# COTTON GIN DRYING TIME RELATIONSHIPS

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## Abstract

Cotton gin drying systems were mathematically modeled using calculations based on laboratory data showing drying rates for small samples. The model was used to predict expected moisture transfer rates for different components of machine-stripped cotton in typical cotton gin drying systems. The calculated results were compared with actual results for two types of gin drying systems. The source of apparent rewetting that has been noted in seed cotton downstream of gin drying systems was examined using vapor pressure relationships. Possible ways for modifying drying processes to compensate for component drying rates, and to maintain the drying gradient are suggested. The results show that some rethinking of cotton gin drying processes is in order and additional research is needed. Fundamental data showing vapor pressure for cotton in terms of temperature and moisture level is needed so that it can be integrated with vapor pressure and temperature data for air to describe the interactions through the entire drying system and allow design of ways to compensate for imbalances originating from the drying process.

## Introduction

Drying is regularly used to prepare seed cotton for cleaning and ginning processes. Wet cotton which is not adequately dried before processing will have lower grades and also may affect gin plant processing efficiency. Maximum cleaning is accomplished with seed cotton cleaning machines when the moisture content of the cotton is below 5 percent (Childers and Baker, 1978). Ginning at such low moisture levels can give static electricity problems and can cause fiber damage in the gin stands and lint cleaners. The normally recommended moisture level for gin processing is 6.5 to 8 percent (USDA, 1994). Knowledge of what happens on an instantaneous basis in a dryer as cotton is processed is important for design and optimization of the dryers. Obtaining data is difficult and most data available has been collected from samples taken upstream and downstream of dryers.

At ordinary ambient temperatures cotton gradually reaches an equilibrium moisture level that is determined by vapor pressure balance between the cotton and air. Drying is accomplished by using heat and aeration to impose a vapor pressure gradient that moves moisture out of the cotton. The farther the imposed conditions are from equilibrium the greater the drying rate. Equilibrium moisture level results from a temperature dependent affinity of cotton for moisture that varies because of the complex chemical makeup of cotton. Equilibrium moisture content is different for the lint, seeds, leaf trash, burs, and sticks and stems contained in harvested cotton. The equilibrium moisture content for each fraction tends to fall into a small range for a given set of conditions.

Data in the literature shows that the maximum equilibrium moisture content for cotton lint in saturated air (100 percent relative humidity) is approximately 22 to 25 percent moisture, (Urquhart and Williams, 1924. Abernathy, et. al. 1991). Both Abernathy et. al. (1994) and Barker (1992) have developed equations describing the relationship of equilibrium moisture content of cotton lint to temperature and relative humidity. Laird and Barker (1995) show equilibrium moisture level and vapor pressure as functions of temperature and relative humidity for the range of 45 to 125 °F. Vapor pressure is the independent force determining moisture level in cotton. The effect of relative humidity is confounded with temperature. The purpose of the work described in this paper is to try to use drying rate equations to model two gin drying systems and to use vapor pressure relationships to determine the reasons for unexpected moisture changes noted in gin drying and cleaning systems.

## Cotton Drying Rate

Contact time and heat transfer rate are significant controlling factors on the amount of drying obtained in a drying process. Vapor pressure gradient developed is the driving force. Data for the time rate of drying under good aeration conditions over the range of temperatures used in gin dryers has recently been developed, (Barker and Laird, 1993, 1994). The apparatus used to obtain the data was a cross flow system with small samples of material suspended from a microbalance in a constant air flow which provided a complete air change every two seconds. The high relative air flow rate assured that the cotton was exposed to an unchanging air condition and is equivalent to a very large air-to-cotton mass ratio.

The drying rate as a function of initial moisture levels for cotton lint, leaf, hulls, and sticks and stems follows the time relationships shown in Figure 1 for constant exposure to air heated to 250 °F. Drying rate is also highly affected by drying temperature, as shown in Figure 2 for lint. Data for plotting Figures 1 and 2 was generated by rearranging the equations given by Barker and Laird, (1993) to solve for moisture content as a function of drying time and initial moisture level. The equilibrium moisture content for cotton at the dryer temperature is needed in the equation. We used an equilibrium moisture content of 0.56 percent for cotton at 250 °F arrived at by extrapolation of raw data from Barker (personal communication) to higher temperatures.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1590-1597 (1996)
National Cotton Council, Memphis TN

The standard oven moisture test procedure uses 5 hours of exposure to 230 °F air to determine the zero moisture level for seed cotton. More information is needed on equilibrium moisture content for cotton at high temperatures.

Drying curves are different for each fraction of the cotton, consequently drying creates an inherently unbalanced condition. Concurrent flow with changing air conditions in conventional pneumatic seed cotton drying processes results in slower drying than found from the small scale laboratory drying tests. Heat loss through dryer surfaces resulting in temperature decreases and increasing humidity reduce the vapor pressure gradient and drying potential. Cross flow, counter flow, and hot shelf drying system designs partially avoid these handicaps.

