AIR TEMPERATURE VARIATION ACROSS THE SEED COTTON DRYER MIXPOINT

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Abstract

Eighteen tests were conducted in six gins in the fall of 2008, to measure air temperature variation within various heated air seed cotton drying systems. The purpose of this study was to validate recommendations by a professional engineering society and to measure air temperature variation across the airflow ductwork preceding the mixpoint of seed cotton drying systems. The cooperating gins were located in west Texas, the San Joaquin Valley, California, and other locations in the western U.S. Drying systems tested include: tower, pipe, crossflow blow-box, hot box, hi-slip, fountain – collider type, and vertical type systems. Regarding air temperature variation across the airflow ductwork preceding the mixpoint of heated air seed cotton drying systems, five of the eighteen systems tested had significant variation in air temperature, ranging up to a temperature difference of 120 ^{o}F (67 ^{o}C) among the four locations tested. Drying systems which dispersed the drying air across large widths (up to 8 feet or 2.5 m), such as the crossflow blow-box and the hi-slip drying systems, were more likely to have a large variation than were systems which kept the drying air concentrated, such as the pipe, jet, and pipe-fed tower drying systems. Systems which were operated at higher temperatures (above 250 ^{o}F or 121 ^{o}C) also showed a larger variation in temperature than that for systems which were operated at a low temperature (below 200 ^{o}F or 93 ^{o}C). Further testing should be done that would investigate methods of reducing the temperature variation in drying systems in that area.

Introduction

A number of systems have been developed for removing moisture from seed cotton using heated air as the cotton is conveyed through the seed cotton cleaning equipment; Mayfield (1997) provides a review of many of these systems. The purpose of these systems is to remove moisture so that seed cotton cleaning can be more effective, while at the same time avoiding an adverse effect on the fiber and seed quality and minimizing the amount of additional energy required for operating the gin.

Heated air drying systems operate by supplying heated air (usually with a fan and a gas burner) and mixing it with a stream of seed cotton on a continuous-flow basis. The seed cotton is often added to the flowing air stream using an air lock feeder, although some systems have been developed that do not require this (such as the collider dryer, fountain dryer and hi-slip dryer). As the heated air and the seed cotton are mixed, the heated air temperature drops significantly due to sensible heat transfer from the air to the seed cotton (the seed cotton warms as the air cools) and due to latent heat transfer (moisture is evaporated from the seed cotton causing it to dry and the air to cool). As the seed cotton and air continue to flow through the length of drying system, the heated air temperature will continue to drop due to continued drying as well as heat transfer from the walls of the drying system (Hughs, et al., 1994).

The American Society of Agricultural and Biological Engineers (ASABE) has developed a standard regarding placement and temperature settings for the heater controls for seed cotton drying systems (ASABE, 2007). This standard recommends the use of two temperature controls for the heater, a primary sensor located in the airstream after the seed cotton and heated air have mixed, referred to as the mixpoint, and a maximum temperature control sensor located before the mixpoint. The standard also categorizes seed cotton drying systems into four types, including: 1) tower drying systems; 2) mechanical transport drying systems; 3) blow-box or towerless drying systems; and 4) fountain or other short residence-time drying systems.

Although not stated in the standard, the purpose of the primary sensor is to allow the system to respond to changes in the amount of seed cotton flow and to changes in the moisture content of the seed cotton (Hughs, et al, 1994). For example, if one of the gin stands is not working, then the temperature after the mixpoint would rise unless the primary sensor is in place to keep the temperature more constant. This prevents overdrying of and damage to the cotton fiber. The standard allows the gin personnel to set the desired temperature for the primary sensor control at whatever level is necessary, while the recommended location of the primary sensor depends upon which of the previously mentioned four types of drying systems.

The maximum temperature control is necessary to limit the temperature of the heated air and thus avoid the possibility of scorching or igniting the seed cotton in the system (Griffin, 1977). The standard states that the maximum temperature sensor control be set at 350 ^{o}F (177 ^{o}C) or lower, and that the location of the maximum temperature sensor be 10 feet (3 meters) or less ahead of the mixpoint.

