Drying Rates of Intact Burley Tobacco Plant Components

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ABSTRACT

DRYING rates of the lamina, midrib, and stalk of intact burley tobacco plants were determined at temperatures and relative humidities of 16 °C, 70%; 24 °C, 70%; and 32 °C, 70% during test 1, at 16 °C, 51%; 24 °C, 70%; and 32 °C, 83% during test 2, and at 27 °C, 70%; 27 °C, 80%; and 27 °C, 90% during test 3. Air velocity was held constant at 4.6 m/min. The environmental conditions were designed to determine drying rates at constant humidity and varying temperature during test 1, at constant vapor pressure deficit and varying temperature during test 2 and at constant temperature and varying relative humidity during test 3. The results showed that the stalk is an important contributor of moisture to the environment during curing. The average time required for the lamina, midrib and stalk to lose half their moisture was 4.4, 8.7, and 38.3 days, respectively.

INTRODUCTION

Curing is the sum-total of the physical and biochemical processes that convert burley tobacco from the yellowish-green high moisture leaf at harvest to the brown aromatic low moisture leaf found on the warehouse floor. The most obvious physical and biochemical processes are drying and color changes, respectively. Tobacco is a hygroscopic material which has considerable intercellular pore space. Tobacco exchanges moisture with the ambient air until the moisture content of the leaf is in equilibrium with the relative humidity of the ambient air. The intercellular space plays an important part in the moisture transfer process. During curing, the interior cells give up moisture to the air in the intercellular pore space which then moves out of the leaf through the epidermal cells and stomata as a result of the moisture content gradient between the leaf and the ambient environment. This process continues until the relative humidity within the intercellular pore space is equal to the relative humidity of the ambient air. The color change is indicative of the myriad enzymatic reactions taking place within the leaf. The drying and enzymatic reaction rates must be compatible for good curing (Walton and Henson, 1971 and Walton et al., 1973). If the enzymatic reactions are slow, drying must be slow; if enzymatic reactions are rapid, drying must be rapid.

Bunn and Henson (1968), Chang and Johnson (1971) and Bunn et al. (1972) determined the drying rate of primed whole tobacco leaves. Humphries (1963) devised an experimental technique for determining the resistance of the epidermal layers of the tobacco leaf to the diffusion of moisture during yellowing of flue-cured tobacco. Walton et al. (1982) demonstrated the differential in drying rate between the lamina and midrib during curing and showed that a significant amount of midrib moisture is transferred through the lamina to the ambient air. However, their research was also carried out on primed whole leaves and separated components.

During conventional harvesting burley tobacco plants are severed just above ground level and impaled on wooden sticks in groups of five or six. These sticks of tobacco are then suspended on rails in a well-ventilated curing barn and permitted to cure in response to naturally occurring weather conditions with some control of drying by opening and closing ventilators. The lamina, midrib, and stalk are the components of the plant, each of which is affected by the transfer of moisture among themselves, and each of which contributes moisture to the drying air as it moves through the barn. The drying rates of the plant components are needed before improved curing control can be evaluated. The objective of this research was to determine drying rates of the lamina, midrib, and stalk components of the burley tobacco plant during whole plant curing.

MATERIALS AND METHODS

Drying rates of burley plant components were determined during three curing tests. The first test was conducted in the fall of 1981 and the second and third tests were conducted in the fall of 1982. Three temperature and relative humidity combinations, investigated during each test, were as follows:

Test 1	Test 2	Test 3
32 °C, 70%	32 °C, 83%	27 °C, 90%
24 °C, 70%	24 °C, 70%	27 °C, 80%
16 °C, 70%	16 °C, 51%	27 °C, 70%

The air velocity entering the tobacco was held constant at 4.6 m/min. The temperatures and humidities used in test 1 were chosen to cover a wide range of environmental conditions (16 to 32 °C, 65 to 70%) over which burley tobacco has been reported to cure well (Jeffrey, 1940). Certain environmental factors were held constant for each test. Relative humidity was held constant in test 1. Vapor pressure deficit was held constant in test 2. Temperature was held constant in test 3.