## Model Test Procedure

Mathematically modeling conventional drying processes required the adoption of a function describing the air quality changes for the dryer along with several simplifying assumptions. The model was developed using test data from two similar gin systems, one equipped with a belt dryer and the other equipped with two stages of tower dryers. The test used four replicates of machine-stripped cotton from the 1994 crop, all from the same field. Each replicate consisted of a module. One half of each module was ginned on each gin in random order. The test procedure consisted of bringing a module in from the field, breaking it in half with the module truck, and laying 1/2 of it down on the module disperser slab at the gin equipped with the belt dryer. These four 1/2 modules were ginned in order. The remaining half of each module was temporarily stored on the gin yard and the next day they were picked up and hauled 50 miles to the gin equipped with tower dryers and put down on module pallets. The following day the pallets were pulled under the suction and the half modules were ginned in the gin system with tower dryers.

The cleaning machinery sequence for the test was the same in each gin plant except for unloading and dryers. The machine sequence consisted of a hopper type rock and green boll trap and airline cleaner in the unloading system, a six cylinder inclined cleaner, a stick machine, a second six cylinder cleaner, a combination bur-stick machine, a high capacity extractor feeder and gin stand. The gin stand was followed by two saw type lint cleaners. There was also a super jet air type lint cleaner behind the gin stand in the system equipped with the tower dryers. The belt dryer was between the unloading system and first inclined cleaner. The two tower dryers were in push-pull pneumatic dryer circuits through the first and second stage cylinder cleaners that exhausted through the incline cleaner bellys. Therefore the drying and cleaning in this gin included the effect of air through the cylinder cleaners. The hot air system for the belt dryer was independent of the conveying function and the cotton was handled mechanically throughout this system following the unloading system separator.

## Test Results

Using different gin plants for the test introduced some variables in the process that could not be eliminated. There was a change in initial moisture content of the cotton, which dried down about 1.8 percentage points, dry basis, between the time the first half of each module was ginned in the belt dryer system and the time the other half was ginned in the tower dryer system, Table 1. This was probably caused by extra handling of the modules and the two day delay required before ginning the cotton in the system with tower dryers. The gin equipped with the belt dryer used a mobile module disperser which cleaned some trash out of the cotton through expanded metal grids underneath the cross augers. This resulted in small differences in trash content of cotton entering the dryer, Table 2.

Location of the dryer controller sensors caused problems in comparability of dryer set point temperature for the different dryers. The temperature controller for the belt dryer is in the hot air line about 40 feet ahead of where it connects to the hot air supply plenum on the top of the dryer housing. The controller for the belt dryer generally holds the temperature of air contacting the cotton within ± 5 °F of the set point. The sensor for the tower dryers is located downstream from the mix point and was influenced by cotton and airflow variations.

An array of five thermocouples in the hot air distribution plenum that supplies air into the top of the belt dryer was used to provide an indication of the input temperature. An array of six thermocouples measured temperature of the stream of air leaving the bottom of the layer of cotton on the belt. These thermocouples were about 3 inches below the belt. The thermocouple locations were at 12 foot intervals along the belt dryer beginning 4 feet from where the cotton enters. The measuring point was at about one-third of the distance across the width of the conveyor. Thermocouples measuring input temperature for the tower dryer systems were in the hot air pipe about 3 feet ahead of where the air contacts the cotton in the blow box. The controller sensors were at the bottom of the tower where cotton enters the last shelf. The thermocouples measuring exhaust temperature for the towers were in the incline cleaner bellys about 5 feet below the grids under the cleaner cylinders. Total drying time in the belt dryer was 51 seconds.

There was a gradient in the temperature measurements for air leaving the cotton in the belt dryer. As expected, the temperature of air leaving the cotton increases as the cotton travels through the dryer. The thermocouple at the 40 foot location was damaged before the test and did not give a correct indication of temperature. The temperature indicated by the last thermocouple under the cotton in the belt dryer was taken as the exhaust temperature because it indicates the approximate final minimum air temperature that the cotton was exposed to. The drying system controls were adjusted to try to match the exhaust temperatures for both types of dryers since we have found that this seems to be the best indicator of the same amount of drying in each system.

It was more difficult to get a stable mix point temperature for the tower dryers, Table 3, and we experienced a wider variation in the average temperature between modules. The temperature for these dryers fluctuates continually as the controller located downstream in the tower responds to cotton and air flow variations. There was a lot of lag in this control system and it tended to overshoot in both directions. A thermocouple in the hot air pipe ahead of the mix point indicated temperatures as high as 280 °F and as low as 150 °F. The temperatures at the bottom of the tower and the incline cleaner belly were more stable. The controller in the second tower responded to the heating and flow smoothing of the first stage and maintained a lower and more stable mix point temperature. We tried to hold the no. 1 tower dryer exhaust at 105 °F to match the belt dryer final exhaust temperature, and the no. 2 tower exhaust at 100 °F. We used a lower temperature on the second stage tower dryer to avoid double exposure of the cotton to the highest mix point temperature. The approximate exposure time of cotton to hot air was 6.0 and 6.2 seconds in the first and second tower dryer respectively and 3 seconds in the first cleaner stage.