The objectives of this study were to measure air temperature variation in various heated air seed cotton drying systems to validate the recommendations in ASABE standard S530.1, *Temperature Sensor Locations for Seed-Cotton Drying Systems* and to measure air temperature variation across the airflow ductwork preceding the mixpoint of heated air seed cotton drying systems.

Materials and Methods

With the assistance of the Texas Cotton Ginners Association and the California Cotton Growers and Ginners Association, cooperating gins were located in the West Texas and San Joaquin Valley, California, and other western U.S. locations. The gins were selected on willingness to cooperate and on type of drying system, so that most drying system types could be tested. The drying systems tested are listed in Table 1. Arrangements had been made to test nearly all dryer types, but some were not available for testing the day of the visit.

Table 1. Drying systems tested in the fall 2008 gin dryer study.

System type	Dryer type, number tested, and general location
Tower	Standard (6 – Calif.), Hot shelf (0), High volume (1 – Texas)
Mechanical transport	Belt dryer (0), Big reel dryer (0), Vertical (1 – Texas)
Blow-box or towerless	Pipe dryer (1 – Texas, 1 – Calif.), Crossflow blow-box dryer (2 – Calif.), Hi-slip dryer (1 – Calif.), Hot-box (3 – Texas)
Short residence-time	Collider dryer (1 – Texas), Fountain dryer (1 – Texas), Jet dryer (0)

At each gin, all drying systems in use (ranging from two to four per gin) were tested. Type T (copper-constantan) thermocouples were installed to measure air temperature at various locations in the drying system as well as the ambient air temperature. Four thermocouples were installed in the airstream before the mixpoint and no more than 10 feet (3 m) from the mixpoint. After the mixpoint, one thermocouple was installed every 6.5 feet (2 m), if possible, depending upon the type of drying system. For the purposes of this study, the mixpoint was defined as the midpoint of the conveyance length over which the cotton was added to the airstream.

A typical test lasted for two hours. Temperatures were recorded every 10 seconds using one Lascar thermocouple data logger (model EL-USB-TC) for each thermocouple. Thermocouple junctions in airstreams that were conveying seed cotton were somewhat likely to break. Broken thermocouple junctions were repaired when observed, if accessible. Four seed cotton samples of approximately 60 grams each were collected every 15 minutes during the test, two from the module or module feeder belt and another two from a gin stand or the overflow feeder for the gin stands. Seed cotton samples that were collected were weighed within five minutes of the time they were collected. One of each of the samples collected before and after drying was stored and shipped to the Southwestern Cotton Ginning Research Laboratory in Mesilla Park, New Mexico, for oven drying using a modified Shepard method. The other sample was hand-cleaned and then ginned immediately after weighing on a small portable roller gin 16 inches (40 cm) wide. Seed from this ginned sample was collected, weighed, and then stored and shipped to the Southwestern Cotton Ginning Research Laboratory in for oven drying. Lint from the ginned sample was discarded, since lint moisture changes rapidly. Lint moisture for the samples was determined from the seed cotton moisture, the seed moisture, and the initial seed cotton and seed sample weights using the equation:

Lint m.c., % w.b. = (Seed cotton m.c., %w.b. x Seed cotton wt., g – Seed m.c., %w.b. x Seed wt., g) / (Seed cotton wt., g – Seed wt., g)

Airflow through the drying system was determined either from measurements made by the gin before the current ginning season or by a Pitot tube measurement in the center of the air duct. Lint turnout was obtained from the gin records. The ginning rate (bales per hour) was determined by calculation based on the number of bales processed in an approximate 2 hour time period without a flow interruption. Airflow, lint turnout, and ginning rate were used to calculate the volume of conveying air to seed cotton ratio (cubic feet of air per pound of seed cotton) using the equation:

$$\textit{Air to seed cotton ratio } (ft^3/lb) = \textit{Airflow (cfm)} \times \textit{Turnout (\%)} / \textit{Ginning rate (bales/hr)} / 833.3$$

Other data recorded included location of burner controls and their set points, dimensions of duct transitions from pipe to dryer inlet, burner type, and static pressure drop across the dryer.

