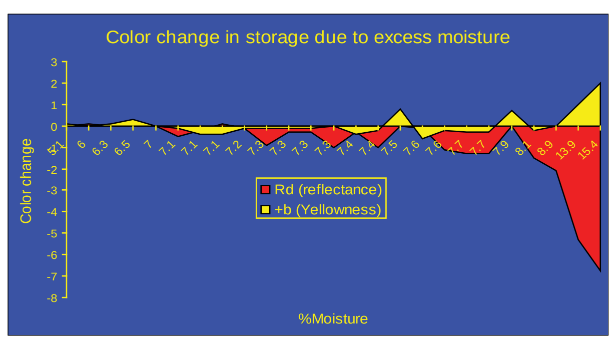

Figure 1: Cotton bale color change during storage due to high moisture content.

M.G. Pelletier, USDA-ARS, Cotton Production & Processing Research Unit,1604 E. FM 1294, Lubbock, TX 79403; R.K. Byler, USDA-ARS, Stoneville Cotton Ginning Research Unit, P.O. Box 256, Stoneville, MS 38776
Corresponding author: Mathew.Pelletier@ARS.USDA.GOV

Figure 2: Discolored cotton bale from mold growth in storage due to high moisture content.

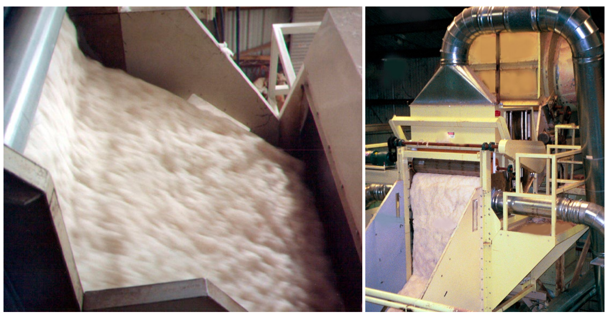

Figure 3: Moisture restoration system showing dry cotton flowing on (left) and conditioned and compressed bat flow out of restoration system.

Figure 4: A selection of commercially available resistance-based hand-held moisture meters (listed by manufacturer: A. Strandberg, B. Delmhorst, C. Aquaboy).

BACKGROUND

Measurement of physical properties is an area of specialty of many engineers and scientists. The main factors of importance for any measurement are: (1) accuracy—how close to the true value the measurement is, (2) precision—the number of digits on the meter (dynamic range), and (3) repeatability—how close to previously measured value the next readings are for the same material under test (MUT). Whenever repeated measurements of the same property are made with an instrument, some range of results is expected as no instrument is perfect, and some error is introduced by the instrument that is superimposed onto each measurement. This error can be observed by taking repeated measurements of the same sample.

In performing measurements, these key concepts are utilized: accuracy, repeatability, precision, sensor calibration, measurement procedures, presentation issues, sample handling, and issues pertinent to process control. These concepts are discussed in more detail in the following subsections.

Accuracy. The accuracy of a measurement is a metric that specifies how close to the true value the readings are. Another perspective is how well the various readings agree with the agreed upon correct measure for that sample. Generally speaking, there is no way of knowing exactly what the true reading should be, but specialists making the measurement develop specialized protocols for obtaining measurements that provide results that are as close as possible to the true value. These specialized protocols for obtaining the accepted true values are called standard methods or standards. Given the amount of economic commerce that is dependent upon accurate measurements, the U.S has an entire governmental department dedicated to standard measurements, called the National Institute of Standards and Technology (NIST).

Repeatability. The repeatability of a measurement is a metric that quantifies how close to the same answer, not necessarily the correct answer, the meter or sensor provides for the same or identical samples when the sample is repeatedly tested by the meter.

Precision. The precision of an instrument, sensor, scale, or meter refers to how many gradations there are in the measurement. For example, when measuring weight, the scale can provide a read-out to the nearest 1 kg or it could provide a finer gradation with a read-out of a finer resolution of 0.1 kg. In the second case, the scale has more precision as you can resolve finer scale readings of the value.

