RELATIVE VELOCITY EFFECTS ON COTTON MOISTURE TRANSFER RATES

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Abstract

Moisture control during the harvesting, storage, and processing phases of cotton production is essential for producing a quality product. We are attempting to quantify the moisture transfer rates for cotton and its component parts during the drying process. We measured moisture transfer rates in cotton lint, cotton burs, and gin run cottonseed at 104 °F and cotton lint at 176 °F using humid and dry air at relative velocities varying from 10 to 100 ft/min. As relative velocity increased for burs in humid air and on cotton lint at 176 °F, the moisture transfer rates increased. However, all other test conditions showed little or no response to relative velocity. Increasing lint density was found to decrease moisture transfer rates.

Introduction

Controlling moisture during the cotton harvesting and processing phases is a major concern to cotton producers and ginners. Development of methods to control moisture during ginning has been a major priority of the U.S. Cotton Ginning Research Laboratories, since their inception. Fiber deterioration (especially color) along with reduced yields can result from excessive moisture during cotton harvesting (Barker et al., 1979 and Barker, 1982). Leonard et al. (1970) showed that cleaning efficiency was improved when the cotton was dried early, however, excessively dry cotton is subject to fiber breakage and results in operating difficulties (static electricity) during the ginning process (Childers and Baker, 1978). Thus, the optimum moisture content, for the ginning process, is a compromise and is reported to be in the 6-8 percent range (Griffin, 1977).

Moisture, like most other vapor or liquid mixtures, is transferred from a region with high vapor pressure (or concentration) to a region of lower vapor pressure potential. The rate of transfer is dependent on the gradient between the two areas. This gradient can be enhanced by temperature or by reducing the distance between the two regions of interest. Thus, cotton machinery manufacturers use increased relative velocity to reduce the boundary layer and increase the gradient for drying cotton. Hughs, Mangialardi and Jackson (1994) list dryer types as reel-type, tower, tower hybrid, and towerless systems. They indicate that the air volume used, for these dryers, varies from 20 cubic feet per pound to 50 cubic feet per pound of seed cotton depending on dryer type.

The objective of this study was to determine the effect of relative air velocity on absorption and desorption (drying) rates for gin-run cottonseed, cotton burs and cotton lint under controlled temperature and humidity conditions. The air flow rate used ranged from 0.22 to1.75 CFM through a 2.75 inch diameter pipe. The results will be useful to scientists developing models for ginning and harvesting systems and to engineers designing conditioning systems for the cotton processing industry.

Equipment and Test Procedure

The equipment assembled by Barker and Laird (1997) was used to control temperature, humidity and air velocity in this study. A Wilkerson compact heatless dryer was used to provide a continuous source of dry air. Saturated air was generated by bubbling air through a column of water and a mist created with a spray nozzle. Three constant-temperature water baths were used to control the temperature of the sample, the humidification tank and the dew point temperature of the humid air. The dew point temperature of the air was measured with a General Eastern Hygro M2 Dew point sensor located upstream of the sample chamber. Small thermocouples (type J, iron-constantan) and Platinum RTD sensors were inserted into the sample chamber up and down stream from the sample to provide an indication of the air temperature surrounding the sample.

Air entered the top of the sample chamber and then flowed around the sample before exiting to the atmosphere, Figure 1. The flow rate was controlled with needle valves and measured using a Brooks variable area flow meter with an accuracy of 0.025 CFM and a range of 0.22 to 1.75 CFM. We found that the equipment used to generate humid air did not have sufficient capacity to handle the flow rates above 1 CFM for any length of time. The temperature used for this study was 104 °F for both the hydration and dehydration cycles of burs, seed and lint. A temperature of 176 °F was also used for hydration and dehydration of the lint. The sample size was approximately 3 g, for seed (28-30 seed) and burs and between 1 and 2 grams for the lint. The devices used to hold the samples in this experiment are shown in Figure 2.