Results and Discussion

Tests Conducted

Eighteen dryers were tested in six gins located in west Texas, the San Joaquin Valley of California, and other western U.S. locations. Results for temperature differences across the heated air stream just ahead of the mixpoint have been analyzed and are presented in this paper. A summary of supporting data including airflow rate, ginning rate, turnout, air to seed cotton ratio, seed cotton moisture before and after drying, and temperature control information are listed in Table 2. In cases where two drying systems shared all heated air from the same dryer, the cells in the table are merged. Moisture data is over all drying systems in use, since the before drying sample was at the module feeder and the end drying sample was at or near the gin stand.

Table 2. Supporting data for drying systems tested in the fall 2008 gin dryer study.

System type	Airflow (cfm)	Gin. Rate (bale/hr)	Turnout (%)	Airflow (ft^3/lb)	Cotton moisture [1] before (%w.b.)	end (%w.b.)	diff. (%pt.)	Primary control used? & set point °F	Max. temp. control used? & set point, °F
Hot box 1	21,000	50	31	15.6	sc - 5.7	sc - 5.1	sc- .6	No	Yes - 126
Collider	18,500	25	31	27.5	s - 6.2	s - 6.1	s - 0.1	Yes- 100	Yes - 126
Fountain	19,000	50	31	14.1	l - 5.2	l - 4.4	l - 1.8	Yes- 100	Yes - 140
Hot box 2	NA	27	32	NA	sc - 7.1	sc - 6.2	sc- .9	Yes - 3.5	Yes - 350
Vertical	NA	27	32	NA	s - 7.3	s - 6.9	s - 0.4	(moisture)	
Pipe 1	NA	27	32	NA	l - 6.8	l - 5.2	l - 1.6	Yes- 100	Yes - 140
Hot box 3	26,000	30	31.6	32.9	sc - 7.0	sc - 5.7	sc- 1.3	NA	Yes - 325
Hi-vol tower	18,000	15	31.6	45.5	s - 7.3	s - 7.0	s - 0.3		
Pipe 2	13,500	15	31.6	34.1	l - 6.5	l - 3.9	l - 2.6	NA	Yes - 225
Pipe 3	26,750	15	31	66.3	sc - 9.9	sc - 6.9	sc- 3.0	Yes- 100	Yes - 380
CF blow-box 1	26,750	15	31	66.3	s - 9.9	s - 8.0	s - 1.9	Yes- 100	Yes - off
CF blow-box 2	12,000	15	31	29.8	l - 9.9	l - 4.1	l - 5.8	No	Yes - 395
Short tower 1	14,700	16.1	32	35.0	sc- 12.3	sc - 9.3	sc- 3.0	No	Yes - 300
Short tower 2	8,700	16.1	32	20.8	s - 12.6	s -	s - 0.6	Yes- 300	No
Short tower 3	8,100	16.1	32	19.3	l - 11.8	12.0	l - 7.0	Yes- 290	No
						l - 4.8			
Hi-slip	21,200	18	34	48.0	sc - 7.1	sc - 5.4	sc- 1.7	Yes- 200	No
Std. tower 1	10,600	18	34	24.0	s - 7.2	s - 6.4	s - 0.8		
Std. tower 2	10,700	18	34	24.3	l - 6.9	l - 4.0	l - 2.9	Yes- 175	No
Std. tower 3	8,600	18	34	19.5				Yes- off	No

[1] sc is seed cotton moisture, s is seed moisture, and l is lint moisture

Temperature variation of heated air across the dryer inlet (preceding the mixpoint)

Tower drying systems: Each of the two tower drying systems that were tested for temperature variation (the high-volume tower dryer and standard tower dryer 1) were 6 feet (1.8 m) wide and had little temperature variation among the three or four temperatures that were recorded approximately 10 feet (3 m) ahead of the mixpoint. Both of these systems used air ducts that fed into the center of the dryer. In the high volume dryer, inlet seed cotton / air mix temperature averaged 175 °F (79 °C) and temperature variation for the individual locations in the seed cotton flow stream were all less than 8 °F (4.5 °C) above or below the overall average. Temperature was lowest on one side of the dryer, channel 01 (Figure 1). This dryer also had heated air supplied to it; however, the location of the heated air duct was inaccessible for this test. In standard dryer 1, inlet air temperature averaged 135 ^{o}F (57 ^{o}C) and temperature variation for the individual locations in the air stream were all less than 2 ^{o}F (1 ^{o}C) above or below the overall average (Figure 2). The dip in temperature that is shown between 50 and 58 minutes into the test occurred because the burner was shut down to clean lint off of the inlet screen. Ginning continued during this cleaning process.