Sensor Calibration. Gins often check the calibration of the MC meter. The meter to be calibrated is used to measure the MC of cotton under normal operating conditions and samples are taken from the same cotton for a true MC determination by the oven method. For proper calibration, the samples should include MC levels across the full range of MCs of interest, that is, across the span from maximum to minimum MC. It is difficult to obtain samples covering the full range of interest, so a reduced range must be used. Often the cotton being processed is at a relatively narrow range of MC for a given harvest season, which is usually dryer than the upper MC of interest. In addition, even when higher MC cotton is available for calibration, the gin might not be able to process cotton near the upper MC limit. It is important to have multiple samples at several different MC levels when checking the calibration of meters in gins. Meters are often linear, so the result can be projected to a MC slightly beyond what was included in the calibration without too much concern.

After data are available from the reading of the meter being calibrated and the oven-based MC data of the same cotton, the two readings are compared statistically. Often a linear curve fitting is appropriate and sometimes a simple offset, where a value determined statistically is added to the meter reading, will result in significantly improved accuracy of MC predictions from the meter. The statistical analysis will also result in estimates of how close the corrected individual MC readings with the meter are expected to be to the oven-based MC value.

Basic Measurement Procedures. Each sensor, scale, or meter has a well-defined protocol for its use that is well described and published in its operating manual. Also defined in this manual are the specifications that provide the accuracy, precision, and repeatability of that instrument. To obtain measurement results that are comparable to those as published in the manual, it is critical to follow the manufacturer's guidelines carefully. Several key factors will address how well the meter performs with respect to its published specifications: how the sample is handled, the number of samples measured, the environment that meter is used in, and how well the sample is presented to the meter with respect to how it was designed to be presented. An example of environmental influence can be seen with hand-held resistance cotton MC sensors that are sensitive to cotton temperature. In practice, meter readings must be adjusted to account for the temperature deviation from instrument's designed temperature (normal ambient temperature of 20 °C [68 °F.]). The magnitude of this adjustment is stated in the owner's manual for the meter and should be consulted. Note that the calibration scale is typically different for seed cotton versus cotton lint, so the correct scale must be selected on the meter before use.

Presentation of sample to the meter. Closely following the instrument's protocol for placing or presenting the sample is a critical requirement. For example, if you gently place a sample on a weigh-scale and wait for the reading to stabilize, you will generally obtain results that are faithful to the published specifications. However, if the sample is roughly bounced onto the scale and the reading obtained before it has a chance to stop moving, the accuracy and repeatability of the obtained measurements will be significantly compromised. Rough handling of the instrument can also cause it to fall out of specification, which would likely require factory servicing to return it to its original performance. Other examples are: allowing a wide variation in the pressure of the cotton sample in a hand-held moisture meter or allowing sweat from your hands fall onto the cotton sample before making a measurement. More details on specific instruments are explored in later sections.

Sampling and sample handling. Proper sampling is the crucial first step in obtaining meaningful MC data. A minimum of three repeat samples should be collected for each situation, and the samples should be obtained in such a way that they represent the material as a whole. Cotton lint changes MC quickly so samples normally should be taken from deep within the mass of cotton being studied. They should be handled with clean, dry hands, preferably wearing gloves. They need to be placed in an air-tight suitable container as quickly as practical. The samples should be large enough to reasonably fill the container so that the MC measured later is not substantially affected by the MC of the air in the container (Byler, 2004a). The container must be hermetically sealed to ensure no moisture can enter or escape the container, thereby contaminating the sample MUT.

Obtaining samples of seed cotton for MC determination after drying, or any MC adjustment, is problematic. During drying the lint changes MC rapidly, whereas the seed barely changes MC over a short time span, thus, the sample will have substantial differences in MC between the lint and seed. While the samples are stored awaiting MC determination, moisture will move from the seed to the lint often making the MC measurement of limited value. Usually the gin is concerned about the lint MC at the gin stand or at the lint cleaner, as generally the seed MC has little influence on the ginning performance if the seeds are still hard. Conversely, dry lint with soggy seeds is hard to gin. Determination of MC of lint samples collected immediately after the gin stand or the lint cleaner will provide the data necessary for proper gin operation.