Air flow rate in each of the dryers was measured after the test with the systems processing cotton at the rate used in the test. We used an Omega HHF 6002 HT1 series air velocity meter and probe to take readings at standard 10 point equal area traverse stations in vertical and horizontal directions. The meter records velocity referenced to standard air conditions of 70 °F and 760 mm Hg. Average velocity for the 21-inch diameter round sheet metal pipe supplying the belt dryer was 3550 ft/min. Average flow velocity in the two 16-inch diameter pipes supplying the first and second tower dryers was 4100 and 3400 ft/min respectively, (5600 and 4200 ft/min at mix point conditions).

Mass flow ratio (lb of air per lb of cotton conveyed) was near 0.65 to 1 for the belt dryer and about 3.8 to 1 for the tower dryers (2.1 to 1 for the first and 1.7 to 1 for the second stage). Because of slightly greater specific heat cotton requires about 1.25 times as much heat per unit mass for each degree of warming as air does. Total air volume used per unit mass of cotton in each tower dryer was from 2.2 to 2.9 times that used in the belt dryer and the total air volume through the two stages of tower dryers was about 5 times as great. The high volume in the towers is necessary for pneumatic conveying.

Heating cotton increases the vapor pressure of moisture within the cotton and produces rapid drying. Residual heat retained by the cotton leaving the dryer represents a potential for drying to continue but, because cotton has a greater affinity for moisture as its temperature increases, an inverse vapor pressure relationship may develop and cause a reversal of drying if the cotton is put back into cool air. We tried two methods for measuring the temperature of the cotton to examine how much heat it picked up in the dryers. One set of readings was obtained from the digital readout of an infrared temperature sensor pointed at the cotton from a distance of about 12 inches. Another method was to grab about 1/2 cubic foot of the cotton and drop it in a small box. A fine wire thermocouple was inserted into the center of the wad of cotton and the highest reading reached on a digital temperature indicator was recorded. The thermocouple method was not used on the belt dryer part of the test. From 3 to 19 readings (samples) were taken on each half module. Fewer readings were possible for the gin with the belt dryer because the high processing rate gave only a limited time for sampling.

Infrared meters indicated that the cotton was warmed up about 30 degrees in the dryers, Table 4. The cotton temperature did not approach very near to the balance point of 115 °F for the belt dryer and 160 °F for the tower dryers calculated by using an air and cotton heat balance equation based on mass flows and specific heats. The exhaust air and cotton temperatures also show that heat exchange between air and cotton was not complete in these dryers. Latent heat of evaporation and heat losses could account for part of the difference. The assumption that heat transfer is rapid and that the cotton and air reach equilibrium early in the dryer is not correct based on these results. More work is needed to verify the cotton temperature measurements over a wider range of conditions.

Moisture content of ginned seeds (Table 5) was lower than the original seed cotton moisture from Table 1. Cotton that has been stored for a long period as these modules were usually reaches equilibrium and seed moisture content typically is about 1 percent point higher than seed cotton moisture. If the lower than expected seed moisture content was due to seed drying then both dryers produced some seed drying. For the belt dryer system final seed moisture content was 0.7 percentage point below the beginning seed cotton moisture. Final seed moisture for the tower dryers was the same as beginning seed cotton moisture content.

An iteration process was used for modeling the gin dryers. The rearranged drying rate equations from Barker were used to calculate moisture based on mean dryer temperature for each one second interval. Linear interpolation between temperatures measured at the mix point and exhaust of the tower dryers was used to estimate the mean temperature of the mixture in the dryer for each second. Mean temperature was more difficult to estimate for the belt dryer because it is a cross flow process and the air always enters the bed of cotton at the mix point temperature while the gradient through the bed changes continually as the cotton proceeds through the dryer. Average temperature between the mix point and the air leaving the bed of cotton at a given travel point was obtained by drawing smooth lines through the data from the thermocouples at intervals above and below the belt on a time axis and then calculating the temperature for each second, Figure 3.

We calculated second by second drying rate in the belt dryer for each of the fractions in the machine-stripped cotton, Figure 4, using the estimated mean dryer temperature. We arrived at the initial moisture content for each fraction by applying adjustments to measured seed cotton moisture based on differences reported (Barker and Laird, 1994, and Barker, personal communication) for cotton at equilibrium. The drying curves developed for the belt dryer conditions showed good drying potential for lint and leaf but burrs and sticks had little drying potential. There is not a published equation for seed drying. We estimated seed drying to be one percent for the complete pass in the belt dryer based on previous experience and used a straight line for it. The measured moisture content for ginned seeds showed more drying than was estimated. The calculated drying rate curves for the individual fractions shows the moisture imbalance that develops in a dryer because of their different drying rates.

By recombining the moisture levels for the fractions in Figure 4 in proportion based on fractionation data in Table 2, and lint turnout, we were able to generate estimated moisture content for seed cotton as it progressed through the belt dryer, Figure 5. The curve indicates about one percent more drying than we actually measured on samples taken after the second cleaner. Part of the reason for the variation between the results from the model and the measured moisture content is probably inadequate estimation of the temperature profile through the dryer and contact and mixing between the air and cotton. Also the rewetting phenomenon which will be discussed later may have been involved.

