EXPERIMENTAL DRYING OF TOBACCO LEAVES

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ABSTRACT: The purpose of the investigation was to determine the moisture relationship experimentally in the drying of tobacco leaves. A simple experimental model was applied for calculating the moisture ratio. The measurements carried out in a 'climate box', studying different tobacco leaves. Two measuring cycles were carried out during the latest research work. In the first the tobacco leaves were hung up in their natural condition, but in the second trial the midrib was removed from the tobacco leaves. As we expected, the dehydration of the mutilated tobacco leaf – with the midrib removed - was much quicker than drying of the 'whole' leaf. The dehydration of the midrib itself was considerably slower than that of the lamina. An important result was that the Walton exponential function was found to be suitable for describing dehumidification. The final conclusion is that the drying coefficient increased greatly when the drying temperature was raised.

INTRODUCTION

During the dehydration, the tobacco leaf is very sensitive to changes in the technological parameters. The relationship between the tobacco leaf and its environment is not easily defined. Therefore, a way was found to determine of the most important thermo-physical and transport properties of the leaf, e.g., the variation of surface temperature, and the thermal diffusivity, with special regard to the binding and diffusion energies of water in tobacco or other agricultural products (Lengyel *et al., 2003*).

There are different applied theoretical and experimental methods existing to determine for determination of the basic characteristics of the drying tobacco leaves, so we had several suitable systems to use during our research work.

One of the successful ways was a numerical method which controlled the drying process of the basic parts of tobacco leaves mathematically. The continuous change in the dehydration and surface temperature of the whole leaf could be monitored by a computer program. This program was suitable for estimating the model parameters, using our measurements (Fenyvesi *et al., 1998*).

Evaporation and heat development, the most important surface changes, may be fully characterised by the examination of mass transport. The analytical model, which describes the heat development on the leaf surface, provides an opportunity to estimate several typical parameters (α, λ, ρ, c). The model requires a method of measurement which involves a controlled environmental box whose parameters may be fixed.

The accuracy of the thermal material characteristics which we have determined with the numerical model may be improved by increasing the number of measurements. The conditions under which the measurements are taken should match those typically employed during actual tobacco curing technology. This was done for some measurements of the thermal properties of the tobacco leaves during experimental curing. Surface temperature changes were monitored with an infrared camera (Kerekes *et al., 1998*).

The series of the pictures showed differences in different parts of the leaf. It was concluded, that the temperature of the leaf surface was only homogeneous at the end of the drying. The temperature was lower at the midrib. Presumably, the properties of the material changed for the different components of the tobacco leaf.

THEORY

The purpose of the research work was to find mathematical models and experimentally determine their applicability to the moisture content of the dried tobacco lamina and midrib. The applied mathematical model for the rate of average moisture content of the lamina as a function of time is expressed as follows (Walton *et al., 1976*):

$$\Theta(t) = \sum_{n=0}^{\infty} \frac{2}{(\lambda_n \cdot L)^2} \cdot e^{-D \cdot \lambda_n^2 \cdot t} \tag{1}$$

where: Θ = moisture ratio

L = half thickness of the lamina (m)

$\lambda_n = \frac{(2 \cdot n + 1) \cdot \pi}{2 \cdot L}$ (m^{-1})

$n = 0, 1, 2, \ldots$

D = diffusion coefficient based on the mass of water per unit mass of solid $(m^2 s^{-1})$

t = time (s)

It is well known that the sorption isotherms change almost linearly with the following equation:

$$\frac{dM}{dt} = -k(M - M_e) \tag{2}$$

where: M = moisture content at time t, dry basis, percent

M_e = equilibrium moisture content, percent

k = drying coefficient (h^{-1})

t = time of drying (h)

The solution of the mentioned differential equation is:

$$\frac{M - M_e}{M_0 - M_e} = e^{-kt} \tag{3}$$

where: M_0 = initial moisture content, percent

The value of “k” can be determined by a regression approach on the basis of the moisture ratio. The moisture ratio can be calculated by using the results of the experimentation (4):

$$\Theta = \frac{M - M_e}{M_0 - M_e} \tag{4}$$

Several assumptions were made during the determination of the drying and mass diffusion coefficients:

- each component is a homogeneous material;
- the moisture content of the tobacco is a linear function of the leaf temperature and vapour concentration in the pore spaces;
- the diffusion coefficient is a constant for a given set of environmental conditions;
- the moisture in the pore space of the leaf is in the vapour phase.