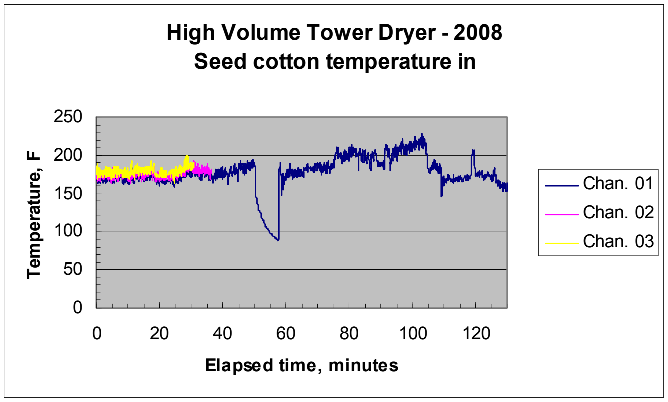

Figure 1. Temperature variation of the seed cotton flow stream 10 feet (3 m) preceding the mixpoint of a high volume tower drying system. Channel 01, channel 02, and channel 03 refer to the code numbers for the thermocouples as recorded by the data acquisition system. Note that thermocouples for channel 02 and channel 03 broke during the test.

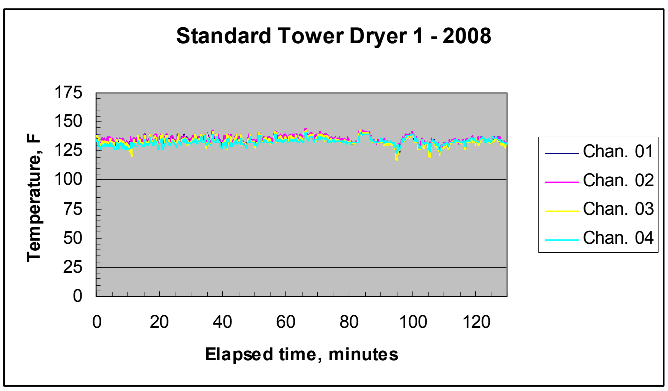

Figure 2. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of standard tower drying system 1. Channel 01, channel 02, channel 03 and channel 04 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

Pipe drying system: Pipe drying systems keep the mixed heated air and seed cotton flow stream concentrated in a smaller area than any of the other drying systems. In pipe drying system 3, the pipe diameter was 22 inches (56 cm) and had moderate temperature variation among the three temperatures that were recorded approximately 10 feet (3 m) ahead of the mixpoint. Inlet air temperature averaged 380 ^{o}F (193 ^{o}C) and temperature variation for the individual locations in the air stream were all less than 12 ^{o}F (6.5 ^{o}C) above or below the overall average (Figure 3). The pipe drying system used a high volume of air and kept the airflow concentrated within the small area of the duct, both of which were helpful in reducing the temperature variation. Temperature was lowest on one side of the dryer (channel 03).

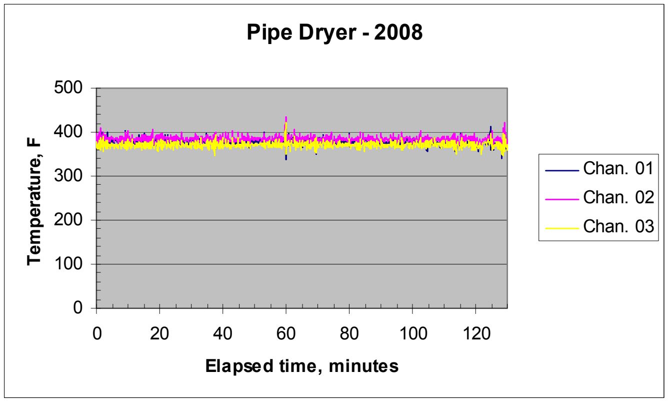

Figure 3. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of pipe drying system 3. Channel 01, channel 02, and channel 03 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