Since the air and cotton move along together in a tower dryer it is easier to arrive at the temperature gradient. We estimated temperature at one second intervals by fitting a straight line between temperatures measured at the mix point and exhaust. The straight line may not be the proper fit. More work is planned to determine the actual temperature gradient through the tower dryers. We plotted the temperature gradient on a time scale that included the time in the cylinder cleaners, Figure 6. We assumed that temperature drops to ambient in the second cleaner.

Drying curves based on the estimated temperature gradient in the tower dryers were calculated for the individual seed cotton components, Figure 7. We estimated seed drying to be 0.5 percent in the tower dryer system. The calculated curves indicated there was not a lot of drying potential for this system at the temperatures used in the test. This agrees with experience. The results for individual fractions of the seed cotton mass, when combined in proper proportion, produced the drying curve for the tower dryer, Figure 8. The curve indicated slightly less drying after the second cleaner than was measured for this system. With better estimates for the initial moisture levels and temperature gradient we expect that the drying equations will fit this type of dryer fairly well. Further work needed includes additional instrumentation to enhance our understanding of heat transfer in the dryer and the inclusion of latent heat of vaporization and drying rate data for seed.

The large difference in drying rate between lint and trash may cause over drying and possibly over heating of the lint. Over drying may occur when high temperatures are necessary to dry damp high trash cotton enough to allow the gin machines to operate. There seem to be two ways to help provide a solution to the problem. One is to design drying processes that have long dryer retention times to allow acceptable drying of the trash components at lower temperatures. Another possibility is to use accumulation bins downstream from the drying system in gins to give the cotton a tempering period to allow the over dried lint to regain moisture from the under dried trash and seeds.

Because of the large effect of initial moisture content, accurate instruments for sensing moisture and flow rate, and versatile control systems for gin dryers are necessary to achieve uniform drying results. The drying rate is too dependent on initial moisture content and too responsive to dryer temperature for a dryer control using fixed temperature settings to maintain the proper drying. The drying control system needs to be programmable over a wide range to handle varying initial moisture contents, especially where short time high temperature drying systems are used.

The drying rate curves reveal a very important set of concepts for improving drying effectiveness, efficiency, and control consistency. Use of drying times in the 60 to 90 second range on wet cotton, (>12 % M), considerably reduces the temperature needed and will allow adequate drying of lint cotton up to 20 percent or more beginning moisture content. This results in reduced fuel cost and also reduces the potential for heat damage to the cotton. Using relatively long dryer residence times moves the drying endpoint into the time range where the effect of starting moisture content is greatly reduced, allowing better control of the process. It also makes time control less critical.

## Regain After Drying

In a number of tests where cotton was heated up by using long drying times in belt dryer systems we have found that samples taken after the cotton left the dryer and returned to cool ambient air showed a regain of moisture over that indicated by samples from the dryer outlet. This was unexpected because the moisture level of the cotton was substantially above the equilibrium moisture level for the ambient air conditions. At first we attributed it to sampling error but the same observations have consistently occurred over several years and a wide range of conditions in different dryer installations across the cotton belt. Typical results at the ginning laboratory at Lubbock, Texas and at a commercial gin in Windsor, Virginia are given in table 6.

We finally decided that the phenomena had to be real and that there was an underlying physical reason for it. As data became available relating equilibrium moisture content of cotton to temperature, relative humidity and vapor pressure it became possible to look for the cause of the phenomenon. It now seems that the important factor is that the affinity of cotton for moisture varies directly with temperature. The reason for the regain can be seen by overlaying the test data on graphs containing lines of constant equilibrium moisture for lint and relative humidity plotted on temperature and vapor pressure axes. It becomes evident that when cotton is warmed up and partially dried in the dryer it changes to a condition which is equivalent to a much higher vapor pressure. This creates an unstable state with a strong potential for rapid moisture change. This condition is not apparent if only the temperature and relative humidity factors are considered.

The situation for the example from the Lubbock laboratory is illustrated in figure 9. The circles with a dot in the center represent the measured cotton moisture content before drying, and after it was dried and warmed up. These points are connected with dotted lines to show they are related, the path traced out by the dotted lines indicates only the general direction of the change the cotton passes through. The cotton at the dryer exit was at 8.5 percent moisture and its mean temperature was approximately equal to the belt dryer final exhaust temperature of 113 °F. Two squares with a dot in the center are plotted at 69 and 113 °F to illustrate the air condition at the ambient temperature and in the dryer at the exhaust temperature before it has gained moisture from the cotton. The partial pressure for vapor in the air remains constant as the air is heated until moisture is added to the air. In dryers a small amount of vapor is added from the products of combustion and much more from moisture removed from the cotton. In this example dryer temperature was 230 °F so the cotton was not yet near equilibrium with the drying air. Projecting from the final cotton condition back to 69 °F ambient temperature along a line of constant vapor pressure illustrates what happens if the warm cotton is dumped back into ambient air. A large reverse vapor pressure imbalance is created which will resolve itself by the cotton taking moisture from the air and giving heat up to the air.