A suitable method was developed to determine the diffusion coefficient – characteristic of material transport – using some well known mathematical expressions for the moisture content of the tobacco leaf. The most suitable formula was produced by adjusting the practical drying parameters and periodical measurement of the water content, considering the thickness of tobacco leaf.

EXPERIMENTATION

The measurements were done in a climate box, studying different tobacco leaves. The test parameters were adjusted according to the suggested technological parameters of drying air. The examinations were completed after they had reached an equilibrium (constant) moisture content. The whole drying process was monitored to attain isothermal conditions (reading of the instruments every 4-8 hours).

Two measuring trials were conducted during the latest piece of research work. In the first the tobacco leaves were hung up in their natural condition, but in the second the midrib was removed from the tobacco leaf, so we could examine the pure lamina and midrib separately. At the end of the two cycles the tobacco leaves were exsiccated at 105^{o}C. The measured mass was considered to be the dry mass of the tobacco. The specific dry masses were calculated from the rates of the masses. Figure 1 shows the experimental drying of the matured tobacco leaves.

Figure 1 – The normal tobacco leaves in the dryer

Table 1. Conditions of the measurements

Drying period, t (h)	Drying temperature, T (^{o}C)	Relative humidity, φ (%)
0	32	90
30	38	85
44	40	80
55	44	78
80	47	70
84	48	65
105	51	54
113	57	36
142	63	25

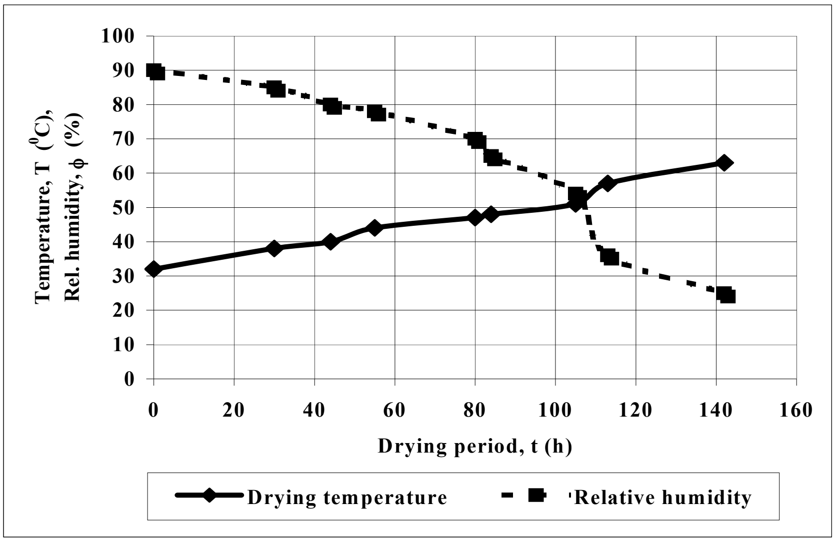

Figure 2 – Test parameters for the experimental drying

RESULT AND DISCUSSION

Table 2 contains the results of the experimental curing (drying), with special regard to the changes of the mass (Δm) and the time (t), (m = mass at the end of a given drying period).

Table 2. The average mass change during dehydration

Time, t (h)	Relative mass change, (Δm/m) x 100, %		
	Normal (whole) tobacco leaf	lamina	midrib
30	35	57	74
44	42	64	81
55	48	69	86
80	60	70	88
84	63	71	89
105	70	73	89
113	74	74	90
142	83	75	92