Byler (2004b) compared the use of quart-sized metal cans sold for transporting paint and zipper-sealed freezer plastic bags such as can be purchased at grocery stores for transporting and storing moisture samples. The metal cans were superior for sample storage especially when new. These cans are reusable but the lids become noticeably looser with repeated use and ultimately must be discarded. They also have the disadvantage of being heavy and bulky to store and transport. Zip-lock bags are inexpensive, compact, and easy to use. Double bagged, freezer-type zipper-sealed bags are adequate for storage of no more than three days. Recently quart-sized plastic cans with plastic lids have been available at a competitive price. Unpublished data obtained at the Cotton Ginning Research Unit in Stoneville, MS, has shown that these cans are as good as metal cans for storing the samples and the lid seal does not deteriorate as rapidly as metal cans. A word of caution on using rigid cans: if containers must be shipped across country, changes in elevation put additional pressure on the cans leading to greater chance of leakage. In such cases heat-sealed freezer bags with fast transport times are preferred. Any container should be protected from direct sunlight while being transported and should not be shipped by air. Both cans and plastic bags have arrived opened after air transport presumably because of pressure changes due to extreme drop in pressure at 30,000 ft that the planes fly at with cargo stored in unpressurized holds. Even modest elevation changes that occur when shipping from sea-level locations to higher elevations are cause for concern.

Process Control Issues. In many situations it is beneficial for the gin to automate control over a process such as drying. This can be done by installing sensors that automatically assess cotton MC and automatically adjust the burners to provide optimum efficiency and MC. This is termed closed-loop control (for more detail please refer to the Controls chapter). When sensors are used to close the loop on gin machinery, a key requirement is for the sensor to provide a stable and slowly changing repeatable reading. For process control, the precision of the sensor should provide at least a dynamic range of 100:1. In many cases this requirement outweighs the need for accuracy, as the process control system can become unstable. For this reason, some sensor manufacturers emphasize stability, even if they produce a sensor with less than optimal accuracy. Thus, it is important to know when you are using that type of sensor, so you can run spot-checks with another off-line meter or sensor to establish the actual MC to ensure you are not producing a product that is too wet to enter into the marketplace. Note that sensors fail over time and can output readings that are not representative of the actual process variables being measured. It is critical for gin personnel to periodically check their sensors to ensure they are working within the manufacturers designed specifications. This can be done with off-line hand-held meters. For sensors used in closed-loop process control it is critical to test them frequently to ensure they are operating within specifications. Failure to do this has been known to produce numerous non-sellable bales, which in turn cost producers and gin lots of money. In extreme cases, this can lead to significant lawsuits and loss of future business to the gin.

PHYSICAL PRINCIPLES USED FOR MOISTURE MEASUREMENT

By applying basic physics to the measurement of the amount of water in materials, scientists have developed both direct methods of sensing water and indirect methods relying on surrogates that are highly correlated to the water content. The main direct and indirect techniques are discussed below.

Gravimetric Standard Method for Moisture Content Determination (Oven-based). The basic direct measurement principle used in determining the MC of a sample is the standard oven drying or gravimetric method. This method compares the difference between the original sample's weight to its weight after it has been dried in an oven. In this approach, the only part of the sample that is lost is water (with some trace, 0.1-0.2%, loss due to other volatiles lost in drying process); hence, the greater the sample weight change, the higher the amount of water in the original sample, thus, the sample is at higher MC.