A Hewlett Packard data logger (model 75000) was used to record all the test information which included weight, temperature, dew point temperature, barometric pressure, velocity pressure and time. A one second interval was used for data collection during the first ten minutes of the study, followed by a fifteen second interval for the next eight hours. This was followed by a two minute sampling interval for the remainder of the experiment.

The samples were placed in the proper position in the chamber and conditioned in dry air at the test temperature

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until dry, then conditioned in humid air (90-95% RH) until equilibrium was reached. The sample was then exposed to dry air until equilibrium was reached (no change in weight). The final step was to expose the sample to air at or above 212 °F for the necessary time to determine the true dry weight of the sample.

Results

Plots of the normalized moisture content (percent dry basis) show an exponential decrease with time until the sample approaches equilibrium (Figures 3-5). This is analogous to a falling-rate drying process. The classical three dimensional diffusion equation can be used to describe this phenomenon (Newman, 1932):

$$\frac{\partial c}{\partial \theta}=k\left(\frac{\partial^2 c}{\partial x^2}+\frac{\partial^2 c}{\partial y^2}+\frac{\partial^2 c}{\partial z^2}\right) \quad \textbf{(1)}$$

Where:

- θ = Elapsed time, Hours
- **c** = concentration of water vapor
- **k** = diffusivity (diffusion coefficient) (m^2/h)
- **x, y,** and **z** are Cartesian coordinates.

Newman (1932) presented solutions of equation 1 for a flat plate, a sphere, a cylinder and combinations thereof for drying by diffusion. All of the solutions presented were infinite series. A simplified version of the solution to equation 1 presented by Newman is:

$$\frac{M-M_E}{M_O-M_E}=\beta\left(\frac{1}{\alpha}e^{-\alpha D\theta}+\frac{1}{\gamma}e^{-\gamma D\theta}+\frac{1}{\eta}e^{-\eta D\theta}...\right) \quad \textbf{(2)}$$

$$D=D_0 e^{-\frac{A}{T}} \quad \textbf{(3)}$$

Where:

- **M** = Moisture content, % dry basis, after a period of time, θ
- $\mathbf{M_0}$ = Initial moisture content, % dry basis, at time zero
- $\mathbf{M_E}$ = Equilibrium moisture, % dry basis, moisture content when the air and the lint are in equilibrium (stagnant sample weight)
- **D** = Coefficient containing diffusivity, hr^{-1}
- $\mathbf{D_0}$ = Coefficient D when $\mathbf{T} \simeq \infty$, hr^{-1}
- **A** = A constant
- **T** = Absolute Temperature, °K
- β = $6/\pi^2$ for the spherical solution. (Actual value used should produce a value of 1 when $\theta = 0$, therefore, we used 0.7346 for the 3 term model).
- α = 1 for the spherical solution.
- γ = 4 for the spherical solution.
- η = 9 for the spherical solution.

Henderson and Perry (1979) showed that the term, D, containing diffusivity in equation 2 is a function of temperature, equation 3. They stated that it can be related to the temperature of the drying air, although technically it should be the temperature of the drying object.

The SAS procedure, Proc SYSNLIN, (Freund et al., 1986) was used to determine the value of D, in Equation 2, for each individual data set. Values for $\mathbf{M_0}$ and $\mathbf{M_E}$ used in equation 2 were determined from the individual data sets.

Examination of equation 2 shows that the value of the coefficient D approaches the value of the slope of each individual curve when the data is transformed to logarithmic form. Thus, the larger the value of the coefficient D, the faster the drying rate.

The values of the coefficient D (using a three term model in equation 2) are shown plotted, for each cotton component tested, against the relative velocity for that component in Figures 6-11. Examination of this data shows that, at 104 °F, the relative velocity, within the range tested, had no significant effect on the value of D for lint and seed when exposed to either humid or dry air. There was also no effect for the burs exposed to dry air at this temperature. However, burs exposed to humid air (relative humidity between 90 and 95 %) showed a definite response to relative velocity at 104 °F, Figure 10. Increasing the temperature to 176 °F, resulted in noticeable increases in moisture transfer rates with increasing relative velocity, Figures 6 and 7. Lint density (0.57 to 1.27 lbs/ft^3) was also found to have a significant effect on the moisture transfer rates of cotton lint, Figure 12.