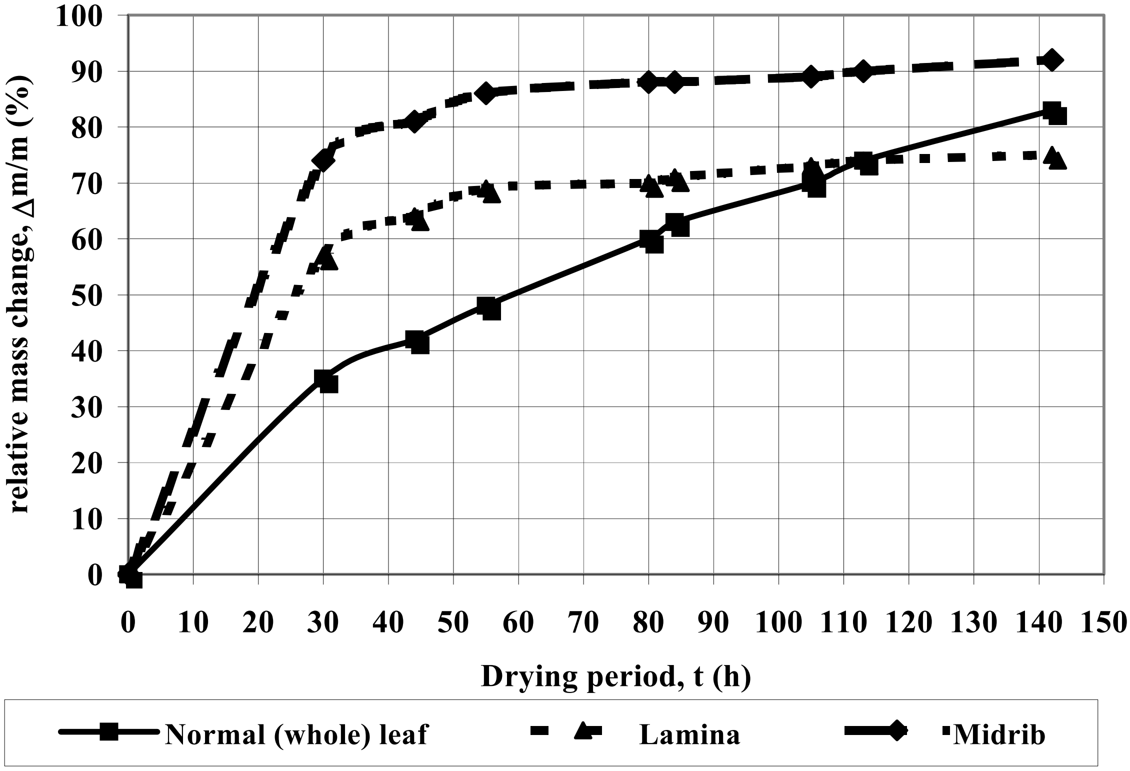

Figure 3 – The relative mass change of different tobacco samples

After drying different tobacco leaves we determined the equilibrium moisture content (M_e) to calculate the moisture ratio (Θ). In this way we could estimate the drying coefficients (k), according to Table 3. The reliability of the experimental data – originating from the tests which were repeated four times – was over 90 %. The error in the experimental data was about 8 %.

Table 3. Calculated values of the drying coefficient

Drying temperature (^0C)	Drying coefficient, k (h^{-1})		
	normal (whole) leaf	Lamina	midrib
38	0,0490	0,0454	0,0394
40	0,0673	0,0628	0,0651
44	0,1286	0,1547	0,1030
47	0,1338	0,1666	0,1057
48	0,5602	0,7589	0,3953
51	0,7750	0,8334	0,4208
57	1,6770	1,7650	0,5521
63	1,8709	2,2650	0,9434

