METHOD FOR THE DETERMINATION OF HEAT AND MASS TRANSFER COEFFICIENTS IN THE CASE OF THROUGH-CIRCULATION DRYING OF LUCERNE*

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Summary

The present paper deals with the determination method of the drying characteristics of lucerne. The determination principle of heat and mass transfer coefficients required for modelling the through-circulation drying process of a lucerne bed, on the basis of drying experiments, the calculation method of the so-called specific phase contact surfaces will be described here, in the knowledge of the preceding notions as well as of the volumetric transport coefficients. The transport characteristics, measured according to the above-mentioned principle and further the comparison of the measured and numerically calculated results of the drying process of an experimental lucerne bed will be discussed, too.

Introduction

One of the conservation modes of agricultural products is that by means of drying. The conservation of green feed, e.g. sorts of lucerne by means of through-circulation drying occurs in drying-storing barns in a way that warm air will be circulated through an immobile bed of reaped lucerne. The object of this artificial drying process is to preserve — as much as possible — the internal, grown nutritive values of the plant (carotine, protein, carbonhydrate). In order to attain this target, a drying strategy must be developed which is minimized regarding energy consumption and enables the favourable decomposition processes at the beginning of drying, and later on the formation of moisture content differences between the two widely differing constituents of the plant (stem, leaf), keeping the leaves from tearing off.

In order to develop an optimal drying strategy, a model has to be established for the physical process of drying. The so-called two-component

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mathematical model of through-circulation drying has been elaborated, where hay was not regarded as a homogeneous material having only a single group of concentrated parameters, but leaf and stem were characterized separately each, in the above described manner [1, 2, 3, 4].

The greatest problem regarding the numerical solution of the mathematical model, is to attain knowledge of the heat transfer and mass transfer coefficients, as well as of the specific heat transfer and evaporation surfaces. These coefficients vary during the drying process, due to shrinkage of the bed [4, 5].

Therefore, an experimental examination and measurement method must be elaborated for the determination of the above-mentioned transport coefficients and specific phase contact surfaces, on the basis of drying experiments with lucerne. A procedure has to be developed which enables to determine the specific phase contact surfaces of stem and leaf, considered separately each, and their changes, by means of measurements of the so-called volumetric transport coefficients and the "real transport coefficients" throughout the entire drying process.

Principle of the examination method, in brief

If the saturation of air circulated through the bed, as well as the sorption properties of the plant are known, the volumetric heat transfer and mass transfer coefficients can be determined at any instant of the drying process. For the determination of the specific phase contact surface the magnitude of the real transport coefficients must be known, too. These values can be calculated on the basis of the constitutional equations of heat transfer and mass transfer, if these are known. The constants of these constitutional equations have been determined in a way by placing a few stalks of lucerne only into the dryer under identical drying conditions, taking care that as regards the transport process no covered surfaces should occur. The surface of the lucerne fibres placed into the dryer was measured in advance, the surface of stem and of leaves, separately each. Hence, in the present case, from the saturation of air, in the knowledge of the surface, the real transport coefficients and the constants of the constitutional equation can be determined.

The specific phase contact surfaces of the constituents of the plant (stem and leaves) have to be known separately. Since the geometric surface of the leaves is considerably larger, we have assumed that the phase boundary surface of the stem to be considered with respect to mass and heat transfer, does not essentially differ from its geometric surface, while the leaves cover and overlap each other in a major way due to shrinkage of the bed and thus their phase boundary surface varies and is much smaller than their geometric surface.

On basis of the method developed and knowing the volumetric transport coefficients and the constitutional equations, the specific phase contact surfaces can be calculated according to the previous assumption.

Determination of volumetric heat transfer and evaporation coefficient

The moisture content of drying air circulated through an immobile bed, packed with lucerne increases, due to the liquid which evaporates from the wet material. This recognition is expressed by the material balance of moisture. For the bed-portion of elementary height dH, we can write the following equation:

$$\dot{m}_G dY_G = N dF_e \tag{1}$$

according to Fig. 1.