Casual inspection of the graph would seem to indicate that the high vapor pressure is associated with the cotton and low vapor pressure with the air so moisture transfer would be from the cotton to the air, but this is incorrect because we are considering two different vapor pressure functions. Vapor pressure for the air is the positive pressure associated with ordinary humidity of ambient air. Vapor pressure for the cotton is the bonding energy for water in the cotton that is a function of its temperature. In this case the cotton has become an aggressive vapor sink rather than a source and essentially will act as a desiccant for the cool dry air. This is evident from the plots of constant relative humidity and equilibrium moisture content for cotton lint; we are projecting into the excluded region beyond saturation for either material. We might think that the cotton would be cooled down by the air and become a less aggressive sink for the moisture, but outside of the pneumatic system in the dryer the mass of cotton is very large compared to still air occupying the same space, and heat of wetting will cause the cotton and air to gain in temperature. Extensive exposure and exchange with the general atmosphere is required before this situation is alleviated.

Another example of the same things is shown in Figure 10 which is data taken on the 1995 crop in a commercial gin equipped with a belt dryer at Windsor, Virginia. In this case cotton at 15 percent moisture was dried to 9 percent at the dryer exit and we expected continued drying due to residual heat to reduce it to 7 percent or less in two additional pneumatic conveying stages carrying it through the first and second overhead cleaners. These stages both used unheated ambient air at 72 °F and 65 percent relative humidity. Samples from seed cotton at the feeder apron showed the cotton had regained about 1.5 percent points and was at 10.4 percent moisture. Handling the cotton in the two pneumatic stages without drying it first would have given some drying. Projecting back to ambient temperature along a constant vapor pressure line shows why the cotton took moisture from the cooler air. The problem was solved by removing flights from the separator at the dryer outlet to allow heated air to continue with the cotton into the next stage conveying air system.

The regain phenomenon apparently happens for other types of dryers but the amount of heating is too small because of the short drying time for it to be very evident. With tower dryers it has been the normal practice to use a dryer in each pneumatic circuit so the cotton is kept in heated air up to the distributor. In retrospect this appears to have been for a good reason that is now very evident. For some of the newer system designs where a single large dryer is used before the overhead cleaning machinery the regain problem should be considered if there are additional pneumatic circuits in the system. The phenomenon is probably also the reason that ginners have traditionally felt that using a small amount of heat on the first stage dryer with dry cotton improves the performance of the machines even when moisture content is too low initially. A slight warming at the first stage may cause the cotton to gain moisture in later stages and become softer and run smoother. The results for this study also suggest that for cotton at intermediate moisture levels that only needs a little drying it would be better to use low heat in all dryer stages rather than high temperature in the first stage and no heat in later stages. Further study of these ideas is warranted.

## Summary and Conclusions

Drying rates in two types of dryers for the fractions contained in machine-stripped cotton were calculated using temperature data from tests and equations for drying rates published by Barker and Laird, 1994. The results showed that models describe dryer performance, but good data on the temperature profile in each type of dryer is needed. Drying rate equations for cotton seeds is also needed so that each component in the seed cotton mass can be included in the model. More research is needed to determine temperature profiles for each type of dryer related to mass flow rates and moisture level so that the performance of each type can be fully described in terms of the potential drying rate. Further development of methods for measuring cotton temperature as it proceeds through the dryer is needed so that heat transfer for all the dryer types can be optimized. Different drying rates for lint and the other components of seed cotton cause imbalance in drying which can be detrimental to quality if damp cotton is ginned and subjected to lint cleaning immediately. Changing the gin process to provide a static equilibration period after drying for moisture equilibration to take place could allow more drying without causing fiber damage.

Plotting cotton moisture level related to drying on graphs of constant equilibrium moisture and constant relative humidity lines using temperature and vapor pressure for the axes shows that a potential for regain of moisture is created if warm lint cotton from a dryer is put back into cool ambient air. The reason was found to be in the temperature dependent vapor pressure relationship of cotton. This should be considered in research and in design and operation of cotton ginning systems.

Note: Specific product names are used in this paper in order to give factual information and their use does not constitute endorsement or recommendation by USDA-ARS over other similar products.

## References


1. Abernathy, G. H., S. E. Hughs, and M. N. Gillum. 1991. Improved Equilibrium Moisture Content Models for Cotton. ASAE Paper No. 911506. ASAE. St. Joseph, MI.

2. Abernathy, G. H., S. E. Hughs, and M. N. Gillum. 1994. Improvements of Equilibrium Moisture Content Models for Cotton. Transactions of the ASAE 37(2):561-569.

3. Barker, G. L. 1992. Temperature Effects on Lint Cotton Equilibrium Moisture Content. Transactions of the ASAE 35(5):1377-1380.

4. Barker, G. L., and Laird, J. W. 1993. Drying and Humidification Rates for Cotton lint. Transactions of the ASAE 36(6):1555-1562.

5. Barker, G. L., and Laird, J. W. 1994. Moisture Relationships for Cotton Lint and Trash. Report No. 94-G-002. AgEng Milano '94.

6. Childers, R. E., and R. V. Baker. 1978. Effect of Moisture Conditioning on Ginning Performance and Fiber Quality of High Plains Cotton. Transactions of the ASAE 21(2):379-384.

7. Laird, J. W. and Barker, G. L. 1995 Time, Temperature and Moisture Level Relationships for Cotton Drying Processes. 1995 Proceedings Beltwide Cotton Conferences. National Cotton Council of America. Memphis, TN.

