Moisture in cotton – the fundamentals

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The level of moisture in seed-cotton at harvest through to the level in baled lint can have significant effects on the quality of fibre sold to the spinning mill. There are optimum moisture levels for seed-cotton and lint for each harvest and ginning process that allow good and efficient harvesting, cleaning, ginning, baling and safe storage.

To optimise processing and fibre quality the amount of moisture taken up or lost by cotton needs to be balanced with an appropriate amount of drying or moisture application during the pre-cleaning, ginning and baling processes.

It is well known that cotton with an acceptable moisture level has improved fibre tensile properties resulting in greater strength, extensibility and work-to-break values. These effects make cotton fibre more resilient during ginning and lint cleaning, and less prone to damage.

Dry cotton is easier to clean but will be damaged during ginning and lint cleaning. On the other hand, cotton with excessive moisture is difficult to gin and clean, and will degrade during storage.

This article is the first in a series of reviews on the management of moisture and fibre quality in cotton from harvesting through to bale storage in warehouses. Its aim is to provide growers, ginners and merchants with an up-to-date and concise collection of information on the subject of measuring and managing fibre quality during early stage processing and shipment.

In this first article the fundamental relationships that determine the extent and rate of moisture absorption (or more correctly moisture adsorption) and drying in cotton are discussed. The interaction of water at a molecular level and the effects on fibre properties are also discussed and will be used in subsequent reviews on the addition of moisture or humidification of cotton during ginning and baling.

Cotton fibre cellulose and water

As living plant cells, cotton fibres within a growing boll are literally full of water. Water is critical for fibre growth and the availability of water during early boll growth is related to the final length achieved by the fibre.

When the boll matures and opens, fibres lose water and equilibrate with the ambient humidity. Both constituents of seed-cotton – fibre and seed – are hygroscopic, for example sensitive to moisture, but to different degrees. For example, if seed-cotton is placed in air of 50 per cent relative humidity (rh) and 21°C:

- The fibres will tend to reach a moisture content of approximately six per cent;
- The seed will tend to reach a moisture content of about nine per cent; and,
- The combined moisture content will be around eight per cent.

In its mature dried form, nearly 90 per cent by weight of the cotton fibre is cellulose. In fact the cellulose found in cotton fibres is the purest form of cellulose found in all plants. The cellulose in cotton fibres is mostly (88–96.5 per cent) α-cellulose. The non-cellulose components (4–12 per cent) are located either on the outer layers of the cotton fibre in the cuticle and primary cell wall or inside the residual protoplasm called the lumen. The secondary wall of mature fibres is primarily cellulose in its most highly crystalline and oriented form (see Figure 1).

Figure 2 shows the structure of the cellulose molecules in cotton. From a physical viewpoint the molecule is a ribbon-like structure of linked six-membered rings each with three hydroxyl groups (OH) on the C2, C3 and C6 atoms projecting out of the plane of the ribbon.

As well as providing structural stability the hydroxyl groups allow extensive intermolecular hydrogen bonding with many molecules, including water. The accessibility of water to these hydroxyl groups depends on the spacing between crystal lattice planes. From a completely dry state, water molecules will form hydrogen bonds with hydroxyl groups that are not already linked within crystalline regions.

FIGURE 1: Representation of the structure of a cotton fibre

AT A GLANCE...

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Both constituents of seed-cotton – fibre and seed – are hygroscopic, for example sensitive to moisture, but to different degrees. In this article the fundamental relationships that determine the extent and rate of moisture absorption and drying in cotton are discussed.
As humidity is increased, water will be attracted to these accessible hydroxyl groups. In this respect, available hydroxyl groups will ordinarily be located on the surface of crystalline fibrils, a unit of the cellulose crystal structure. The first water molecules to be adsorbed will be directly attached to hydroxyl groups. Later adsorption may occur on the remaining available hydroxyl groups or form secondary layers attached to already adsorbed water molecules.

Figure 3 is interesting because it shows the change in density of cotton with changes in moisture content. From the dry state the density of cotton increases as empty space (in proximity of available hydroxyl groups) within the cellulose structure fills with water. Direct adsorption of water molecules onto these hydroxyl groups results in more efficient molecular packing and gives an initial increase in density.

The density then decreases as moisture content increases past four per cent, and layers of water molecules in effect dilute the density of the cotton cellulose structure. The relationship in Figure 3 suggests that at moisture contents in excess of five per cent, cotton cellulose is as full of bound water as it can be, and that beyond this level cotton contains more loosely bound water, or unbound water held by surface tension effects such as capillary action.

The shape of the drying and wetting curves (called isotherms, see Figure 4) for cotton are determined by the multi-layer adsorption of water molecules within the cellulose structure. The salient point is that for every combination of ambient air temperature and rh, there are corresponding moisture equilibriums for the seed-cotton, fibre and seed. The equilibrium moisture content at a given rh is also a function of barometric pressure.