Two standard methods have been developed for the gravimetric oven method of MC determination of cotton: the method documented by Shephard (1972) and the American Society for Testing and Materials (ASTM) standard D2495—Standard Test Method for Moisture in Cotton by Oven-Drying (ASTM, 2012a). The ASTM standard is more detailed and complete than the Shephard publication and includes several variations. Shepherd documented the actual procedures as performed at the U.S. Cotton Ginning Laboratory in Stoneville, MS, more accurately than the ASTM standard. However, the ASTM standard includes not only the calculation of a WB MC (the only value described in the Shepherd procedure), as well as moisture regain, which is the MC dry basis, and formulas to convert MC from one basis to the other. It should be noted than many other industries only use dry-basis reporting, so it is important to keep the different reporting metrics in mind. The two MC reporting method values are calculated as:

MC = (OW - FW)/OW

MR = (OW - FW)/FW

Where: OW = the original (wet) weight of the sample,

FW = the final (dry) weight of the sample after proper oven drying,

MC = the moisture content (MC WB), and

MR = the moisture regain (MC dry basis).

The ASTM standard calls for the oven to be in the range 105±2 °C (221±3.6 °F), whereas the Shepherd procedure specifies 220 °F to 230 °F, which is equivalent to 107.2±2.8 °C, which are overlapping ranges and nearly the same. Both procedures call for drying the specimens "for 1 h or until the change in mass between successive weighing's at intervals of at least 15 min. is less than 0.1% of the specimen weight" (ASTM, 2012a; Shepard, 1972). Typically, the time required to dry samples above 7% MC is at least 1 h 20 to 30 min. It is important not to greatly exceed these times as the trace volatiles that are lost increase leading to larger errors. The ASTM standard calls for specimens of at least 5 g, whereas Shepherd calls for 20-g specimens. In practice one should avoid samples less than 20 g and although processing time should be minimized to avoid lint losing or gaining moisture from air, all samples processed should be at or near to the target 20-g sample size. A similar protocol is also available for seed cotton.

Byler (2004a) examined the use of 20-g specimens compared to 1-, 5-, and 10-g specimens. The means of the MC determined using the different specimen sizes were not significantly different. However, smaller specimens required a larger number of specimens to obtain the same level of confidence in the average MC reading. Note that if an approximation is made by weighing the samples hot out of the oven instead of following the standard method that weighs the samples in the oven, the use of 20-g samples will be important to minimize the buoyancy error. Even then, the buoyancy effect will likely cause a bias in the data of 0.5% MC or more. This approximation method is easier because it does not require expensive ovens, is more convenient, and for most cases, the bias is consistent and within 0.5% MC ,which is sufficient for gin operations. The reference for weighing hot outside the oven is provided in Funk et al. (2018). Byler's (2004a) test reported that seven, 1-g samples were found to result in the same confidence in MC values as three, 20-g specimens, while consuming 12% as much cotton. However, the smaller specimens required more care in handling and processing and seven specimens require more labor and oven space than three, so if adequate material is available, the use of 20-g specimens is preferred. However, if there is a limited amount of cotton available then the 1-g specimens could be used if sufficient replication testing is performed.

Resistance Sensing of Moisture. Resistance sensing of moisture is an indirect method that relies on the physical principal that when water is introduced into cotton fiber, the water provides a lower impedance pathway for electrons passing through the cotton, which lowers the resistance to electrical flow that can be measured easily with a meter. Resistance-based meters (Fig. 4) have been used for many years in the cotton industry (Leonard, 1964). The resistance of the cotton sample is usually measured between two points at a fixed distance and has been found to be highly correlated to the MC. The resistance increases exponentially as the MC decreases (Byler, 1998), which makes higher MC easier to measure, with lower resistance in the k-Ohms. Conversely, as MC drops, the resistance increases exponentially; as MC approaches and drops below 4% the readings are increasingly less accurate as the resistance climbs into elevated G-Ohms region where it is progressively harder to measure as the current through the meter drops to and below pico-amp range. For practical gin usage, a sample at MC 4% or below is dry and there is no need to assess the difference. An assessment of resistance-based hand-held meters was performed in a joint USDA-Agricultural Research Services' cotton ginning research laboratories evaluation for use on estimating MC of cotton bales (Byler et al., 2009; Byler, 2012, 2013, 2014).

