MODELING SEED COTTON MOISTURE FROM AIR TEMPERATURE DROP AND MASS FLOWS

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Abstract

A mathematical model predicts seed cotton moisture content during seed cotton conditioning. The model uses air temperature, air mass flow, and seed cotton mass flow to account for the following: heat transfer (sensible heat lost) from the conveying air, heat added to the room, heat added to the seed cotton, heat added to the moisture in the seed cotton to raise the water temperature, and heat added to vaporize the moisture in the seed cotton. Two seed cotton conditioning rates, two mixpoint temperatures, and two levels of moisture content are used to calibrate the model. The model is simplistic in that in considers seed cotton as a whole, and does not split the seed cotton into the lint and seed components. The model has an acceptable R^2 of 0.80 when regressed against actual seed cotton moisture content. The model does not work well at moisture contents below 6%, but most gin plants have no reason to dry below this level.

Introduction

Knowing how much heat to use when drying seed cotton is a problem that ginners face. Using not enough heat may not adequately dry the seed cotton, resulting in poor cleaning and ginning and in the worst case, choke-ups which can damage the machinery. Using too much heat not only damages the fiber, making it brittle and more prone to breakage, but also creates static problems, causing choke-ups. And a dry bale is more difficult to press. The aim is to use only enough heat to obtain a seed cotton moisture content of 6-7% prior to ginning (Hughs et al, 1994). The problem is that ginners do not have a way of obtaining an accurate online moisture content reading. If a reading was available, ginners would then have some guidance on how much heat to use.

Past research on online moisture meters have not been completely successful. Waldie et. al. (1984) used impedance, resistance, and infrared sensors to measure seed cotton moisture content. The impedance sensor measured moisture content to the nearest 1.1% of the oven dry method, but this was over a range of 9-19%. The resistance and infrared sensors were not as accurate over the same range, measuring moisture content to the nearest 3.3 and 2.5%, respectively. In addition to not being able to measure accurately below 9% moisture content, the sensors faced other problems. The impedance and resistance sensors needed a uniform and constant seed cotton density to measure, but this is difficult to obtain, especially in a gin. The infrared sensor did not need to be in contact with the seed cotton, but the sensor did need a smooth surface to measure. Unfortunately, seed cotton is rough in appearance, and the infrared readings were too variable.

More recent research on moisture measurement has not been prosperous. Thomasson (1991) tested a silicon sensor, but it was not accurate enough for instrumentation purposes. Byler (1992) did more work on a resistance-type meter, but found too much variability in the data. Research on sensors continues, but perhaps there is a simpler method of determining moisture content which does not involve sophisticated methods or hardware. This simpler method is what concerns this paper.

Seed cotton is conveyed in the overhead with air, and ideally, moisture content should be determined as early as possible during conditioning. If the temperature and mass flow of the seed cotton and the air can are known at particular locations in the overhead, such as between the mixpoint and the 1st piece of equipment (usually a tower dryer or hot air cleaner), then it may be possible to determine relationships between the seed cotton and air. One relationship in particular is the one between the temperature drop of the air caused by the drying of the cotton (during a particular time period) and the moisture content of the cotton. What follows are results of an experiment which used temperature and air mass flow data to predict seed cotton moisture content in the overhead.

Experimental Procedures

The experiment was performed at the USDA-ARS Southwestern Cotton Ginning Research Laboratory located in Mesilla Park, NM. Figure 1 shows where additional conveying pipe and a venturi were installed in the overhead between the vacuum dropper after the steady flow hopper and the 1st tower dryer. The conveying pipe was 14 inches in diameter, and was insulated to minimize heat loss from the pipe, ensuring accurate temperature readings. Insulation consisted of placing 16-inch diameter pipe around the 14-inch pipe, and covering all elbows with R-13 flameproof insulation. The dropper was 72 inches wide, and the dryer was 50 inches wide and contained 17 shelves. Figure 1 also shows locations where the conveying air temperature was measured. Type T thermocouples measured the air temperature, and a pressure transducer measured the air pressure in the venturi.

