

COTTON MOISTURE – ITS IMPORTANCE, MEASUREMENTS AND IMPACTS

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Cotton moisture impacts cotton from field to fabric. The proper control, and measurement to allow for control, of cotton moisture is essential to maintaining and preserving fiber quality. Cotton color, length and strength; as well as other properties, are all impacted by cotton moisture content. There are many ways to measure cotton moisture and many points in the production chain in which the moisture should be measured. Technologies have been developed to allow for cotton moisture monitoring and control in the field, during harvest, seed cotton in storage, the ginning process and into the textile mill and quality testing laboratories. Options allow for a range of product states, locations, costs and needed accuracy to be considered in determining the ideal method to measure moisture content of cotton.

Moisture is an important attribute in the trade of cotton due to not only its impact on bale weight but also the potential impacts on fiber quality and processing. Fiber moisture is important in all aspects of cotton production, from moisture content of the seed cotton during harvesting, storage and ginning through warehousing, shipping and textile processing. Excessively high moisture content can lead to deterioration of seed cotton quality and cause discolored lint and spoiled seed. However, low moisture content of seed cotton can lead to fiber breakage and an overall reduction in fiber quality during harvesting and ginning. Ginners must control the moisture content of cotton carefully to facilitate cleaning and ginning while minimizing fiber damage. Moisture content of the ginned lint is important as too low of a moisture content requires excessive energy at the bale press and too high a moisture content can lead to deterioration of the fiber quality during storage from microbial activity. Temperature and humidity controls are important during textile processing to aid in the cotton fiber performing optimally.

As important as cotton moisture is throughout the production chain, the measurement of cotton moisture is not a simple issue. There have been vast quantities of research on measuring moisture of seed cotton and ginned lint. Measurement of seed cotton is complicated by the presence of non-lint content and cotton seed which have inherently different moisture contents than the lint. Ginned lint measurement is complicated by the presence of foreign matter, mass effects, and the natural convection of warm air and other volatiles present on the fiber in addition to moisture.

THE IMPORTANCE OF COTTON MOISTURE

Harvesting and ginning

Cotton is a perishable crop, especially prior to ginning. Proper moisture control begins during harvesting (Anthony and Byler, 1998; van der Sluijs and Long, 2015). In areas where cotton is handpicked there may be a temptation to begin picking cotton while the cotton is still damp from morning dew as the cotton will weigh more. In areas where machine harvesting is the norm there is also a temptation to begin the harvest as soon as there is

enough light to enter the field. Contract harvesters may be motivated to get as many acres harvested as possible in a day and even producers who own their own equipment are motivated to get maximum use of their harvester. No matter the harvest method, cotton that is picked with excessive moisture content is at risk of losing quality during storage, as well as causing problems with the harvesting equipment by sticking to machinery and causing blockages to build up inside equipment.

Conventional machine picked cotton has been stored in modules which are covered with tarps to minimize quality deterioration from rain or harm to the module from wind. New developments of on-board module builder equipped harvesters, such as the John Deere CP690 (Deere & Company, Moline, IL, USA), produce modules which are better protected from the elements. While the round modules produced by the John Deere on-board module builder harvesters are surrounded in a plastic wrap that may better prevent moisture from entering the module; that same packaging material may prevent excess moisture from leaving the module as well. The round modules have been shown to better preserve the quality of the seed cotton allowing for longer-term storage prior to ginning, but only when the seed cotton has been harvested at proper conditions (van der Sluijs et al, 2015). Recently there have been new developments to equip cotton harvesters with moisture sensors, such as the Vomax Model 760 (Vomax Instrumentation Pty. Ltd., Adelaide, Australia) to enable producers to monitor the moisture of seed cotton during the harvest.

Proper moisture control during harvest and storage of seed cotton impacts the efficient operation of the cotton gin. As seed cotton is fed into the ginning plant it is subjected to drying to facilitate the removal of non-lint content. Excessive moisture, as well as very variable moisture, causes the gin plant to operate inefficiently. Excessive moisture increases energy costs to the gin by requiring more drying. Variable moisture can cause the gin plant to erratically increase and decrease fuel usage as the equipment is “chasing” the proper moisture content of the cotton. Increased fuel use and energy costs add to the cost of ginning the cotton, so in addition to potential harming the quality of the lint and thereby reducing the economic value of the ginned lint, the cost of producing the ginned lint is also increased (Boykin, 2005; Byler, 2006; Gordon et al, 2011). Proper air temperature sensor placement in the gin is an important factor in efficiently controlling the fuel-usage and drying at the gin, in addition to controlling the moisture during harvest and storage.