Temperature influence on resistance sensing of moisture. Resistance of cotton has been found to be temperature sensitive, with an increase in temperature resulting in lower resistance. Typically, the resistance meter will have been calibrated at normal room temperature. If cotton is at a temperature different from the calibration temperature, a correction equation should be applied to obtain the correct moisture estimation. Consult the instruction manual for the meter for the specific correction equation to apply.

Surface moisture influence on resistance sensing of moisture. As cotton becomes dry, the resistance becomes so high that any alternative stray pathway (e.g., your hands) becomes more influential; hence, it becomes critical that all oils and water from sweat are eliminated from the sensing area and cotton sample under investigation. The use of an insulated holder, or gloves, to remove the hands from the sensing region is advised when measuring samples.

Sample pressure influence on resistance sensing of moisture. Resistance-based meters measure the conductance of the sample when held between electrodes. With cotton resistance sensing if pressure increases on the sample, conductivity will increase thereby changing the reading. This effect is caused by more fibers being pressed onto the conducting electrodes, thus more fibers become available to conduct current, which in turn leads to a lower resistance. For this reason, it is important to use the same or similar pressure on the sample that was used to calibrate the meter. Best results are obtained by using a static, nonconducting weight to apply a uniform and repeatable pressure to the lint when pressing the cotton sample onto the electrode sensing region.

Microwave Sensing of Moisture. Microwaves can readily pass through nonconductive materials such as cotton lint and seed cotton. With other materials such as water, the electro-magnetic field induces oscillations in the water molecules that result in the absorption of energy. In moisture sensing, the power required to sense moisture is low (much lower than that used in modern cell phones), so there is no danger from their use or by standing in close proximity to the active antennae of the systems. Further details covering the principals for using microwaves to measure MC of seed cotton can be found in Pelletier et al. (2016). There are several advantages to using microwave energy for MC estimation: (1) microwaves do not respond to many other properties of the material or mix of materials; (2) microwaves pass through the material, so surface plus interior moisture is measured; (3) microwaves pass through air easily, so the meter does not need to be in contact with the material being measured; (4) microwave measurements can be fast, fractions of a second; (5) microwave sensors on conveyor lines can provide an image of the interior moisture; and (6) microwaves are reflective, so care should be taken to minimize metal reflectors in the vicinity of the sensors.

Temperature influence on microwave sensing of moisture. Water molecules become more active on fibers as temperature increases and as a result the response to the microwave signal is altered. Care should be exercised to maintain consistence bale temperatures for optimal use. Consult the manufacturer of the instrument for details on how to compensate for the effect of temperature on the readings.

Surface moisture influence on microwave sensing of moisture. Microwaves respond to absorbed water in and on the fiber; however, this response is much less on water that is absorbed onto the fibers than it is for water drops on the surface of the cotton. Hence, the sensor will respond differently if the cotton has water droplets on it than if it is well assimilated into the cotton fibers. The response will increase much faster with surface moisture, so there will be a significant difference in calibration, so care should be exercised if this is the case. Further details on principals and techniques used to measure MC via microwave sensing were reported in Pelletier and Barnes (2008) and Pelletier et al. (2010, 2016). It should also be noted that if free water is present on the fiber, it is likely the bale is being conditioned to well past the safe MC range.

Sample density influence on microwave sensing of moisture. The microwave system works by inducing oscillations of water molecules, whereby samples with more water molecules result in a progressively stronger signal to the measuring instrument. Hence, heavier bales will be measured as being wetter than light bales for bales at the same MC.

