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THE curing process in a burley tobacco facility is an important step in the preparation of the tobacco for sale on the warehouse floor. The environmental conditions that are present during this process largely determine the success or failure of the cure as measured by the quality of the end-product. Among the factors that affect the tobacco quality are the temperature and relative humidity of the ambient air, the rate of air flow within the curing facility and the moisture content of the tobacco.

A deep-layer drying model for burley tobacco (Bridges et al., 1981) has been developed to predict temperature, humidity and tobacoo moisture content during the curing process. The model can aid both the tobacco producer and researcher alike to understand better the curing process and to determine proper management strategies that will enhance the quality of the final product. As a necessary step in any model development, the values predicted by the drying model were compared to existing data as a measure of the accuracy and usefulness of the model.

OBJECTIVES

The objective of the study reported in this paper was to validate the one-dimensional drying analysis used in the deep-layer drying model. This was to be accomplished by comparing the predicted temperatures and relative humidities of the drying model with observed data collected from a solar curing facility during the curing process. This allowed a means of verifying the procedure used in predicting these values and its usefulness in evaluating the conditions during the drying process.

MODEL BACKGROUND

The drying model (Bridges et al., 1981) was designed to predict temperatures and relative humidities in a burley curing facility as a function of the ambient weather and wind conditions during the curing season. The model was developed using a three-dimensional analysis. The one-dimensional analysis consisted of dividing the curing facility into a rectangular grid of equally spaced points, allowing the grid points facing the wind to assume the values of the ambient temperature and humidity and then predicting the temperatures, humidities and tobacco moisture content for the remaining grid points in the direction of the wind. A second dimension was added to the model by allowing the wind to approach the barn from eight different directions providing a capability of analyzing the drying process with varying airflow directions through the grid. The third dimension involved consideration of the solar heating of the roof and the temperature rise of the drying air due to heating of the boundary layer. This allowed the model to calculate temperatures and humidities at selected depths throughout the barn as well as those at each grid point.

In the one-dimensional model analysis, drying always occurs from point to point along the grid path in the direction of the airflow and is an adiabatic process. The model calculates temperature and humidity at each suceeding point based on the existing air conditions, the mositure content of the tobacco, and the amount of moisture given up at the previous grid point. The entire grid is analyzed in this manner for a given time interval. As a new time interval is begun, the model notes changes in the ambient temperature, humidity or wind direction and continues the analysis. The distance between grid points is always of equal spacing and is determined by the barn geometry with the plane of the grid being parallel to the barn floor. For a detailed discussion of the procedure used in the model the reader is referred to Bridges et al. (1981).

The drying model was developed primarily for use with a three-tier conventional-type curing facility. A major conclusion during the model development was that these facilities are dependent upon the changing wind directions and the natural variation of the air currents for successful quality cures. While the model was developed with this in mind, these air flow rates are small, extremely difficult to measure and may not be maintained in a constant direction for any substantial period of time. For purposes of validating the one-dimensional model analysis a more controlled situation was desirable for comparison of results.

PROCEDURE

A solar curing structure containing three separate curing chambers (Walton et al., 1980) was instrumented during the 1977 curing season to evaluate the capabilities of forced ventilation using solar heat. This structure was designed to simulate the two-tier forced ventilation barn developed at the University of Kentucky (Bunn et al., 1973). The curing chambers consisted of a conventional unheated chamber with a metal roof and two solar chambers with an insulated and uninsulated rock bed, respectively. The tobacco was loaded on the tier rails in each chamber at approximately 6.6 sticks/m (2 sticks/ft) while a fan positioned above the tier rails provided a constant ventilation rate of 4.57 m/min (15 ft/min) down through the robacco. Thermocouple psychrometers were placed directly above and below tobacco in each

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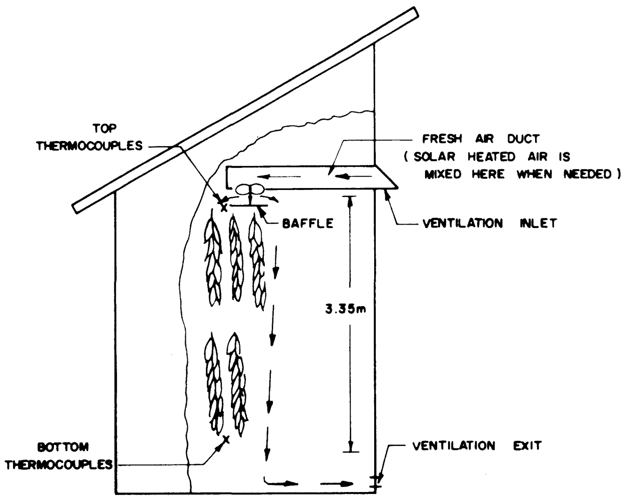

FIG. 1 Schematic diagram of solar curing facility.

chamber. This represented a vertical spacing of 3.35 m (11.0 ft) between psychrometers in the direction of the airflow (Fig. 1).