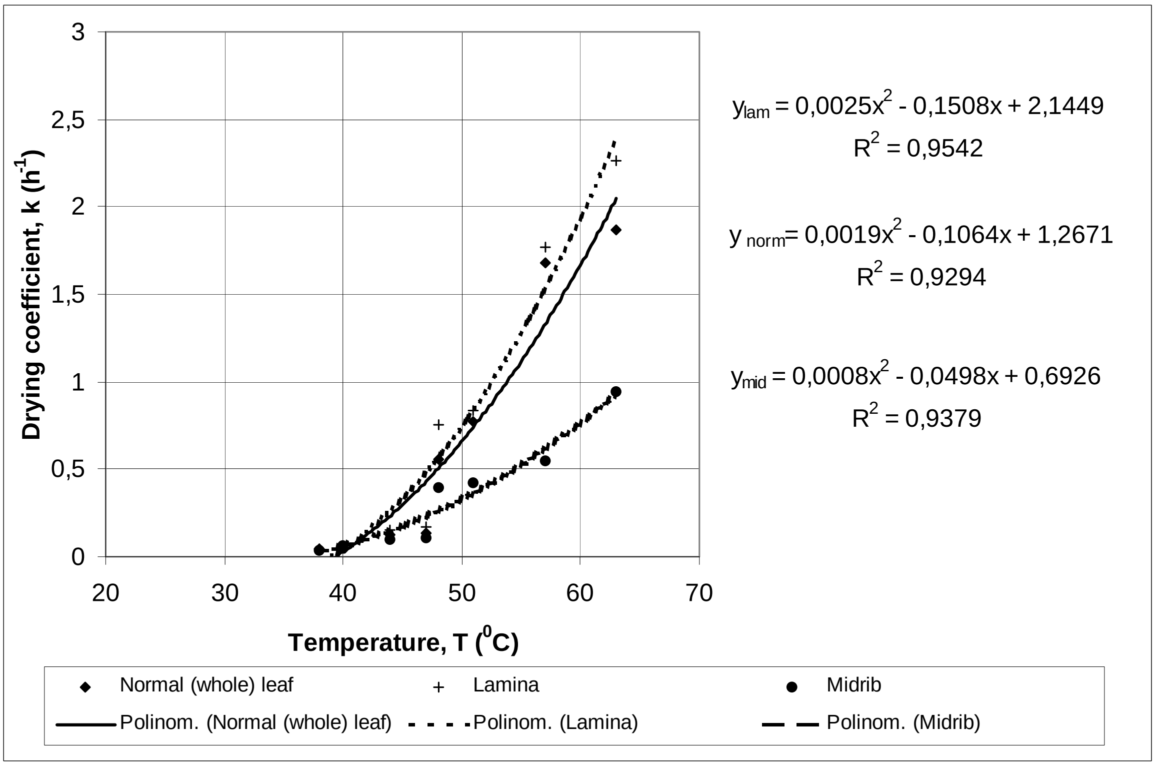

Figure 4 – Change of the drying coefficients

To determine of the mass diffusion coefficients, we applied the previously mentioned Walton formula. On the basis of the change of mass we calculated the moisture content against the temperature and relative humidity for the lamina part of the leaves.

Applying the formula the diffusion coefficients (D) were estimated progressively as a function of time, temperature and relative humidity. We attempted to fit the equation to the moisture content data by minimizing the sum of squares of the differences between the observed and predicted values of the moisture ratio (Θ), through an iterative process. The computer parameter was the mass diffusion coefficient which gave the best fit of the equation to the experimental data. The estimated mass diffusion coefficients are shown in Table 4. At these times we examined the same samples, not new ones. So the tobacco was gradually dried throughout the process.

Table 4. Average mass diffusion coefficients (D) as a function of time (t), temperature (T) and relative humidity (φ)

t (h)	**T (^oC)**	**φ (%)**	**D (m^2s^{-1})x10^8 (lamina, sorption)**
30	38	85	12,695
44	40	80	15,163
55	44	78	20,106
80	47	70	30,503
84	48	65	35,729
105	51	54	48,096
113	57	36	119,250
142	63	25	221,419

CONCLUSIONS

The main conclusion was that the initial relative humidity of the drying cycle was of decisive importance for the whole curing process.

The best drying process occurred when the relative humidity was about 80% in the climatic chamber when over-ripened (yellowed) tobacco leaves were used.

As expected the dehydration of the mutilated tobacco leaf – without the midrib – was much quicker than that of the whole leaf. The dehydration of the midrib differed considerably from the behaviour of the lamina or the complete leaf.

The results confirmed that the applied model was sufficiently accurate in describing the experimental moisture curves. The model describes the nature of the moisture transfer process of the lamina well. The range of the calculated mass diffusion coefficients corresponds to the data described previously in different tobacco reports. The mass diffusion coefficients of the lamina and midrib are analogous to the vapour diffusion coefficient of packed flue-cured leaves as determined by Stinson *et al*., 1974.

The moisture content change of the midrib as a function of time is different from the moisture content change of the lamina, so it is necessary to apply a modified mathematical model to describe the nature of the midrib.

An important result is that a suitable mathematical model for the drying coefficient is a simple exponential equation which includes the drying coefficient but does not characterise the change in diffusion (Walton *el al.,* 1976).

We finally conclude that the drying coefficient increased substantially by raising the drying temperature.

NOTATION

Latin Symbols

D	diffusion coefficient	m^2s^{-1}
K	drying coefficient	h^{-1}
L	thickness of the lamina	m
M	moisture content	%
M_e	equilibrium moisture content	%
M_0	initial moisture content	%
t	time of drying	h

Greek Symbols

λ	tobacco leaf coefficient	m^{-1}
Θ	moisture ratio	

Subscripts

n	number of iteration
o	initial
∞	infinite

LITERATURE

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