Testing

The economic value of ginned lint is assessed by various testing methods. The control of the moisture content of cotton during testing is important as the hygroscopic nature of cotton allows for many fiber properties to vary in response to the ambient environment (Morton and Hearle, 2008). ASTM D1776-15 is the recognized guide for conditioning and testing textiles, including cotton fiber. The ASTM standard calls for a temperature of $21\pm 1^{\circ}\text{C}$ and $65\pm 2\%$ relative humidity when testing cotton fiber and a relative humidity specification of $65\pm 5\%$ for testing yarns and fabrics. Some laboratories utilize ISO 139:2005 which calls for a temperature of $21\pm 1^{\circ}\text{C}$ and $65\pm 4\%$ relative humidity. The strength and elongation measurement of cotton fiber is subject to change based on moisture content, with other physical measurements subject to a lesser amount of change.

Processing

The textile industry recognizes the importance of moisture control during processing. Standard practice across the textile industry is for bales within a laydown to be opened and

allowed to equilibrate prior to being processed. Proper control of environmental conditions during processing is important to the effective and efficient processing of cotton fiber. As moisture content of cotton lowers the fiber becomes more brittle and subject to damage during processing. Also, as relative humidity lowers static electricity can begin to build which may lead to fibers wrapping on rollers or failing to doff properly which will have a negative impact both on processing efficiency as well as product quality. Conversely, if relative humidity is allowed to increase too high there are potential problems with the fibers drafting and doffing properly as well as the propensity for blockages in the duct work.

Dyeing and finishing can ultimately be affected by poor moisture control of the fiber. Color changes due to improper moisture control in seed cotton and ginned lint may still cause shade variation in the final dyed and finished fabric. These color differences may not be noticeable until after dyeing and finishing and lead to claims against suppliers. Proper control of cotton color in the laydown may be thwarted by bales which did not have proper moisture control from the beginning.

THE MEASUREMENT OF COTTON MOISTURE

Measurement of cotton moisture is not an easy task. The variable nature of the fiber, the inclusion of non-lint content and the presence of volatiles besides water all serve to confound the measurement of cotton moisture content. It is imperative for good quality that cotton moisture be monitored in seed cotton form, during ginning and prior to testing of ginned lint. The need to measure cotton moisture in various states of cotton and various types of locations requires a wide arrange of techniques and abilities with the need ranging from in-situ measurement of cotton moisture in the field through measurement in a laboratory.

Seed Cotton Measurement

Seed cotton may be measured on the harvester by microwave sensors, such as the Vomax Model 760 (Vomax Instrumentation Pty. Ltd., Adelaide, Australia) in real-time during harvesting. Alternatively, a producer may utilize a handheld electrically based moisture meter, such as the Delmhorst 52-E/C (Delmhorst Instrumentation Co., Towaco, New Jersey, USA), often using a cup shaped electrode to hold the seed cotton. If seed cotton moisture is to be measured in a laboratory environment then an oven-drying method (Shepherd, 1972) or even a laboratory microwave-based method, such as the Aqua-Lab (Mesdan S.p.A., Brescia, Italy).

Measurement at the Gin

As previously stated, measurement and control of cotton moisture at the gin is paramount to maintaining quality. The placement of temperature sensors to control the drying of the seed cotton is a complex issue devoted to many reports on its own. Careful use of drying at the gin is needed to reduce energy costs but also to preserve fiber quality and not scorch the lint due to excessive temperatures. Many of the issues of moisture measurement during ginning are addressed in the Cotton Ginners Handbook (Anthony and Mayfield, 1994). Gin control systems such as the Intelligen (Uster Technologies AG, Uster, Switzerland) use electrically-based sensors to measure moisture content during and after the ginning process. Many diverse systems, such as the Moisture Mirror and Tex-Max (Samuel Jackson Inc., Lubbock, Texas, USA) and the Vomax 851 (Vomax Instrumentation Pty. Ltd., Adelaide, Australia) can be used to monitor moisture content from the module through to the finished bale. Numerous

handheld instruments can be employed, with varying accuracy, to measure the moisture content of the final ginned and baled lint. The same laboratory environment methods that may be used on seed cotton are viable on ginned lint as well.

Measurement in the Laboratory

Drying the fiber at a specific time and temperature, better known as the oven drying moisture measurement method, remains the primary moisture measurement method used internationally (Montalvo, 2008). The oven method is a standard test method (ASTM D2495-07) and is largely based on the USDA developed method (Shepherd, 1972). There are several terms used to express the moisture present in fibers and yarns by the oven method, but the two primary terms are moisture content (MC) and moisture regain (MR). MC is calculated by determining the weight difference between the original fiber weight and dried fiber weight, then dividing that difference by the original fiber weight to obtain MC (%). MR is calculated by determining the weight difference between the original fiber weight and dried fiber weight, then dividing that difference by the dried fiber weight to obtain MR (%). The oven method is a low cost and easy to use method, but there are concerns. Primarily, drying the sample at temperatures $>100^{\circ}\text{C}$ can remove more than just water present in the fiber and can lead to oxidation volatiles (Montalvo, 2010; Cheuk, 2011; and Fortier, 2014).