Crossflow blow-box drying systems: Each of the two crossflow blow-box (CFBB) drying systems were 8 feet (2.4 m) wide. Both of these systems used air ducts that fed into the center of the dryer. Some differences between the two systems were observed regarding temperature variation among the three temperatures that were recorded approximately 10 feet (3 m) ahead of the mixpoint. In the CFBB dryer 1, inlet air temperature averaged 300 ^{o}F (149 ^{o}C) and temperature variation for the individual locations in the seed cotton flow stream were all less than 10 ^{o}F (5.5 ^{o}C) above or below the overall average. Temperature was lowest on one side of the dryer, channel 01 (Figure 4). In CFBB dryer 2, inlet air temperature averaged 390 ^{o}F (199 ^{o}C) and a greater temperature variation for the individual locations in the air stream. This temperature variation was as much as 32 ^{o}F (17.5 ^{o}C) above or below the overall average. Temperature was lowest on both sides of the dryer, channels 01 and 03 (Figure 5). The airflow rate through CFBB dryer 1 was over twice that of CFBB dryer 2. The higher airflow rate may be the reason that the temperature variation was lower for CFBB dryer 1 than for CFBB dryer 2.

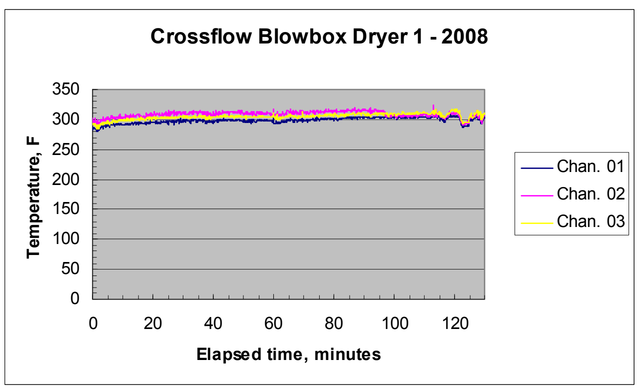

Figure 4. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of crossflow blow-box drying system 1. Channel 01, channel 02, and channel 03 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

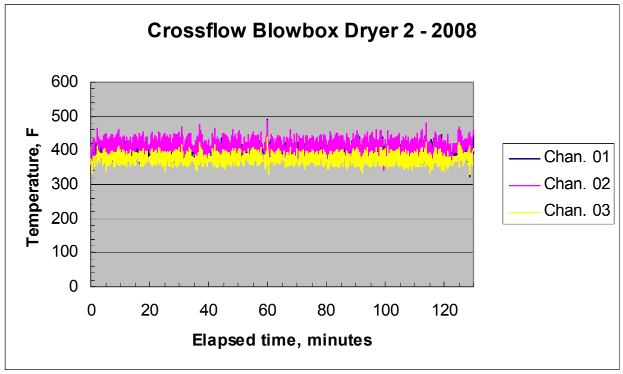

Figure 5. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of crossflow blow-box drying system 2. Channel 01, channel 02, and channel 03 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

Hi-slip drying system: The hi-slip drying system was 8 feet (2.4 m) wide and had little temperature variation among the three temperatures that were recorded approximately 10 feet (3 m) ahead of the mixpoint. This system was different from all other systems tested in that the air flowed into one end of the dryer (parallel to the dryer orientation rather than perpendicular to it). Inlet air temperature averaged 235 ^{o}F (113 ^{o}C). Average temperatures for the individual locations were all less than 4 ^{o}F (2 ^{o}C) above or below the overall average (Figure 6). Temperature variation was low for this dryer in which the air flowed into one end of the dryer; however, more tests would be needed to conclude that temperature variation would be lower when air flows parallel into the end of a long dryer rather than perpendicular into the center of the dryer. Temperature was lowest on both ends of the dryer (channels 01 and 03).