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The experiment consisted of four treatments times four replications times two harvest conditions for a total of 32 bale-sized lots of Delta Pine 90 cotton. The cotton was grown in the Mesilla Valley of Southern New Mexico. The first 16 lots were picked early season (green) with extra moisture added to the seed cotton from the picker; the objective was to obtain as wet a cotton as possible. The remaining 16 lots were picked after frost and dry (18 days later), the objective being to obtain cotton under normal (dry) harvest conditions. The treatment consisted of varying the seed cotton conditioning rate and the mixpoint temperature. Treatments 1 and 2 had a target seed cotton conditioning rate of 2.5 bales/hr and used mixpoint temperatures of 225 and 350° F, respectively. Treatments 3 and 4 had a target seed cotton conditioning rate of 5.0 bales/hr and used mixpoint temperatures of 225 and 350° F, respectively. The 5.0 bales/hr conditioning rate is the normal rate used at the Laboratory; the lower rate of 2.5 bales/hr was chosen so as to evaluate the maximum effect of cotton mass rate on temperature drop. Table 1 lists treatment definitions with both target and actual values.

For each lot, data were collected in the conveying pipe with heated air only (no seed cotton), and with heated air and seed cotton. To determine actual seed cotton moisture content, twenty seed cotton samples were collected during each lot in a sampling port between the steady flow and the mixpoint. The moisture content was determined from these samples using the standard oven dry method. Although not part of the experiment, the complete seed cotton conditioning setup included two tower dryers, two 6-cylinder inclined cleaners, and one stick machine. Also, ginning was performed on a 46-saw gin stand and lint cleaning included two saw-type lint cleaners. The only problem encountered during the test was a leaky clean-out door on the green boll trap which reduced the air flow on some of the earlier lots; this is why seed cotton conditioning rates were slightly lower than target (see table 1).

Discussion

Figure 2 is a plot of air temperature versus air transit time between the mixpoint and the bottom of the 1st tower dryer (refer to figure 1 for thermocouple locations). The plot shows both levels of mixpoint temperature (350 and 225° F). At each mixpoint temperature (the dashed line), there is one curve (the top one) which indicates air temperature with no seed cotton in the conveying pipe, and four other curves which indicate air temperature at both conditioning rates and both moisture levels. The rapid drop in air temperature that occurs at location #2 is due to the dropper bringing in colder air and seed cotton from the chute above it, and this colder blend then not thoroughly mixing with the heated air. Thorough mixing appears to occur at location #3 since the temperature seems to recover at this location.

Still referring to figure 2, it takes about 1.25 seconds for the conveying air to travel from the mixpoint to the top of the tower dryer, and then about 3.75 seconds to travel through the dryer. These transit times are for air only. Seed cotton travels slower than the air because of some slippage between the air and seed cotton. The amount of slippage depends mainly on the amount of moisture in the seed cotton; very wet seed cotton moves somewhat slower than the air whereas dry seed cotton travels at about the same speed as the air. The average air flow and velocity through the conveying pipe was 4,622 ft^3/min and 4,324 ft/min, respectively.

The shaded areas in figure 2 (and figure 3) represent the heat losses to the room, or the difference in temperature between mixpoint and heated air only (no seed cotton). Heat loss to the room at location #8 (pipe outlet) amounts to 10 and 8% for the 350 and 225° F mixpoint temperature, respectively. At the bottom of the tower dryer (location #10), heat loss to the room is 30 and 25% for the 350 and 225° F mixpoint temperature, respectively. The difference in temperature between heated air only and the conditioning rate/moisture level curves represents the drop in temperature that occurs due to the seed cotton. These temperature differences are more clearly seen in figure 3 where only the additional conveying pipe is shown (the tower dryer has been removed) and the scale of the figure has been changed. It appears that heat loss to the room is greater than heat loss to dry the cotton, especially at the higher mixpoint temperatures.

Table 2 again illustrates temperature differences, but broken out by treatment and seed cotton moisture level. Within each treatment (see table 1 for definitions) are pipe temperatures of heated air only (no seed cotton), heated air with dry seed cotton, and heated air with wet seed cotton. At each location in the pipe, the largest temperature drop occurs between heated air only and heated air with wet seed cotton, indicating that temperature has more of an affect on wet rather than dry seed cotton.