Although the oven method is the most common method, there are numerous diverse moisture measurement methods in use internationally, involving the use of many different technologies. These various moisture measurement techniques may be grouped into four categories: weight loss (gravimetric), chemical, spectroscopy, and electric. With a wide and diverse selection available, which moisture technique is best? The answer depends on the user's technical needs (accuracy, precision, analysis speed, etc.), logistics needs (number of samples measured at one time, ease of use, technical skills required, etc.), and cost constraints. An extensive comparative evaluation was performed on 15 instruments representing the four instrument groups (Rodgers, 2014). The small gravimetric weight loss units (oven and halogen lamps), the KFT instrument (chemical method), and the two NIR instruments (spectroscopy methods) yielded the best overall moisture method agreement. The inexpensive, hand-held, portable electric moisture instruments performed the worse, exhibiting the highest number of outliers overall.

Water-Specific Reference Method

A reference method has been developed for cotton fiber moisture, in which the moisture analysis is specific for water only. This chemical method is the Karl Fisher Titration (KFT) method (ASTM D7785-12), as shown in Figure 1. As noted previously, the gravimetric oven drying methods for determining the cotton fiber MC are not specific for the water content present in the fiber, as drying the sample at high temperatures can remove more than just water present in the fiber. Drying the fiber with moving air can also lead to the formation and removal of volatile oxidation products and the removal of dust and trash particles (Montalvo, 2010; Cheuk, 2011; and Fortier, 2014). In the KFT method, the fiber is placed into a weighed vial, sealed, and heated to evaporate the water in the fiber. The water vapor is transferred to a reaction cell and titrated with a chemical reagent to yield a reaction that is specific only to the water transferred from the fiber. Thus, the water-specific KFT reference method minimizes many of the concerns noted previously with oven drying.



Figure 1. Set-up for the KFT fiber water content measurement.

Microwave Moisture Measurements

The availability of microwave-based instruments for fiber and yarn moisture measurements is increasing. Microwave instruments offer the capability for very rapid and accurate fiber and yarn moisture measurements at a cost less than typical NIR instruments. The Aqua-Lab instrument (Mesdan S.p.A., Italy) received recognition from the ITMF International Committee on Cotton Testing Methods (ICCTM) in 2014. The Aqua-Lab (Figure 2) performs rapid microwave analyses on between 100-150 grams of cotton fiber and yields the fiber's MC, MR, and commercial weight. For fiber measurements, the instrument is normally calibrated with the Scirocco oven system (Mesdan S.p.A., Brescia, Italy)



Figure 2. Mesdan Aqua-Lab instrument, with fiber and yarn modules.

A comparative evaluation was performed to determine the full capabilities of the Aqua-Lab to rapidly and accurately perform cotton fiber MC measurements. The Aqua-Lab was calibrated using both the vendor recommended high capacity Scirocco oven unit and the oven drying method used by the United States Department of Agriculture, Agricultural Research Service, Southern Regional Research Center (USDA, ARS, SRRC) facility at New Orleans, LA, USA. For method agreement, two outlier ranges were used: % $>\pm 0.3\%$ MC (tight limit) and percent $>\pm 0.5\%$ MC (commonly used range); the target was $<30\%$ of the samples being outside of both limits. Overall, very good method agreement was observed between the Aqua-Lab MC results for both the Scirocco and SRRC oven calibrations, as shown in Table I for the SRRC calibration. The Aqua-Lab MC measurements were very fast, accurate, precise, and the instrument easy to use.

Table I. Aqua-Lab MC results, SRRC oven reference.

PARAMETER	SRRC OVEN MC (%)	AQUA-LAB MC (%)
AVERAGE	6.38	6.36
SDD	na	0.35
n	28	28
% Greater Than $\pm 0.3\%$ MC	na	25%
% Greater Than $\pm 0.5\%$ MC	na	7%

THE IMPACT OF COTTON MOISTURE

The impact of cotton moisture is difficult to overstate. Cotton is sold on a weight-basis and moisture content impacts the weight of the bale, therefore at the very heart of the cotton trade, moisture content has a major impact. As previously discussed, cotton moisture is essential to the preservation of quality from the time the cotton is in the field until the bale is processed into yarn and fabric. Cotton moisture impacts color, length and strength in a variety of ways. Testing of the textile products require good moisture control in order for test results to be properly understood and compared. Proper moisture control preserves and maintains the quality of the ginned lint and all of the many products produced from cotton.

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