Additional work, using higher relative velocities and a wider range of lint density, needs to be conducted.

Summary

The objective of this study was to determine the effects of relative velocity on moisture transfer rates of cotton and itscomponent parts. Cotton lint was exposed to two temperatures, 104 and 176 °F, and a range of air flow rates ranging from 0.22 to 1.75 CFM (relative velocity 10 to 100 ft/min) using dry and humid air. Cotton burs and gin run cotton seed were exposed to the same flow rates (and same relative velocities) as the lint but only one temperature, 104 °F. The results indicate that for this limited range of air velocities, only the burs exposed to humid air showed a significant response to relative velocity at 104 °F. There was an increase in moisture transfer rates with increasing relative velocity for the lint exposed to 176 °F. The moisture transfer rates of lint were shown to vary with density (from 0.57 to 1.2 lbs/ft^3) at 104 °F.

Mention of a trade name, proprietary product or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply approval of the product to the exclusion of others that may be available.

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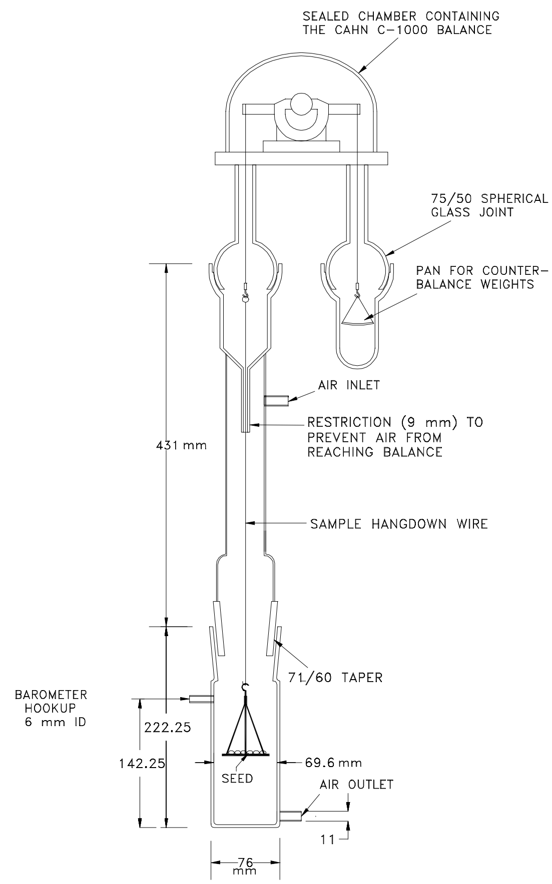

Figure 1. Air tight chamber used to house the Cahn C-1000 balance assembly and the attached glassware containing the acid-delinted cottonseed. Dimensions are in nm.

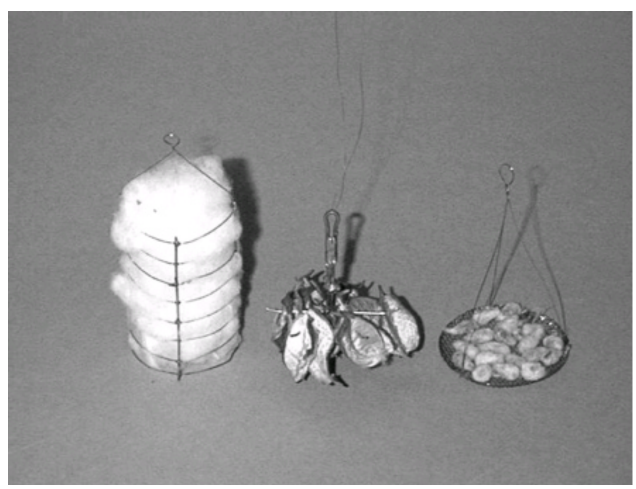

Figure 2. Sample holders for lint, burs, and seed. Two baskets were used for lint, the smallest was 2.27 in^2 and the largest was 3.10 in^2 in cross sectional area. The burs occupied approximately 2.24 in^2 and the seed hanger occupied 2.16 in^2.