The solar curing facility was filled with tobacco at approximately midday on September 9, 1977. The dry and wet bulb temperatures were recorded at the aforementioned points for each chamber over the entire curing season. Generally the values were recorded at 6-h intervals but in some instances a 3-h interval was also used. The first 279 h (11.6 days) of recorded temperatures for both the conventional chamber and the solar chamber with the insulated rock bed were selected as observed data for this study. This initial period is generally the most important in the curing process and the time when the model predictions would be most critical. The dry and wet bulb readings were used to determine the relative humidity at the indicated points for each time interval and these values were used to compare with simulated data from the model.

For this study it was decided to use the observed temperature and humidity at the top of the upper tier rail for a given time interval as the initial or "ambient" values for the model and then predict the temperature and humidity at a distance equal to that between the observed points in the curing facility [(3.35 m)(11.0)ft]. A grid length of 0.84 m (2.75 ft) was chosen so that the model also predicted the temperature and humidity at intermediate points of 0.84 m (2.75 ft), 1.68 m (5.5 ft), and 2.51 m (8.25 ft). This provided the equal grid spacing necessary for the model and examination of the accuracy of the one-dimensional procedure over several grid points. As a measure of model accuracy the standard error of the differences between the predicted and observed temperatures and humidities at the 3.35 m distance was calculated. This was done separately for each chamber as well as both combined for the 51 time intervals in the observed data. The intermediate grid values were not used in the calculation of standard error since observed values were not available.

The moisture content and drying rate of the tobacco are other factors that influence the temperatures and humidities within a curing facility. For this report the initial moisture at loading was estimated to be 700 percent (db). Bunn et al. (1972) determined the exponential drying constant to be a function of the environment as follows:

TABLE 1. THE STANDARD ERROR VALUES FOR THE SIMULATED TEMPERATURE AND HUMIDITIES FOR ANALYSIS NUMBER 1

Drying constant = 2.14×10^{-8} Airflow rate = 4.57 m/min

Initial moisture = 700 percent db Grid interval = 0.84 m

Chamber	Number of observations	Simulated time, h	Standard error temperature at 3.35 m °C	(°F)	Standard error R.H. at 3.35 m %
Solar	51	279	0.73	(1.31)	5.77
Conventional	51	279	0.65	(1.17)	5.51
Combined	102	—	0.68	(1.23)	5.61

$$K = 2.14 \times 10^{-8}\ G \quad [1]$$

where G is the moisture deficit of the drying air, kg H_2O/kg dry air. While this expression is for the tobacco leaf alone the solar curing facility was loaded with whole plants which includes the stalk as well as the leaves. The overall drying rate of the whole plant is lower than that of the leaf alone. To consider this reduced rate of drying, a second analysis was conducted with the exponential drying constant arbitrarily expressed as:

$$K = 1.427 \times 10^{-8}\ G \quad [2]$$

This allowed an evaluation of the model at two different drying rates for both chambers.

RESULTS AND DISCUSSION

Tables 1 and 2 present the standard errors of the simulated temperatures and humidities for both chambers at each drying rate. Included in each table is the number of observed time intervals that were simulated, the total curing time of all observations in hours, the standard error of the predicted temperature °C (°F) and the standard error of the predicted relative humidity in percent. Also presented in each table is the drying contant used for that analysis and the combined standard errors for both chambers.

The standard error values in Tables 1 and 2 generally indicate that the model was effective in predicting the temperature and humidities throughout the simulated time period. The standard error of the predicted temperatures ranged from ± 0.61 °C (1.10 °F) to ± 0.73 °C (1.31 °F) over both analyses while that of the relative humidity varied from ± 5.19 percent to ± 4.77 percent. These ranges would indicate that the one-dimensional drying analysis in the model could ade-

TABLE 2. THE STANDARD ERROR VALUES FOR THE SIMULATED TEMPERATURES AND HUMIDITIES FOR ANALYSIS NUMBER 2

Drying constant = 1.427×10^{-8} Airflow rate = 4.57 m/min

Initial moisture = 700 percent db Grid interval = 0.84 m

Chamber	Number of observations	Simulated time, h	Standard error temperature at 3.35 m °C	(°F)	Standard error R.H. at 3.35 m %
Solar	51	279	0.64	(1.15)	5.19
Conventional	51	279	0.61	(1.10)	5.27
Combined	102	—	0.62	(1.12)	5.20

TABLE 3. PREDICTED AND OBSERVED TEMPERATURE AND RELATIVE HUMIDITY MEANS

				Analysis 1			Analysis 2		
Chamber	Observed mean temp. °C	(°F)	Observed mean R.H. %	Predicted mean temp. °C	(°F)	Predicted mean R.H. %	Predicted mean temp. °C	(°F)	Predicted mean R.H. %
Solar	20.8	(69.4)	79.9	20.2	(68.4)	84.3	20.5	(68.9)	81.9
Conventional	19.9	(67.9)	85.3	19.5	(67.2)	88.7	19.8	(67.7)	86.7

quately predict environmental conditions for a constant airflow rate. While the standard errors for analysis 2 (Table 2) were less than those for analysis 1 (Table 1), the small reduction gained by reducing the drying constant by one-third would indicate that the model was not sensitive to this parameter for the early stages of curing. The drying constant will become more important during the latter stages of the cure when equilibrium conditions between the tobacco and air are less likely to occur.