A model was developed to predict the moisture content of seed cotton. The model took into account the temperature, mass flow, and specific heat of both the air and seed cotton. The model is as follows:

$$MC = \frac{(TERM1 - b0*TERM2 - b1*TERM3)}{(b1*TERM4 + b2*TERM5)}$$

where

MC = Moisture content of the seed cotton (predicted)

TERM1 = Heat transfer (sensible heat lost) from the conveying air
= mass rate of air * specific heat of air * (inlet pipe temp. - outlet pipe temp.)

b0 = coefficient for heat added to the room
TERM2 = Heat added to the room (conveying air only, no seed cotton)
= area of pipe surface * (temp. inside the pipe - ambient temp.)

b1 = coefficient for both heat added to the seed cotton and heat added to the moisture in the seed cotton
TERM3 = Heat added to the seed cotton

= mass rate of seed cotton * specific heat of seed cotton * (temp. of seed cotton at outlet - temp. of seed cotton at inlet)

TERM4 = Heat added to the moisture in the seed cotton to raise the water temperature
= mass rate of seed cotton * specific heat of water *(temp. of seed cotton at outlet - temp. of seed cotton at inlet)

b2 = coefficient for heat added to vaporize moisture in the seed cotton

TERM5 = Heat added to vaporize moisture in the seed cotton
= Mass rate of seed cotton * heat of vaporization of water at ambient

The following constants and assumptions are used in the moisture prediction equation.

- The mass rates of air (in lb/s) is flow times density.
- The mass rate of seed cotton (in lb/s) is a timed (stopwatch) measurement.
- The specific heat of air (at constant pressure, 240 ° F) is 0.242 Btu/lb-° F (Jorgenson, 1970).
- The inlet pipe temperature is at location #1 in figure 1.
- The outlet pipe temperature is at location #8 in figure 1.
- The temperature inside the pipe is the average of the inlet and outlet pipe temperature.
- The specific heat of seed cotton is 0.32 Btu/lb-° F (Mauersberger, 1947).
- The ambient temperature is substituted for the temperature of the seed cotton at the pipe inlet.
- The outlet pipe temperature is substituted for the temperature of the seed cotton at the pipe outlet.
- The specific heat of water at ambient is 1.0 Btu/lb-° F (Jorgenson, 1970).
- The heat of vaporization of water at ambient is h_{fg} = 1075.8965 - 0.56983 * (ambient temp. + 459.69 - 491.69) (ASAE, 1994).

Two-stage regression determines the coefficients in the model. In the first stage, heat lost from the conveying air only (no seed cotton) is regressed against the heat added to the room, and a coefficient of 0.000265 is obtained for heat added to the room; this first stage has an R^2 of 0.9932. In the second regression stage, heat lost from the conveying air with seed cotton (which used the coefficient from the first stage) is regressed against (1) the sum of the heat added to the seed cotton and the heat added to the moisture in the seed cotton, and (2) the heat added to vaporize moisture in the seed cotton. The coefficient obtained for the sum of the heat added to the seed cotton and the heat added to the moisture in the seed cotton is 0.253849 and the coefficient obtained for the heat added to vaporize moisture in the seed cotton is 0.015772. The second regression stage has an R^2 of 0.9908.

Placing the coefficients, constants, and data collected from the experiment into the model and then regressing the model (predicted) against actual seed cotton moisture yields the following equation:

$$MC = -3.679126 + 1.212212 * \text{Actual MC}$$

Both the intercept term and coefficient are significantly different from zero (observed significance levels = 0.0136 and 0.0001, respectively). The regression has an R^2 of 0.7957. Figure 4 is a plot of predicted versus observed moisture content. The regression does not do very well at moisture contents below 6%, particularly when predicting dry seed cotton at lower mixpoint temperatures; this is why the intercept does come out of the origin. A 45° line coming out of the origin has been drawn in figure 4 to show what a one-to-one correspondence would be. Actual seed cotton moisture content averages 5.9 and 16.7% dry base for the dry and wet seed cotton, respectively, with standard deviations of 0.2 and 1.0%, respectively. Predicted seed cotton moisture content averages 3.3 and 16.7% dry base for the dry and wet seed cotton, respectively, with standard deviations of 3.4 and 3.2%, respectively.

Summary

Regressing the model against actual seed cotton moisture content results in an equation with an acceptable R^2 of 0.7957. Although the model does not work well at moisture contents below 6%, most gin plants have no reason to dry below this level. Hardware which used this model could simply ignore all readings below a particular value (such as 6%), and this would not affect the accuracy in the working range.

This is a simple model which uses a minimal number of measurements. More elaborate modeling would take into account separating the seed cotton into lint and seed fractions, and determining both the latent heat loss and moisture content of the conveying air. Splitting the seed cotton into lint and seed fractions in the model was tried, but the results were not as good as just treating the seed cotton as one entity. The lint moisture content at the mixpoint was not known, but there was probably no advantage to knowing it. Working with the seed cotton moisture content was sufficient although the lint portion of the seed cotton was the part receiving most of the heat in the short time interval.