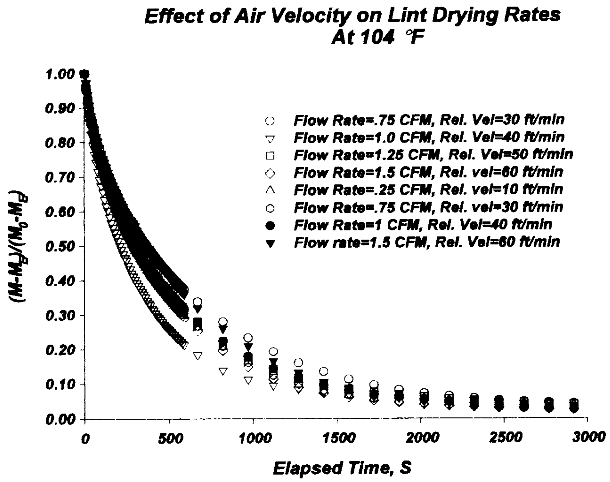

Figure 3. Sample runs for lint, using dry air at 104 °F. Only every 10th data point is shown for clarity.

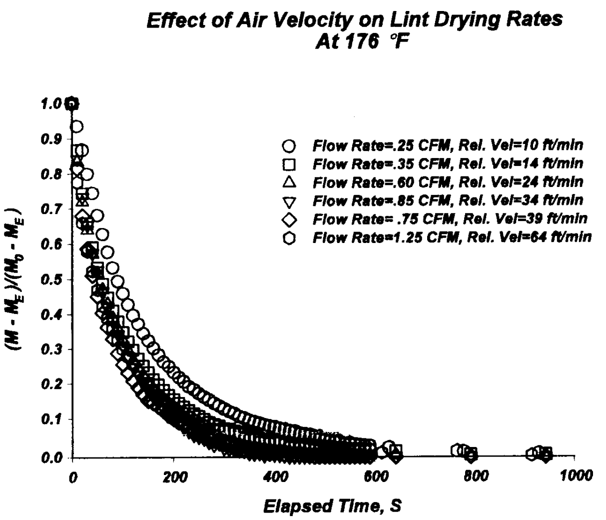

Figure 4. Sample runs for lint using dry air at 176 °F. Only every 10th data point is shown for clarity.

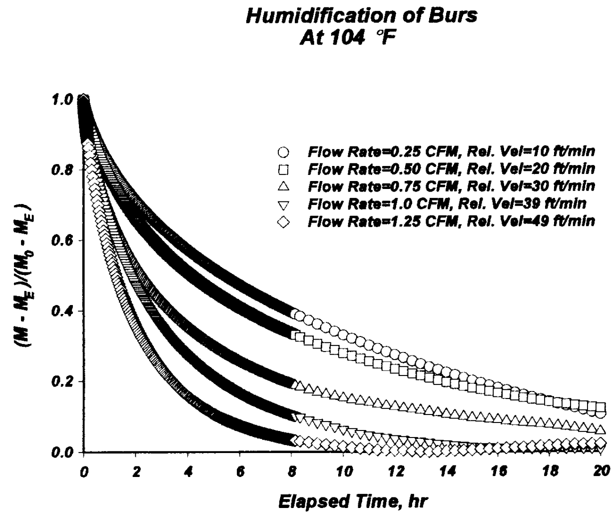

Figure 5. Sample runs for burs (hulls) using 104 °F air with relative humidity ranging from 90 to 95%. Only every 10th data point is shown for clarity.