Operational issues affecting microwave sensing of moisture. (1)Microwaves are polarized by the transmitting antenna and interact with the layers in the bale. Given this, it is important to ensure the bale is properly aligned when conveyed past the sensor, does not wander from side to side or vary from one bale to the next bale, and that it tracks true as it is conveyed past the measuring antennae. (2) Microwave frequencies and filters inside the sensors vary by manufacture so care should be exercised when deploying these sensors to ensure there is no interference with other signal generators, such as other wireless sensors, wireless internet, radios, or cell phones. Depending upon quality of the internal frequency filtering of the system, some instruments can handle extraneous radio frequency interference, others opting to provide lower-cost sensor options to customers cannot and can result in periodic sporadic readings. Other potential causes of sporadic readings could be loose antenna cable connections or broken or cracked cables. As with any sensor, periodic quality control is important. (3) Microwaves are reflective so care should be taken to minimize metal reflectors in the vicinity of the sensors and to ensure that once the system is setup, nearby reflectors do not move.

Near-Infrared Light (NIR) Sensing of Moisture. Light energy in NIR is absorbed by different materials in well-defined, narrow frequency bands. Thus, these meters can be used to estimate the amount of such materials in a carrier product by including specific wavelength bands at which water absorbs the energy. This method is similar to how the eye detects the amount of chlorophyll in a plant leaf: chlorophyll absorbs most of the red and blue light, reflecting the green light back to your eye, so you see the leaf color as green. Similarly, higher levels of water content result in greater absorption of specific wavelengths in the NIR spectrum. Often meters are designed to emit and measure energy at several frequencies: one or more frequencies at which water absorbs the energy and one or more frequencies at which water does not absorb the energy. This combination of frequencies makes the meters more sensitive to changes in moisture and less sensitive to other changes in the material, variations in ambient light, and the meter's internal light source. One key point to recognize is that because light interacts only with the surface of the material, NIR measurements can only measure the surface MC of the material; it cannot determine the MC throughout a large mass of material. It is important to recognize that orientation of the surface of the material to the sensor should be fixed as changes in the orientation can affect the readings. Consistent presentation to NIR sensors is critical to obtaining repeatable results.

Sample surface influence on NIR sensing of moisture. NIR measurements are sensitive to surface preparation. As such it is important to follow the manufacturer's direction in their use. For use on free-flowing cotton, it is likely that in-situ calibration will be required and that attention to minimizing changes in the conditions are addressed.

Geometry influence on NIR sensing of moisture (angle of light and detector). NIR measurements are sensitive to variation between the angle of the light detector and the sample. Hence, care must be taken to ensure that this angle remains consistent and is within specifications provided by the manufacturer. Undulating waves in the cotton bats coming off the battery condenser should be minimized by moving the sensor as close as possible to the output rolls to minimize the distance variation between the bat and the sensor.

Ambient room lighting influence on NIR sensing of moisture. Best results will be obtained when limiting the light to that provided by the manufacturer. Ideally, the sensors would be placed inside a light shield. If this is not possible, the sensor should be tested for consistency across the expected variation in ambient lighting.

Trash content influence on NIR sensing of moisture. NIR measurements only measure the close surface of the fibers; thus, they are sensitive to what is on that surface. As trash levels increase on the lint, calibration can be affected. Different results and a degradation in accuracy occur when using NIR on seed cotton as opposed to lint. This effect is more significant in stripper harvesting areas where the trash contents are significantly higher.

MATERIALS, SAMPLES, AND MEASUREMENT INSIDE PACKAGED MATERIALS

Seed Cotton. A MC reading of the seed cotton before the drying begins is helpful. It can be used to quickly turn the burners up if wet cotton is nearing the dryer, in fact it can be difficult to raise the burners fast enough when a wet spot follows relatively dry seed cotton. It is of questionable importance to measure the MC of seed cotton after any MC change has been imposed because of the imbalance in MC between seed and lint. Several commercial systems are available for seed cotton MC estimation and can be installed before the module feeder head, in the module feeder disperser head, or at the feed control of seed cotton moving on a belt. The ideal place for MC measurement is as far out in front as is practical as it provides the ginner more time to raise the temperatures and heat up the pipes. A new alternative now becoming available is the use of MC data from the cotton picker that could give an even earlier warning of approaching higher MC seed cotton. Several companies offer meters for the measurement of seed cotton MC.