The next step is to find suitable hardware which can handle the rather simple mathematics of the model, and then test the system in a gin plant. Minimal (if any) changes are needed in an existing gin plant. Most plants have a section of pipe just after the unloading, and thermocouples are simple to locate. Once air flow is known, it remains mostly a constant. The most costly and complicated part of the system will be the hardware used to analyze and interpret the data. The hardware can be a simple data logger which measures a few parameters and then calculates moisture content, or the hardware can be more sophisticated and also adjust dryer setpoints. Testing both the model and hardware is the next step in this research.

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Waldie, A. H., S. E. Hughs, and M. N. Gillum. 1984. Electronic moisture sensor performance in commercial gin environments. Transactions of the ASAE. Vol. 27(5):1600-1602.Table 1. Treatment definitions.

Table 1. Treatment definitions.

Treatment no	S/C cond. rate bales/hr		Mixpoint temp. deg. Fahrenheit	
	target	actual	target	actual
1	2.5	1.9	225	224
2	2.5	2.4	350	350
3	5.0	4.5	225	224
4	5.0	4.3	350	351

Table 2. Treatment means of conveying pipe air temperature with heated air only (no seed cotton), heated air with dry seed cotton, and heated air with wet seed cotton (see table 1 and figure 1 for treatment definition and temperature location, respectively).

	Temperature location									
Trt.	1	2	3	4	5	6	7	8	9	10
1										
air	224	214	215	215	214	214	213	212	208	187
dry	224	205	209	208	205	204	202	201	197	178
wet	224	204	207	206	202	201	199	197	192	171
2										
air	350	325	330	330	327	327	324	323	312	268
dry	350	308	314	312	307	306	302	299	290	251
wet	350	302	305	303	295	293	287	284	274	232
3										
air	224	213	215	215	213	213	212	211	206	182
dry	225	199	203	200	194	193	191	190	186	167
wet	224	197	197	194	186	184	180	178	173	152
4										
air	351	324	329	329	326	326	323	321	309	262
dry	351	296	299	297	286	285	280	277	269	234
wet	351	295	295	292	279	278	271	267	256	218

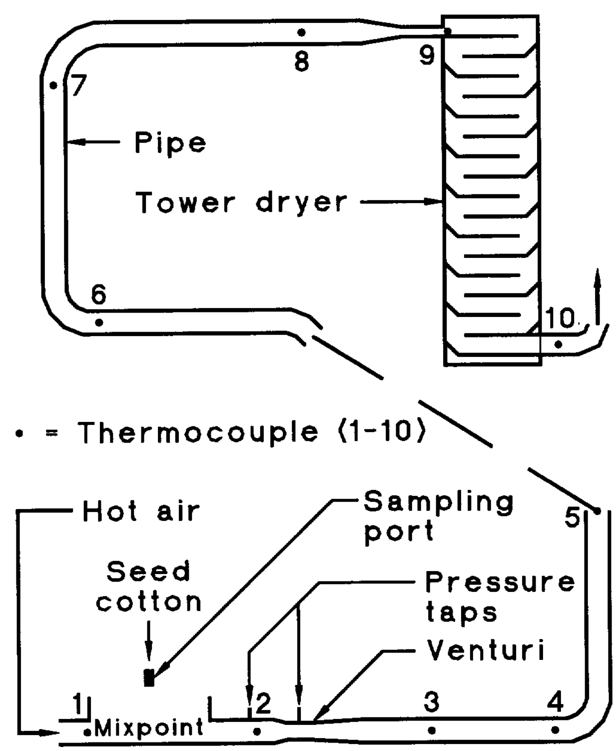

Figure 1. Pipe added between the dropper and 1st tower dryer.