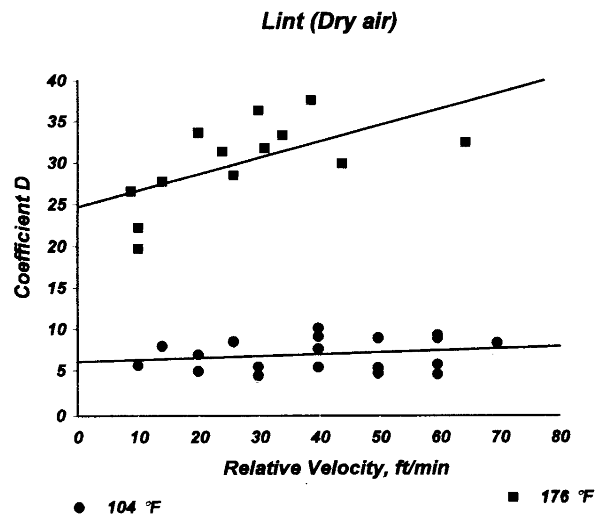

Figure 6. Effects of relative velocity on the coefficient D (from equation 2) for cotton lint exposed to dry air at 104 and 176 °F.

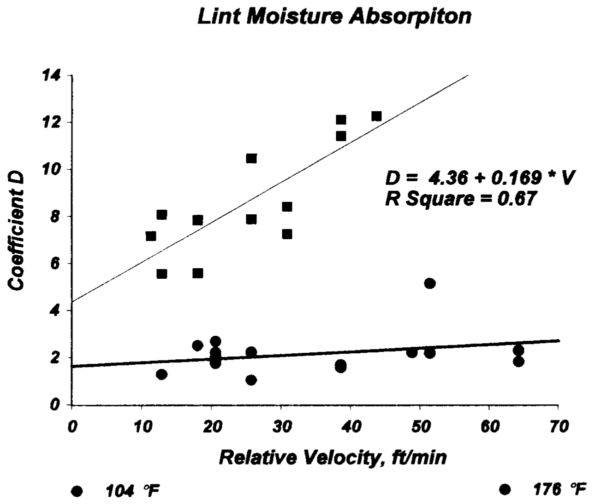

Figure 7. Effects of relative velocity on the coefficient D for lint moisture absorption when exposed to humid air at 104 and 176 °F.

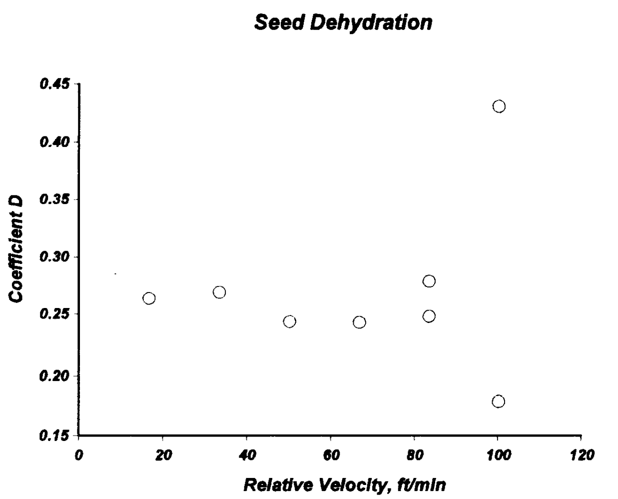

Figure 8. Effects of relative velocity on the coefficient D for gin run cottonseed exposed to dry air at 104 °F.

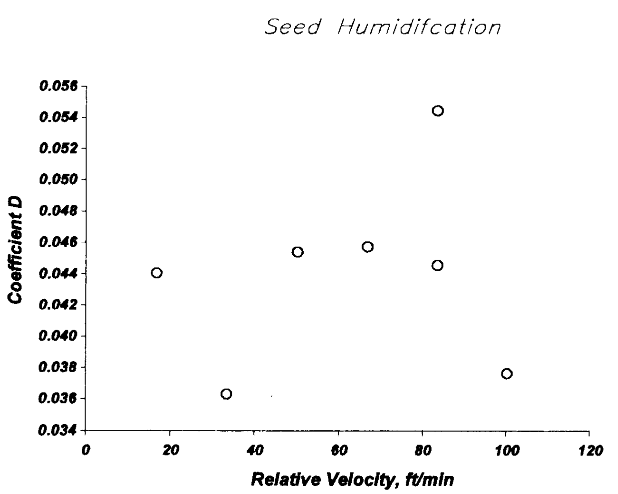

Figure 9. Effects of relative velocity on the coefficient D for gin run cottonseed exposed to humid air (relative humidity between 90 and 95%) at 104 °F.