The tobacco was cured in three curing chambers that were 1.3 m wide, 2.1 m long, and 2.3 m high. Each chamber held 15 sticks of burley tobacco with six plants on each stick. Each chamber was connected to an environmental conditioning unit that controlled the

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temperature, humidity, and rate of airflow to the curing chamber. The air entered at the bottom of the chamber, moved through the tobacco parallel to the stalk, and exited at the top of the chamber.

Samples were taken at various intervals throughout the cure. Two plants were removed from each chamber at each sampling time. The plants were separated into lamina, midrib, and stalk with each plant representing a sample unit with two replications. The plant components were oven dried to determine their moisture content.

The modified mass diffusion coefficient of the lamina was determined from the mathematical model given by Walton et al. (1982) for the average moisture content of the lamina as a function of time:

$$\theta(t) = \sum_{n=0}^{\infty} \frac{2}{(\lambda_n L)^2} e^{-(D/L^2)(\lambda_n L)^2 t} \quad [1]$$

where

θ	=	$(M - M_e) / (M_o - M_e)$
M	=	Moisture content at time t, dry basis, percent
M_e	=	Equilibrium moisture content, dry basis percent
M_o	=	Initial moisture content, dry basis percent
L	=	Half thickness of the lamina, cm
$\lambda_n L$	=	$(2n + 1)\pi/2$
n	=	0, 1, 2 . . .
D	=	Mass diffusion coefficient based on the mass of water per unit mass of solid, cm^2/day
t	=	time, day
(D/L^2)	=	Modified mass diffusion coefficient for the lamina, day^{-1}.

The modified mass diffusion coefficient of the midrib and stalk were determined from the mathematical model given by Walton et al. (1982) for the average moisture content of the midrib or stalk as a function of time. The same model applies to both components because both are geometrically represented as an infinite cylinder:

$$\theta = \sum_{n=1}^{\infty} \frac{4}{(\beta_n R)^2} e^{-(D/R^2)(\beta_n R)^2 t} \quad [2]$$

where

$\beta_n R$	=	nth positive root of $J_o(\beta_n R) = 0$
$J_o(\beta_n R)$	=	Bessell function of order zero
R	=	Radius of midrib or stalk, cm
(D/R^2)	=	Modified mass diffusion coefficient for the midrib or stalk, day^{-1}.

Equations [1] and [2] were fitted to the drying data using the method of Marquardt (1966) of minimizing the sum of squares of the differences between observed and predicted values of moisture ratio, $\theta(t)$, through an iterative process. The computed parameters were the mass diffusion coefficient that gave the best fit of equations [1] and [2] to the experimental data.

RESULTS AND DISCUSSION

Average initial moisture content, initial weight ratio, and equilibrium weight ratio of the lamina, midrib, and stalk components of the burley tobacco plants are shown in Table 1. The initial moisture content of the midrib was over twice that of the lamina. The midrib comprised only 26.4% and 15.1% of the initial plant weight and dried plant weight, respectively. The large change in midrib to plant weight ratio was caused by the high initial moisture content of the midrib compared to that of the lamina and stalk. The lamina comprised 57.4% of the initial leaf weight and 74.0% of the cured leaf weight. A high percentage of lamina in the cured leaf is a desirable trait in a cultivar (in this case KY 14) because the lamina is the basic ingredient of manufactured tobacco products. Henson and Bunn (1969) found that the lamina comprised only 46% of initial leaf weight for cultivar Burley 21.