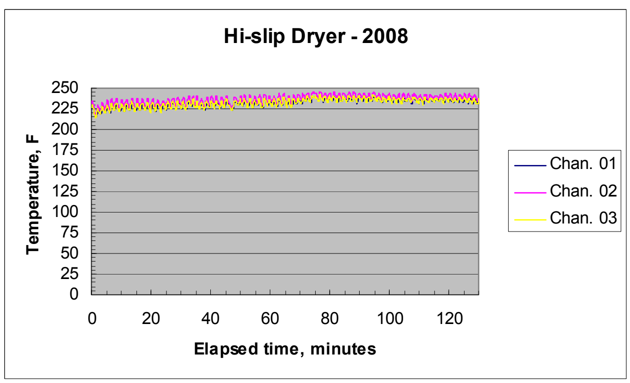

Figure 6. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of a high-slip drying system. Channel 01, channel 02, and channel 03 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

Hot box drying systems: Three hot box drying systems were tested. System 1 was 4 feet (1.2 m) wide and the other two systems were 3 feet (0.9 m) wide. For these systems, the higher the inlet air temperature, the greater the temperature variation. Inlet air temperature for hot box drying system 1 averaged 120 ^{o}F (49 ^{o}C) and average temperatures for the individual locations were all less than 12 ^{o}F (6.5 ^{o}C) above or below the overall average. Temperature was lowest over one half of the dryer, channels 01 and 02 (Figure 7). Inlet air temperature for hot box drying system 2 averaged 255 ^{o}F (124 ^{o}C) and average temperatures for the individual locations were all less than 16 ^{o}F (9 ^{o}C) above or below the overall average. Temperature was lowest on both sides of the dryer, channels 01 and 04 (Figure 8). Inlet air temperature for hot box drying system 3 averaged 320 ^{o}F (160 ^{o}C) and average temperatures for the individual locations were as much as 42 °F (23.5 °C) above or below the overall average. Temperature was lowest in the center of the dryer, channels 02 and 03 (Figure 9). Note that the large oscillations in temperature over short periods of time for hot box drying system 2 indicate that the burner control system was not well matched to the burner that was used. The match between control system and burner was better for hot box system 3 and best for hot box drying system 1.

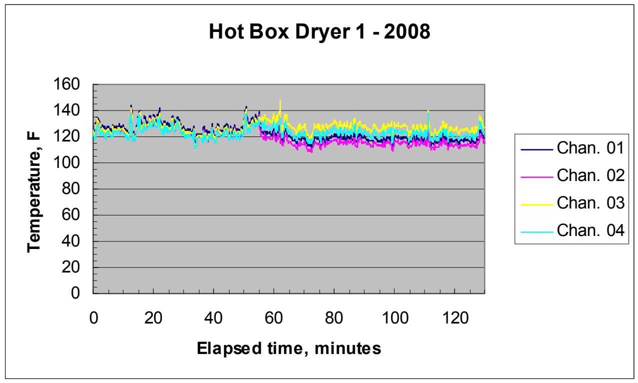

Figure 7. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of hot box drying system 1. Channel 01, channel 02, channel 03 and channel 04 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

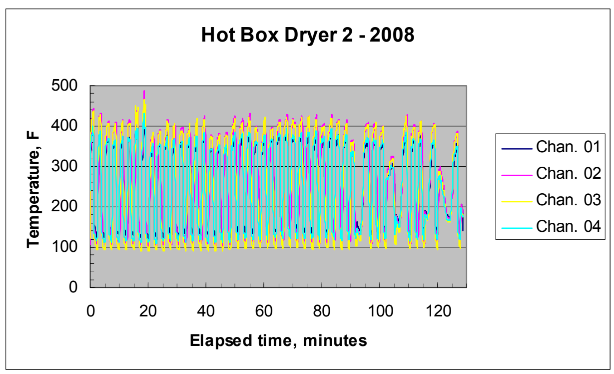

Figure 8. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of hot box drying system 2. Channel 01, channel 02, channel 03 and channel 04 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