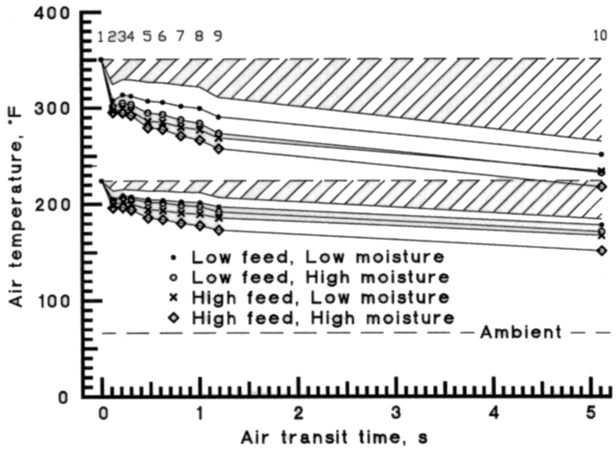

Figure 2. Air temperature vs air transit time between the mixpoint and bottom of the 1st tower dryer.

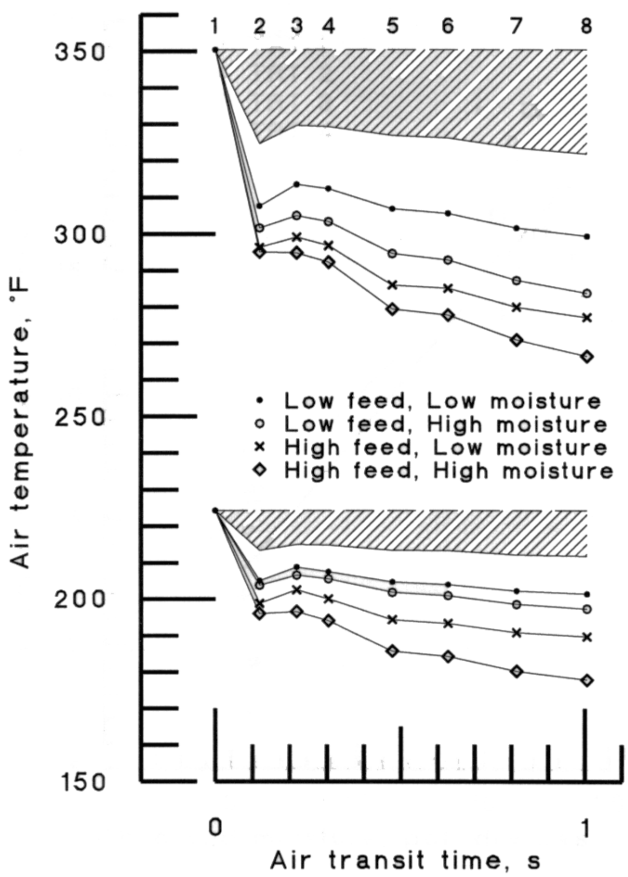

Figure 3. Air temperature vs air transit time between the mixpoint and pipe outlet.

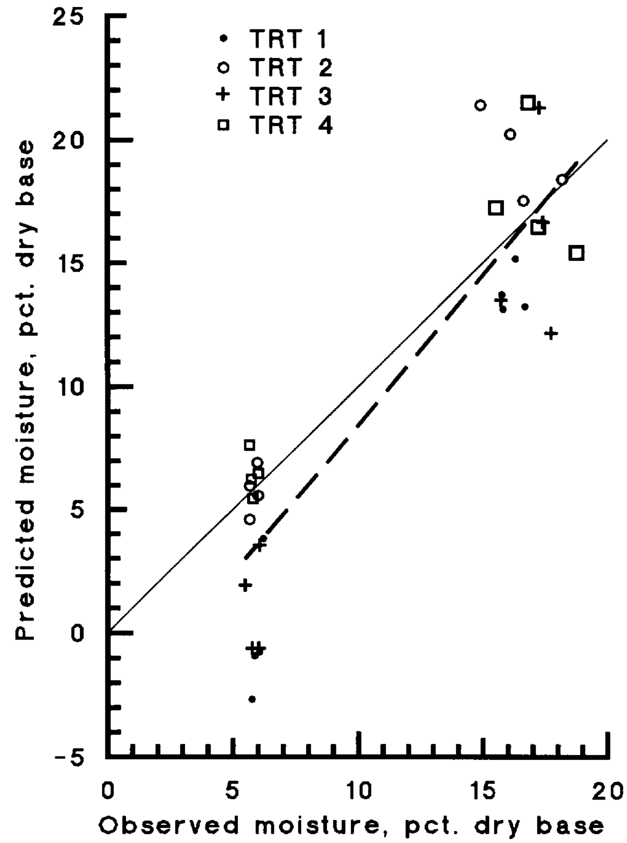

Figure 4. Predicted vs observed seed cotton moisture content.