TABLE 1. AVERAGE INITIAL MOISTURE CONTENT, INITIAL WEIGHT RATIO AND EQUILIBRIUM WEIGHT RATIO OF LAMINA, MIDRIB, AND STALK TO PLANT AND LEAF

Component Property	Component		
	Lamina	Midrib	Stalk
Initial moisture content dry basis, %	420	991	513
Initial weight ratio component/plant	0.356	0.264	0.380
Equilibrium weight ratio component/plant	0.430	0.151	0.419
Initial weight ratio component/leaf	0.574	0.426	—
Equilibrium weight ratio component/leaf	0.740	0.260	—

Modified mass diffusion coefficients for the lamina, midrib, and stalk are shown in Table 2. The data from which these values were derived contained much scatter. The average standard errors of $\theta(t)$ for the lamina, midrib, and stalk were 0.137, 0.155, and 0.094, respectively. The high standard errors resulted from the sampling technique which involved the determination of the moisture of discrete samples of component parts of the plant as opposed to following the weight loss of a sample of these parts throughout the cure. However, the sampling technique employed is at this time the only technique for determining the moisture of the components while they cure as an intact plant. Comparison of the modified diffusion coefficients of the lamina and midrib at 24 °C, 70% as presented in Table 1 to the average modified diffusion coefficients of 0.107 and 0.0175/day for the lamina and midrib respectively of primed leaves at 24 °C, 65% as presented by Walton et al. (1982) showed that leaves dry more slowly on the stalk than off the stalk. The transfer of moisture from the stalk to the midrib during curing on the stalk and the transfer of moisture from the severed end of the midrib during curing off the stalk caused the observed difference in drying rates.

The general trends of the magnitudes of the diffusion coefficients with variations in temperature and relative humidity of curing environment were not as consistent as those found by Walton et al. (1982) and Swetnam and Walton (1982). Inspection of the lowest and highest temperatures of test 1 and the lowest and highest humidities of test 3 showed that diffusion coefficient increased with increasing temperature and decreased with increasing relative humidity as had been previously observed. The results of test 2 showed similar diffusion coefficients for the common vapor pressure gradient as expected. The drying rates at 27 °C, 80% relative humidity found in test 3 were inexplicably high. The environmental conditions were monitored periodically throughout the test and no significant deviation from the set points were observed. The standard errors of regression were actually below the average. Thus no

TABLE 2. MODIFIED MASS DIFFUSION COEFFICIENTS FOR THE LAMINA, MIDRIB, AND STALK OF THE BURLEY TOBACCO PLANT.

Environmental conditions				Modified diffusion coefficients		
Temperature °C	Relative humidity, %	Test number	Replication number	Lamina $(D/L^2) \times 10^2$	Midrib $(D/R^2) \times 10^2$	Stalk $(D/R^2) \times 10^2$
16	70	1	1	3.26	0.626	0.331
			2	4.30	0.603	0.204
24	70		1	4.10	0.577	0.227
			2	4.64	0.454	0.366
32	70		1	5.30	0.919	0.372
			2	4.87	1.036	0.505
16	51	2	1	4.57	0.648	0.205
			2	4.32	0.825	0.239
24	70		1	5.68	0.859	0.165
			2	5.65	0.938	0.393
32	83		1	4.57	0.669	0.070
			2	6.07	0.774	0.138
27	70	3	1	5.57	0.772	0.181
			2	5.08	0.834	0.116
27	80		1	6.63	1.039	0.320
			2	7.64	1.066	0.167
27	90		1	2.82	0.530	0.107
			2	2.44	0.352	0.047

reason has been found for the seemingly high values.

Observed and predicted values of moisture ratio for the lamina, midrib, and stalk at 24 °C, 70% (Test 2, replication 2) are shown in Fig. 1. The general trend, consistent with all sets of data, was rapid drying of the lamina, slower drying of the midrib, and much slower drying of the stalk. The average times required to reach a moisture ratio of 0.5 were 4.4., 8.7, and 38.3 days for the lamina, midrib, and stalk, respectively. The plot of the predicted curves on semilog coordinates showed a curvilinear plot only at small time values with essentially a straight line thereafter. This graphically demonstrated that after a short time period, only the first one or two terms of the infinite series represented by equations [1] and [2] are significant. Therefore equations [1] and [2] may be easily evaluated on a hand calculator and drying curves represented by the values of the modified diffusion coefficients given in Table 2 can be quickly plotted without the need of a computer.