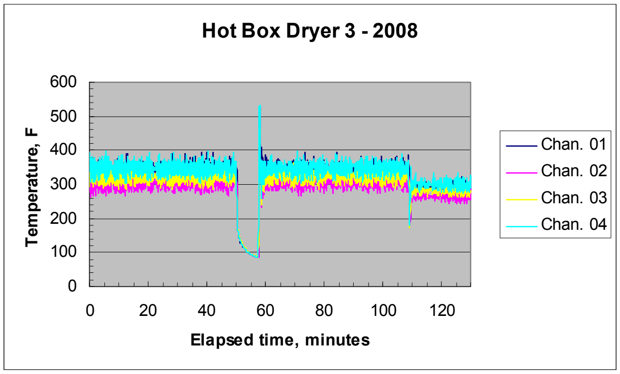

Figure 9. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of hot box drying system 3. Channel 01, channel 02, channel 03 and channel 04 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

Collider dryer: For the collider dryer that was tested, the dryer was a fountain dryer with a collider top. This system was 4.5 feet (1.4 m) wide and had the lowest temperature variation among the four temperatures that were recorded approximately 10 feet (3 m) ahead of the mixpoint of all drying systems that were tested. Inlet air temperature averaged 123 ^{o}F (51 ^{o}C). Average temperatures for the individual locations were all less than 1 ^{o}F (0.5 ^{o}C) above or below the overall average (Figure 10). This dryer also had a seed cotton / air mix stream supplied to it. The average temperature of the seed cotton /air mix stream was 90 ^{o}F (32 ^{o}C).

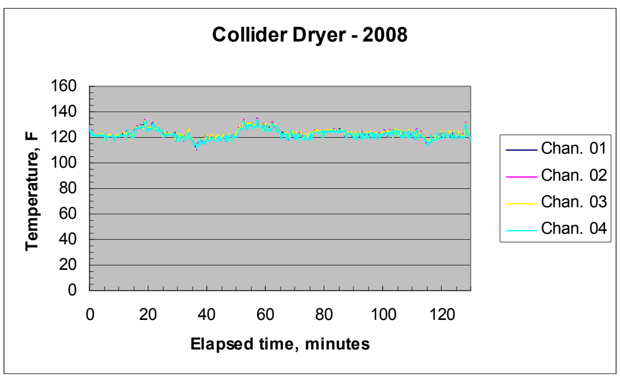

Figure 10. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of a collider drying system. Channel 01, channel 02, channel 03 and channel 04 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

Fountain dryer: A standard bottom-feed fountain dryer was also tested. This system was 4.5 feet (1.4 m) wide and had a higher temperature variation than the collider dryer among the four temperatures that were recorded approximately 10 feet (3 m) ahead of the mixpoint of all drying systems that were tested. Inlet air temperature averaged 138 ^{o}F (59 ^{o}C). Average temperatures for the individual locations were all less than 14 ^{o}F (8 ^{o}C) above or below the overall average (Figure 11). Drying temperature was slightly higher for this dryer than for the collider dryer and airflow rate was about half that of the collider dryer, both factors that may have contributed to the larger temperature variation. This dryer also had a seed cotton / air mix stream supplied to it. The average temperature of the seed cotton /air mix stream was 92 ^{o}F (33 ^{o}C). Temperature was lowest on one side of the dryer (channel 04).

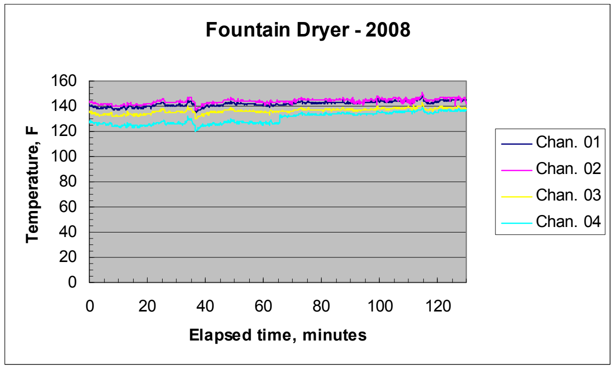

Figure 11. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of a fountain drying system. Channel 01, channel 02, channel 03 and channel 04 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