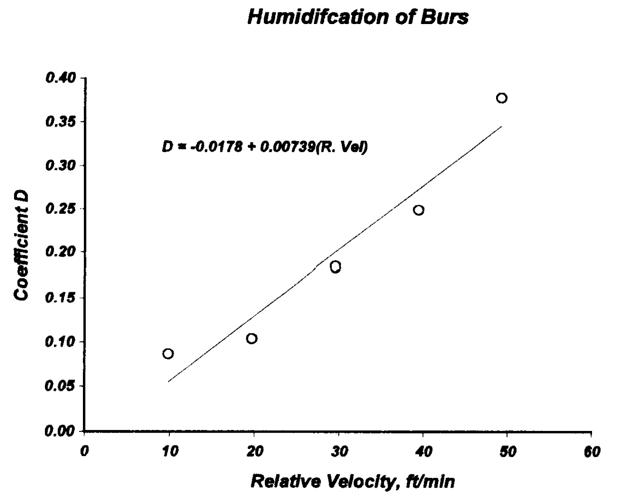

Figure 10. Effects of relative velocity on the coefficient D for cotton burs (hulls) exposed to humid air (relative humidity between 90 and 95%) at 104 °F.

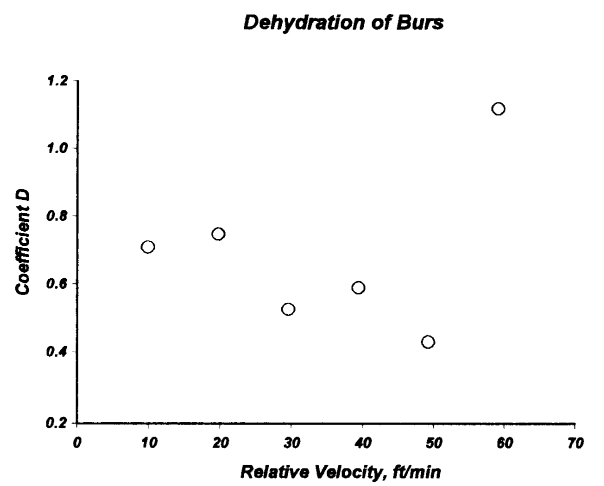

Figure 11. Effects of relative velocity on the coefficient D for cotton burs (hulls) exposed to dry air at 104 °F.

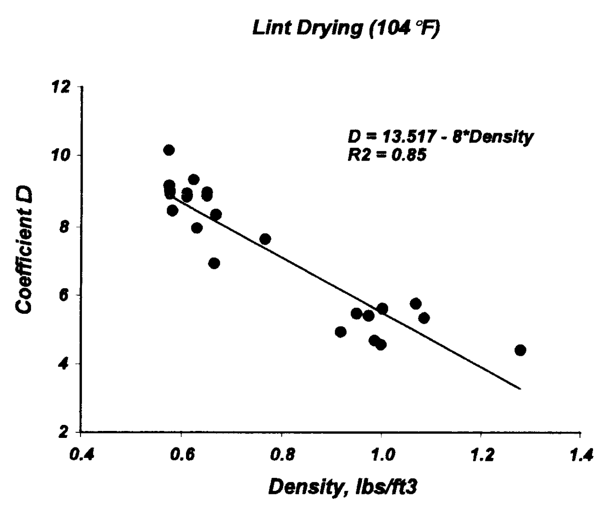

Figure 12. Effects of density on the coefficient D for lint exposed to dry air at 104 °F.