One trend that was noted in the predicted values, was that the model generally over-estimated the drying rate for a given time increment. While this was not to a large degree as shown by the standard errors, generally the predicted temperature was lower than that of the observed value and the predicted relative humidity was larger than the observed value indicating a higher rate of moisture removal by the model than was actually taking place. This conclusion is further borne out by the data in Table 3 showing the predicted and observed temperature and relative humidity means. For both analyses and both chambers the predicted temperature means were smaller than the observed values while the predicted relative humidity means were larger than those of the observed data. Figs. 2 and 3 give a general idea of the range of observed temperatures and humidities for the solar chamber as well as the entire study and show how well the model predicted these values in analysis 2.

It was noted that the observed data contained several time periods (9 for the solar chamber, 11 for the conventional) that were not of a drying nature. These time periods were characterized by a temperature increase and humidity decrease between observed points and since the model does not consider rewetting of the tobacco these values could not be accurately predicted. Table 4 presents the standard errors for the simulated temperatures and humidities with the rewetting periods removed. It can be seen that this was most effective in improving the estimate of the relative humidity over those in Tables 1 and 2. The improvement gained by eliminating these values would indicate that an analysis of rewetting or moisture sorption by the tobacco similar to that used in grain drying models is a necessary addition to the model in future work.

SUMMARY

A deep-layer drying model for tobacco was used to predict the temperatures and relative humidities in a solar curing facility. Temperatures and humidities were simulated at a depth of 3.35 m for 2 curing chambers and 2 drying rates. The standard error of the difference between the predicted and observed values was used to measure the model accuracy. Overall, the standard error indicated that the model was effective in predicting the temperatures and humidities throughout the curing process and that the procedure used in the model was valid. It was also found that the model does over-predict the drying rate and a necessary improvement in the model would be consideration of the tobacco rewetting.

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TABLE 4. THE STANDARD ERROR VALUES FOR THE SIMULATED TEMPERATURES AND HUMIDITIES AFTER REMOVAL OF THE REWETTING TIME PERIODS

Analysis	Chamber	Number of observations	°C	(°F)	Standard error R.H. at 3.35 m %
1	Solar	42	0.63	(1.14)	4.59
1	Conventional	40	0.57	(1.02)	4.36
2	Solar	42	0.50	(0.91)	3.66
2	Conventional	40	0.51	(0.92)	4.02

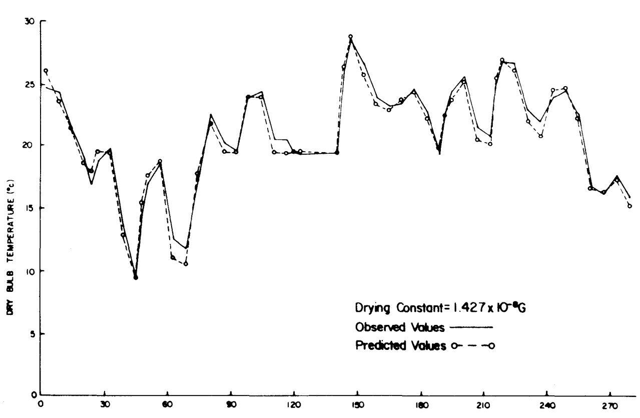

FIG. 2 Predicted and observed dry bulb temperatures for solar curing chamber.

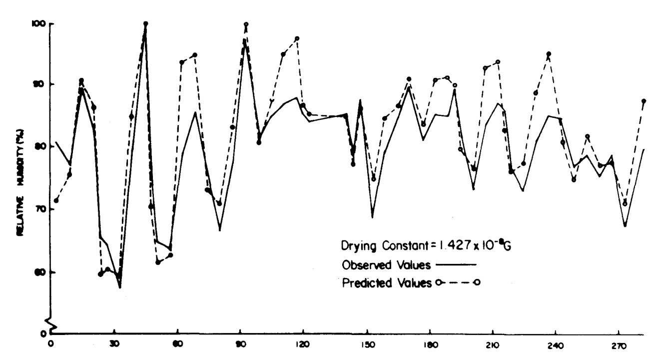

FIG. 3 Predicted and observed relative humidities for solar curing chamber.