Vertical dryer: The vertical dryer tested was a Diamond K (Kimbell Gin Machinery Co., Lubbock, Texas). This system was 12 feet (3.7 m) wide and was fed by two ducts, each center-feeding half of the dryer. Inlet air temperature averaged 128 ^{o}F (53 ^{o}C). Average temperatures for the individual locations were all less than 9 ^{o}F (5 ^{o}C) above or below the overall average (Figure 12). Temperatures were lower in the center of the dryer (channel 02) than at the edges.

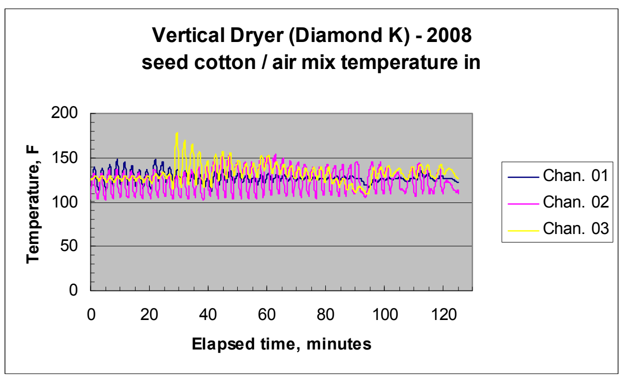

Figure 12. Temperature variation of the air stream 10 feet (3 m) preceding the mixpoint of a high-slip drying system. Channel 01, channel 02, and channel 03 refer to the code numbers for the thermocouples as recorded by the data acquisition system.

Summary and Conclusions

Tests were conducted in the fall of 2008, to measure air temperature variation along various heated air seed cotton drying systems, with the purpose of validating recommendations in the ASABE standard S530.1, *Temperature Sensor Locations for Seed-Cotton Drying System.* The study also measured air temperature variation across the airflow ductwork preceding the mixpoint of heated air seed cotton drying systems, with the purpose of checking for large temperature differences that may exist. The cooperating gins were located in the West Texas and San Joaquin Valley, California, and other locations in the western U.S. Drying systems tested include: standard tower, short tower, high volume tower, pipe, crossflow blow-box, hi-slip, hot box, collider, and fountain types of drying systems. Results for temperature differences across the heated air stream just ahead of the mixpoint have been analyzed and are presented in this paper.

A summary of the data follows with results listed from least to greatest variation (Table 3). Greater temperature variation was observed in systems with higher drying temperatures, as with the three hot box drying systems. Greater temperature was also observed in systems with lower airflow rates, as with the two crossflow blow-box dryers. Among the types of drying systems tested, the hot box systems appear to have the highest temperature difference, although the hi-slip dryers had the largest differences in tests conducted in 2007 (Baker, 2008). In this past study, temperature variation ranged up to a temperature difference of 120 ^{o}F (67 ^{o}C) across the four inlet locations tested.

Table 3. Summary of observed temperature variations and factors that may have contributed to temperature differences.

Drying system	Temperature variation, ^{o}F	Location of lowest temp.	Dryer width ft	Average drying temperature, ^{o}F	Airflow rate, ft^3/lb seed cotton
Collider	1	NA	4.5	123	27.5
Standard tower 1	2	NA	6	135	24.0
High slip (end feed)	4	both sides	8	235	48.0
High-vol. tower	8	one side	6	175	45.5
Vertical	9	center	12	128	NA
Crossflow blow-box 1	10	one side	8	300	66.3
Pipe 3	12	one side	2	380	66.3
Hot box 1	12	one half	4	120	15.6
Fountain	14	one side	4.5	123	27.5
Hot box 2	16	both sides	3	255	NA
Crossflow blow-box 2	32	both sides	8	390	29.8
Hot box 3	42	center	3	320	32.9

The data also indicate that more education is needed for gin managers and operators, so that existing recommendations concerning location of temperature control sensors and maximum drying air temperatures are more closely followed.

Disclaimer

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U. S. Department of Agriculture.

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