8. Urquhart, A. R. and A. M. Williams. 1924. The Moisture Relations of Cotton Taking up Water by Raw and Soda-boiled Cotton at 20 °C. The Journal of the Textile Institute 15:T138-T148.

9. --------. 1924. The Moisture Relations of Cotton ii-The Absorption and Desorption of Water by Soda-boiled Cotton at 25 °C. The Journal of the Textile Institute 15:T433-442.

10. --------. 1924. The Moisture Relations of Cotton -- The Effect of Temperature on the Absorption of Water by Soda-boiled Cotton. The Journal of the Textile Institute 15:T138-T148.

11. Anthony, W. S. and W. D. Mayfield, editors. 1994. Cotton Ginners Handbook. Agriculture Handbook No. 503. USDA-ARS. Superintendent of Documents, Government Printing Office. Washington, DC.


Table 1. Average moisture contents, dry basis, for 6 samples from two bales (3 each) from four 1/2 module lots per dryer, at locations before and after the dryer in similar gin systems equipped with belt and tower dryers.

| Dryer | Moisture content: Before dryer | After dryer | Moisture reduction |
|---|---|---|---|
| | % | % | % points |
| Belt | 11.37 | 9.47 | 1.90 |
| Tower | 9.52 | 8.26 | 1.26 |

Table 2. Foreign matter contents of seed cotton as it entered the drying process in an experiment using similar gin systems equipped with tower or belt dryers.

| Dryer | Hulls | Sticks & stems | Fine trash | Total foreign matter |
|---|---|---|---|---|
| | % | % | % | % |
| Belt | 17.8 | 3.0 | 4.1 | 24.9 |
| Tower | 19.6 | 3.8 | 3.9 | 27.3 |

Table 3. Dryer temperature, °F, at the indicated locations for an experiment determining drying rates for similar gin systems equipped with belt and tower dryers.

| Dryer System | Mix Pt.[1] | Exhaust | Bottom of tower |
|---|---|---|---|
| Belt | 233 | 105 | *na* |
| Tower #1 | 193 | 105 | 116 |
| #2 | 136 | 96 | 100 |

[1] The mix point temperature was the mean for five thermocouples in the hot air distribution plenum on top of the belt dryer or a thermocouple in the hot air pipe 3 feet ahead of where the air contacts cotton for the tower dryers. The exhaust location was the last thermocouple below the belt, or in the incline cleaner belly where the exhaust pipe connects to the bottom of the incline cleaner. The bottom of tower point is in the reversal where cotton enters the last shelf of the tower.

Table 4. Temperature of cotton before and after drying in belt and tower dryer equipped gin systems for machine-stripped cotton[1].

| Type of gin dryer | Cotton temperature, °F[1] | | | | | |
|---|---|---|---|---|---|---|
| | before dryer | | after dryer | | difference | |
| | TC | IR | TC | IR | TC | IR |
| Belt | 58 | 53 | -- | 82 | -- | 29 |
| Towers | 61 | 56 | 86 | 84 | 25 | 28 |

Note: Before drying the cotton was sampled on the module disperser belt for the gin with the belt dryer, and from the steady flow hopper for the gin with tower dryers. After dryer the cotton was sampled at the outlet of the second cylinder cleaner.

[1] Cotton temperature indicated by TC was measured by inserting a fine wire thermocouple into the center of a 1/2 cubic foot wad of cotton and recording the highest temperature it reached in the next few minutes. Temperature indicated by IR was the surface temperature indicated by an infrared temperature sensor gun for a similar mass of cotton.

Table 5. Average moisture contents, wet and dry basis, for samples of ginned seeds dropping out of the gin stand in similar gin systems equipped with belt and tower dryers.

| Dryer | Wet basis | Dry basis |
|---|---|---|
| | % | % |
| Belt | 9.63 | 10.67 |
| 2 Tower | 8.66 | 9.50 |

Table 6. Moisture content, dry basis, for cotton at the entrance end exit of a belt dryer and further downstream in tests conducted at the Lubbock, Texas ginning laboratory and in a commercial gin at Windsor, Virginia.

| System | Before dryer | After dryer | Downstream |
|---|---|---|---|
| | % | % | % |
| Laboratory | 11.4 | 8.5 | 9.8 |
| Commercial | 14.9 | 8.9 | 10.4 |

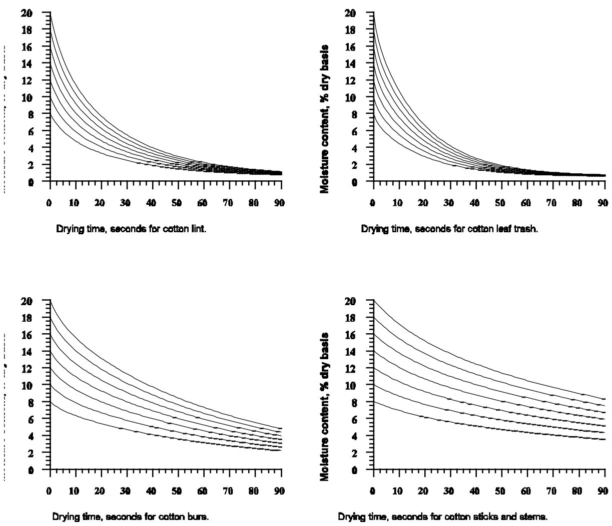


**Figure 1**. Drying rate for cotton lint, leaf, burs, and sticks and stem trash when exposed continuously in 250 °F air.