Lint. The best single place to measure MC for optimal operation of the gin plant is immediately after the gin stand. Lint MC readings are more repeatable than seed cotton readings and any damage done to the lint related to MC is done primarily in the gin stand plus some in the lint cleaner/s. The location immediately after the gin stand is near both crucial pieces of equipment. The MC readings at this location can be used to fine tune the drying to keep the lint MC near the desired MC. However, some allowance must be made to allow a rapid increase in burner temperature when wet seed cotton follows dry seed cotton because measurements at this location will not provide adequate response.

Seeds. In ginning seed, MC is not normally measured, however it is critical to ensure the seed stays dry to ensure the gins can handle the seed cotton. It is also important seeds stay dry to ensure they do not degrade in storage. It is important to ensure the seed houses stay leak free and that trucks do not haul seeds during significant rain and snow events.

Module. The most important MC level for gin operation is the module moisture. Cotton that is too wet will significantly impact the ability of the gin to clean the cotton and in severe cases will prevent or significantly slow down ginning. Measuring module MC can be done using microwave sensors. This is common practice in Australia, yet this valuable technique has yet to find widespread adoption in the U.S.

Bale. For the marketplace, the most important MC level is that in the bale produced by the gin. If this MC level is too low, the bale will gain weight during storage, but damage due to MC would not be expected. If this value is too high, the bale weight will decrease during storage and the quality of the lint will decline, especially in color. Wet cotton has always been unacceptable for the Commodity Credit Corporation Marketing Assistance Loan Program, but wet cotton historically was not well defined. In 2006, the Farm Service Agency of the USDA issued a definition of wet cotton as a bale with lint MC at the gin greater than 7.5% WB at any point in the bale (Federal Register, 2006). The issuance of this definition sparked increased interest in measuring lint MC in the bale.

MOISTURE MEASUREMENT DEVICES

Portable Moisture Meters. Several portable moisture meters based on the resistance moisture principle are currently available for use in cotton gins. They can be used with loose seed cotton, loose lint, and lint in bale form using different electrodes.

Seed cotton (loose). Resistance-based moisture meters respond to the MC of the material in contact with the electrodes plus the material conducting the electric current between the electrodes. Most of the current flowing during measurement passing through the lint and the seed is completely surrounded by lint, therefore the reading is based on the MC of the lint, whereas the MC of seed in moisture equilibrium with that lint will have a MC somewhat higher. So, for more accurate estimation of seed cotton MC, a separate calibration scale should be used than the calibration scale used for lint. Currently this is the only technology in use for determination of loose seed cotton by a hand-held meter.

Lint (loose or in bat form). Resistance-based meters are often used to measure the MC of ginned lint. Because the lint is loose, greater contact pressure results in lower probe-lint resistance and pressing on the sample results in lower fiber-fiber resistance, both of which result in higher MC readings. Therefore, it is important to use firm and repeatable pressure between the lint and the electrodes. Some meters use a cup for one electrode with a metal protrusion in the middle of the cup for the other electrode, whereas other meters use two needles for the probes.

NIR sensors used in the control of moisture restoration systems monitor the cotton lint bat as it comes out of the battery condenser just before the bale press. Due to presentation issues and dust contamination of the optics, this technique is not in widespread use. Its use has been supplanted in recent years by modern microwave bale moisture sensors.

Installed Moisture Meters. Moisture meters that are permanently installed in a gin are more convenient for continuous monitoring of the process than hand-held meters. At some gins, the meters are used for control by the ginner choosing the drying temperature based on the meter. At other gins, the meters are electronically connected to an automated system that controls the drying and possibly the moisture restoration system. High accuracy of the meter is not required but repeatability is more important. Drying can be controlled adequately with an inaccurate meter by judging the final MC and adjusting the drying relative to that meter reading appropriately.