The isotherms in Figure 4 show typical rh-moisture content curves for cotton fibre coming from the dry side at three different ambient temperatures. In a standard atmosphere of 65 per cent rh and 20°C, the absorption moisture content of cotton is nominally six to seven per cent.

The rh and temperature traces in Figure 5 show the cycle of transport air temperature and relative humidity in ginning throughout a single day in winter. The traces illustrate the changes in moisture equilibrium during ginning and the increase in moisture overnight. Note that conditions for this particular period were reasonably moist and cool compared with conditions in other years, when rh values typically fall to less than 20 per cent rh and temperatures exceed 30°C during the afternoon.

**Effect of moisture on cotton fibre properties**

Moisture has important effects on the physical properties of cotton – particularly tensile properties and other property descriptions normalised for weight. The increase in strength with increased moisture content is attributed to the release of internal stresses as hydrogen-bonding is weakened and to the ability of the structure to be pulled into a more oriented form.

In one study, at 55 per cent rh, tenacity was 25.8 g/tex and this increased to 29.1 g/tex after conditioning at 75 per cent rh. Fibre crimp, compress-ability and torsional rotation properties are also affected by high humidity.

These properties affect the resilience and toughness of cotton fibres and textiles subject to normal wear conditions. Moisture content also increases with trash content and fibre yellowness.

**The glass transition temperature**

These physical changes in cotton properties with changes in moisture content reflect changes in the glass transition temperature (Tg), which describes the temperature (and rh) where a material changes from being hard and glassy to one that is...
soft and rubbery. The Tg can be estimated in advance by means of the Fox equation.

Whilst the Tgs of synthetic fibres are well known and easily measured, the Tgs of natural (polymer) fibres are less well known. The glass transition temperature of wool has been measured and the temperature and moisture are known to affect the amount of damage during processing and handling properties of yarns, such as snarling and entangling during knitting.

Little has been reported of cotton’s Tg. But recent work at CSIRO suggests there are sound reasons to expect a Tg in cotton and that the implications for ginning cotton could be quite profound. As per the Fox equation, the Tg in natural materials varies significantly with the amount of water in the fibre and this is determined by the external humidity.

It is proposed that keeping seed-cotton or lint near the Tg of cotton could improve the effectiveness of ginning and that these conditions may improve the mechanical properties of the fibre and reduce damage.

To gain some insight into the potential interactions between the ginning process and the fibre properties, some theoretical calculations have been made using the Fox equation and plotted in Figure 6.

The implications of this are that cotton with a moisture content at temperatures less than the Tg will be more prone to damage than fibres with the same moisture content but processed at temperatures greater than the Tg. Practically, this means cotton will be more resilient if it is processed under warmer, more humid conditions, as defined by the Tg line in Figure 6.

**Rate of drying**

Dry cotton placed in damp air for long periods will gain moisture, and wet cotton placed in dry air will lose moisture. The rate of adsorption and drying of water with change of humidity is very fast for an isolated fibre or small bundle of fibres. For denser assemblies of fibre, the changes are much slower and involve complex interactions between the rate of diffusion of water molecules and the evolution and transmission of heat of sorption – for example, the action of water vaporising and detaching from the surface of cotton cellulose produces a temperature rise.

The diffusion gradient between the fibre assembly and the surrounding environment (rh, temperature and air movement) is also important.

Experimental and theoretical studies suggest that fibre assemblies with the density of a commercial high density (HD) bale, for example around 0.4 g/cm³, have a standard half-change period of around 10 hours. That is, a bale of cotton with seven per cent moisture and stored at a temperature of 18°C, will take around 10 hours to reach a half-way point in its equilibrium to new ambient conditions.

Ninety-nine per cent of the total change is completed in around 11 times the half-change value (about five days). Bale weight losses experienced in Australia reflect this relationship. For example, HD bales with regains replenished to 7.5 per cent will lose two to three kg of weight within half a day of storage in open, dry conditions, and will lose another two to three kg if left in these conditions for periods longer than a week.

Studies by the USDA ARS show that after cotton fibre is baled, moisture transfer occurs very slowly, especially at high densities. Bales at densities of 0.2 g/cm³ required over 60 days to equilibrate with the environment while bales at 0.47 g/cm³ required over 110 days. Equilibration time is also a function of the starting moisture content as well as the humidity and temperature of the environment during storage and bale covering.

**CONCLUSION**

In this article we review current knowledge of the interactions between water, cotton cellulose and cotton fibres. This knowledge is important for understanding
the affects of moisture on processing, especially through the gin, on fibre testing and on bale storage. In future articles we shall review the influence of cotton moisture content on these different processes.

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