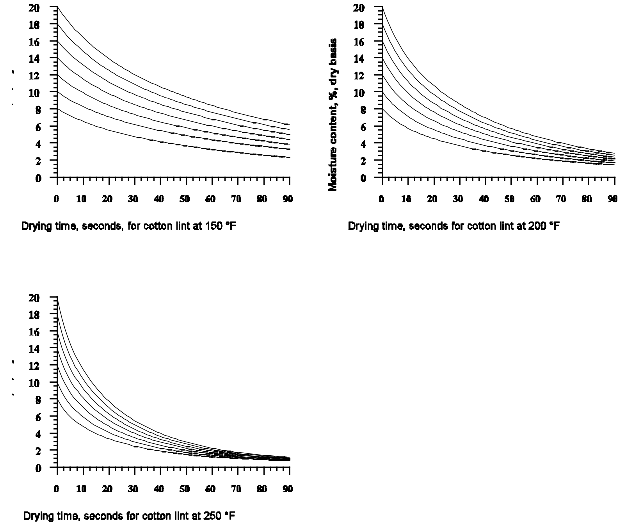


**Figure 2**. Drying rate for cotton lint at constant air conditions for three drying temperatures.

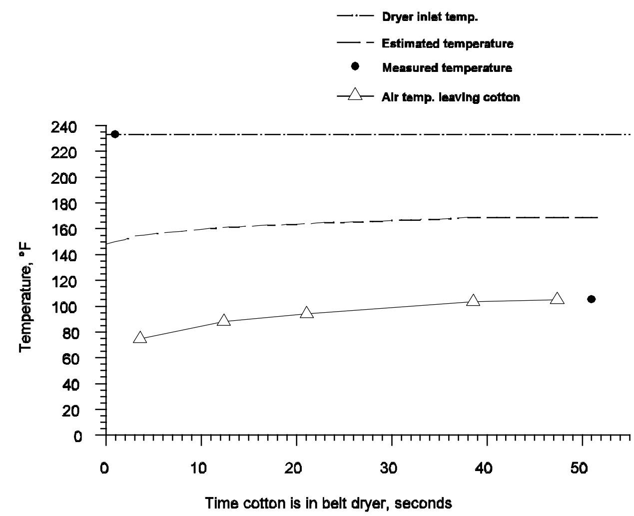


**Figure 3.** Temperature measurements and the estimated mean drying temperature for the belt dryer system test.

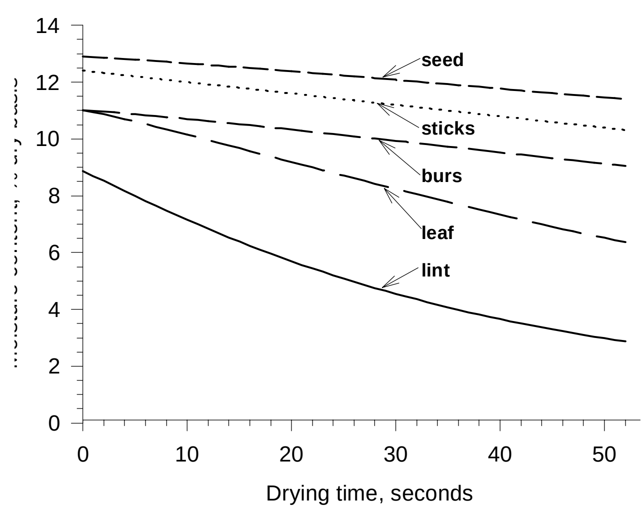


**Figure 4**. Moisture content calculated for lint, leaf, burs, sticks, and seed fractions as machine-stripped cotton was dried in a belt dryer at 233 °F.

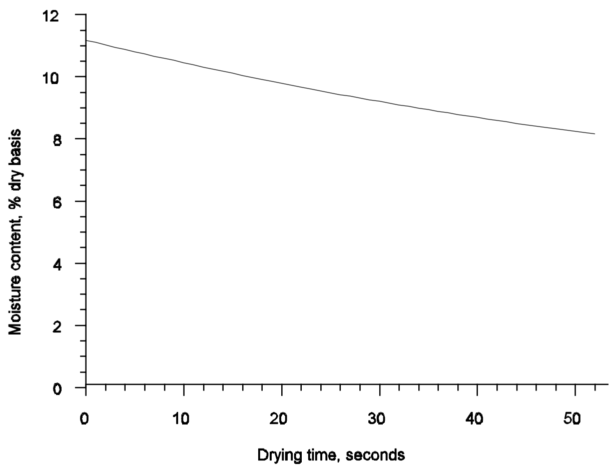


**Figure 5**. Combined moisture content for seed cotton, (combination of calculated moisture content for fractions), as machine-stripped cotton was dried in a belt dryer at 233 °F.