The drying rate of the lamina, midrib, and stalk in g water/day is shown in Fig. 2. The data in Fig. 2 were based on observed values, not predicted values, and were averaged over the four replications at 24 °C, 70%. The transfer of moisture from the stalk to the drying environment was particularly significant during the early stages of the cure. The example of Fig. 2 showed that the drying rates of the stalk and midrib were similar. Even though the stalk dried more slowly than the midrib in terms of moisture ratio, its greater mass as compared to the midrib caused similar drying rates in terms of g water/day. The contribution of moisture from the stalk to the microenvironment is significant in curing of burley tobacco and must be considered in a deep layer analysis of the curing environment. Fig. 2 shows that the moisture transfer to the environment from the lamina, midrib, and stalk are initially (for the first few hours) important, but the lamina dominates the moisture transfer for the next 10 days after which its contribution becomes negligible.

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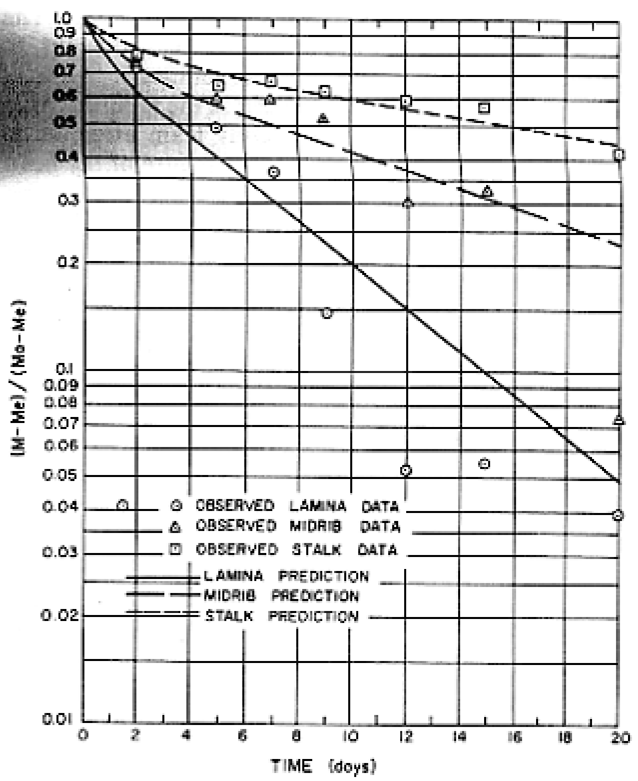

Fig. 1—Observed and predicted lamina, midrib, and stalk moisture ratio as a function of time at 24 °C, 70% humidity.

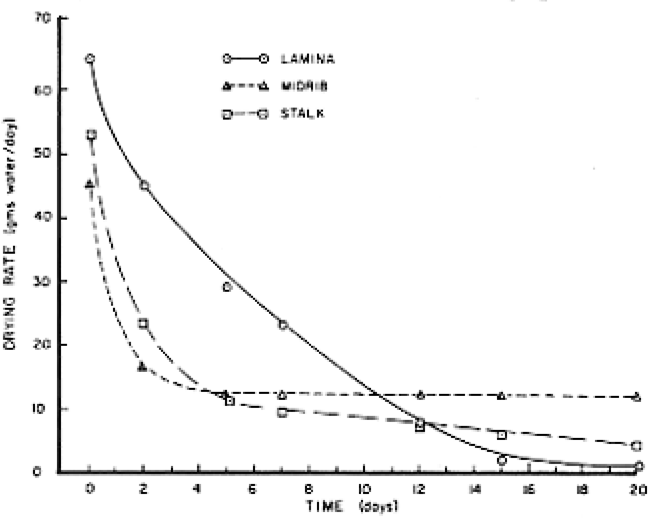

Fig. 2—Drying rates (gm water/day) of the lamina, midrib, and stalk as a function of time at 24 °C, 70% relative humidity.