Module moisture sensors (seed cotton). Due to the large size of bulk packaged seed cotton, the only available technology that can measure MC of cotton inside the module is a microwave sensor. To date in the U.S., this technology has not gained widespread use, although it has in Australia. This is an active area of research in the U.S. that is being further complicated by the rapid adoption of round-module technology.

*Bale moisture sensors (lint).*Two main technologies are available for assessing bale moisture: resistance hand-probe meters and microwave bale-scanning systems. A study by three USDA cotton ginning laboratories was conducted to test accuracy of resistance hand probes. In this study, seven commercially available portable cotton bale MC meter-probe combinations were purchased by each of the three Agricultural Research Service cotton ginning research units and examined for precision and accuracy when used with commercially ginned cotton (Byler et al., 2009). The devices were used to measure the MC at the same six locations on a total of 96 cotton bales. Lint samples were obtained from the same locations in the bales for MC determination by the oven method resulting in more than 7,000 readings with corresponding reference MC values. Based on oven MC, the lint samples had MC in the range 2.3 to 9.4% WB. The oven-MC WB for different samples in the same bale had a standard error from 0.15 to 0.42% WB. The different meters produced significantly different readings from each other, and these were significantly different from the oven-based MC. Most of the meters were found to have a significant offset from the oven-based MC ranging from -3.3 to 3.3 percentage points. However, the standard deviation of the difference between the individual readings of the meters and the oven-based MC resulted in estimates of precision of plus or minus 1 percentage point for most of the individual meters. The precision of the meters was found to be plus or minus 0.8 percentage points or worse, with most of them at least plus or minus 1 percentage point. This is a problem considering that the range of interest for application of these meters would be approximately 3 to 9%.

These hand-held cotton bale moisture meters are useful for a general indication of the bale MC and to monitor whether the bale MC was rising or falling as adjustments are made in a gin, but cannot be recommended for more important applications such as pricing cotton bales or ensuring bales are dry enough for safe storage. Their use in combination with moisture restoration systems also can lead to increased errors as any surface moisture will significantly degrade the accuracy of the meters. This was noted in an internal, unpublished study that was conducted to assess the accuracy of commercially available, microwave bale-moisture sensors in use at commercial cotton gins. Over a three-year period, Byler (2012, 2013, 2014) studied the performance of an installed, paddle sampler-based meter that automatically measures MC using a resistance-based sensor. The study determined that if the sensor was located before any moisture restoration, it worked well. However, the addition of moisture, via moisture restoration, had the effect of adding enough surface moisture to the lint that the readings became unreliable, and thus it is the recommendation of the authors that resistance sensors should be avoided or used with caution for determination of MC at the bale packaging station for gins using moisture restoration systems.

Research is on-going into investigation for performance of microwave sensors for use in determination of bale moisture. To date, experimental data are not available to determine suitability of these systems for use in detection and measurement of bales at damaging levels of moisture greater than 7.5% MC. As such, care in their use is cautioned especially when used to close a control loop to control a moisture restoration system. As with any feedback control system, sensors can and do fail and it is of utmost importance to ensure quality of the product using alternative measurements.

SUMMARY

Moisture measurement is a key control variable for proper cotton gin operation. Cotton that is ginned too wet will create bales with poor grades and poor fiber quality that will not spin well due to the high nep counts created by ginning the cotton at too high of MC. Further, cotton bales degrade and change color grades when placed into storage at MC above 7.5% (Fig. 1), hence, it is critical to the protection and preservation of U.S. cotton that bales are not generated above this threshold MC value. It should also be noted that any bales going into the Commodity Credit Corporation loan program requires bales to be less than 7.5% MC at any point inside the bale. The proper use and maintenance of various moisture sensors and meters that were discussed in this chapter, will ensure a gin will operate in an optimal manner and produce bales that are suitable for sale into the global marketplace.

DISCLAIMER

Mention of a product or tradename in this article does not constitute an endorsement by the USDA-ARS over other compatible products. Products or trade names are listed for reference only. USDA is an equal opportunity provider and employer.

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