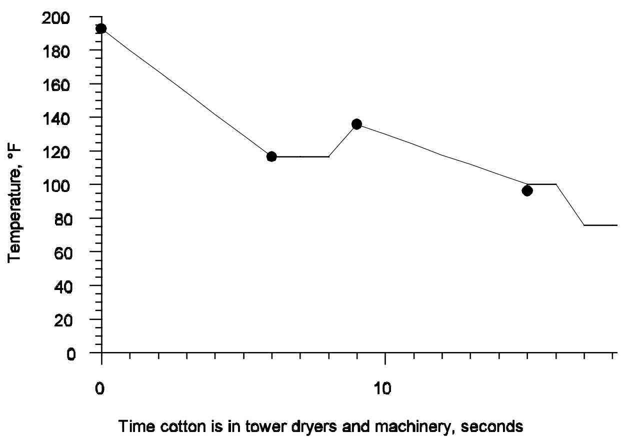


**Figure 6**. Temperature measurements and estimated temperature gradient through a two tower dryer system and associated machinery. Solid circles are the measured temperatures at dryer inlets and outlets.

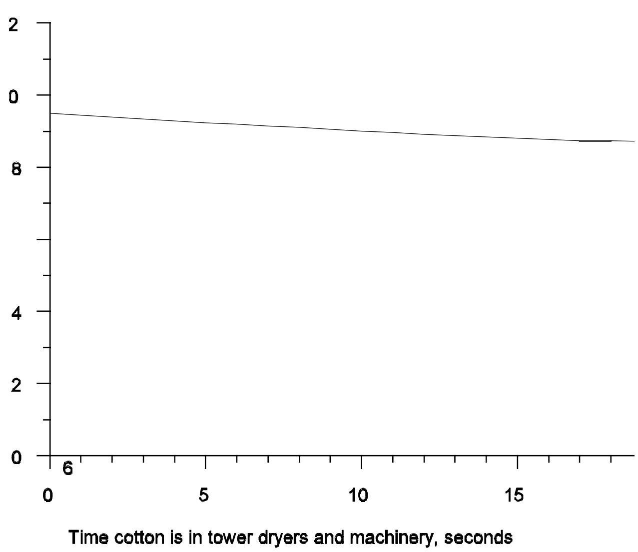


**Figure 8.** Combined moisture content for seed cotton, (combination of calculated moisture content for fractions), as machine-stripped cotton was dried in two tower dryers and associated machinery.

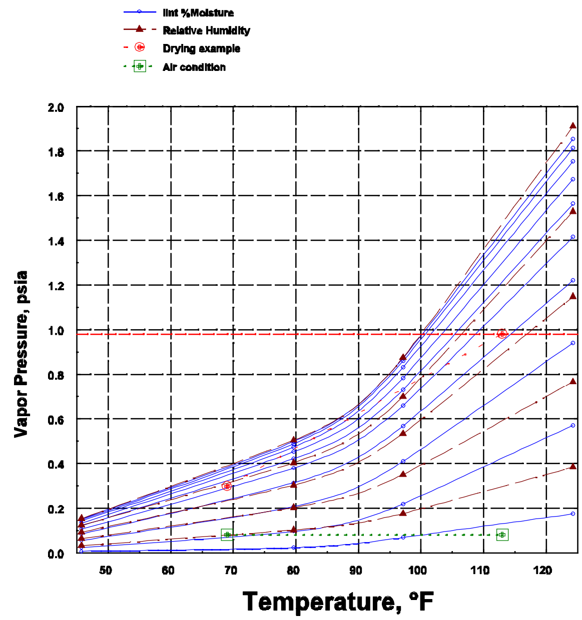


**Figure 9.** Example of cotton that is in an unstable equilibrium condition after drying in a belt dryer and is in equilibrium with higher vapor pressure than ambient and may be subject to moisture regain.

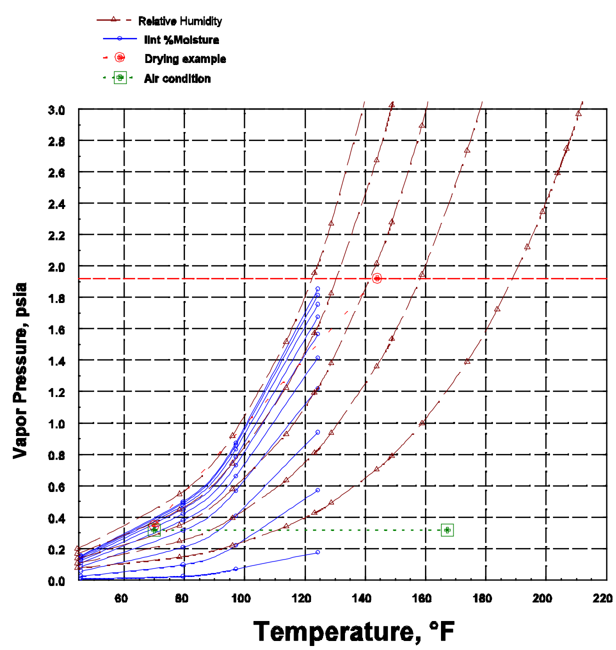


**Figure 10.** Example of cotton that is in unstable equilibrium with vapor pressure that is much higher than ambient air after drying in a belt dryer in a commercial gin.