Let us determine the contact surface related to the empty volume unit of the bed which will be:

$$a = \frac{F_e}{V_{\text{emp}}} = \frac{dF_e}{dH}\frac{1}{A_q}. \tag{2}$$

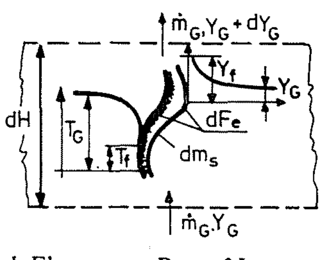

Fig. 1. Elementary Part of Lucerne Bed

After these recognitions, accepting the rate of drying expressed by applying the evaporation coefficient as:

$$N = \sigma(Y_f - Y_G) \tag{3}$$

Eq. (1) can be written in the following form:

$$\dot{m}_G dY_G = \sigma(Y_f - Y_G)\, a A_q dH\,. \tag{4}$$

From Eq. (4) the height of the bed will be:

$$H=\frac{\dot{m}_G}{A_q\sigma a}\int\limits_{Y_{G\,\mathrm{in}}}^{Y_{G\,\mathrm{out}}}\frac{dY_G}{Y_f-Y_G}=H_{YU}\,N_{YU}\,, \tag{5}$$

where

$$H_{YU}=\frac{\dot{m}_G}{A_q\sigma a} \tag{6}$$

represents the height of the transfer unit, applying the evaporation coefficient, and

$$N_{YU}=\int\limits_{Y_{G\,\mathrm{in}}}^{Y_{G\,\mathrm{out}}}\frac{dY_G}{Y_f-Y_G} \tag{7}$$

means the number of transfer units expressed by the moisture difference driving force.

In case of an adiabatic saturation

$$T_f=T_n=\mathrm{const}$$

and hence,

$$Y_f=Y_n=\mathrm{const}$$

and then, Eq. (7) can be written in the following form:

$$(N_{YU})_{at}=\int\limits_{Y_{G\,\mathrm{in}}}^{Y_{G\,\mathrm{out}}}\frac{dY_G}{Y_n-Y_G}=\ln\frac{Y_n-Y_{G\,\mathrm{in}}}{Y_n-Y_{G\,\mathrm{out}}}\,. \tag{8}$$

Let us introduce the logarithmic mean moisture difference driving force:

$$\Delta Y_{\log}=\frac{(Y_n-Y_{G\,\mathrm{in}})-(Y_n-Y_{G\,\mathrm{out}})}{\ln\dfrac{Y_n-Y_{G\,\mathrm{in}}}{Y_n-Y_{G\,\mathrm{out}}}}\,. \tag{9}$$

Hence,

$$(N_{YU})_{at}=\frac{Y_{G\,\mathrm{out}}-Y_{G\,\mathrm{in}}}{\Delta Y_{\log}} \tag{10}$$

and finally,

$$H=\frac{\dot{m}_G}{A_q\sigma a}\,\frac{Y_{G\,\mathrm{out}}-Y_{G\,\mathrm{in}}}{\Delta Y_{\log}} \tag{11}$$

From Eq. (11), considering Eq. (9) it can be seen that because of

$$Y_n=\mathrm{const}$$

the terms H, $\dot{m}_G$, A_q, σ, a will also be constant and in case of

$$Y_{G\,\mathrm{in}} = \mathrm{const}$$

the value

$$Y_{G\,\mathrm{out}} = \mathrm{const}$$

too.
On the basis of Eq. (11) the volumetric evaporation coefficient is:

$$\sigma_V = \sigma a = \frac{\dot{m}_G}{A_q H} \frac{Y_{G\,\mathrm{out}} - Y_{G\,\mathrm{in}}}{\Delta Y_{\log}} . \tag{12}$$

The numerator of Eq. (12) is:

$$\dot{m}_G (Y_{G\,\mathrm{out}} - Y_{G\,\mathrm{in}}) = \int_0^{F_e} N dF_e = -\frac{dm_a}{dt} = -\frac{dm_L}{dt} = -m_s \frac{d\bar{X}}{dt} = \mathrm{const} . \tag{13}$$

If we adjust the constant values $\dot{m}_G$, A_q, H, $Y_{G\,\mathrm{in}}$ and T_{in}, then, after a while $Y_{G\,\mathrm{out}}$ will also set at a constant value, keeping constant for a while (until the moisture content of lucerne reaches the critical value at the spot of air entering the bed). In this interval the volumetric evaporation coefficient can be calculated from the measured constant value according to Eq. (12). On basis of Eq. (13), drying intensity can be calculated, too.

One of the measurement controls is given if the inlet values $Y_{G\,\mathrm{in}} - T_{G\,\mathrm{in}}$ as well as the outlet values $Y_{G\,\mathrm{out}} - T_{G\,\mathrm{out}}$ appear on the same saturation curve related to the bulb temperature T_n, on the diagram $Y_t - T$. Regarding the practical value of the measurements, this means that the wet temperature of the inlet and outlet air must be identical.

In the interval of adiabatic saturation, however, in addition to $Y_{G\,\mathrm{in}}$, $T_{G\,\mathrm{in}}$ and hence φ_{in} which are all constant, besides $Y_{G\,\mathrm{out}}$ the value $T_{G\,\mathrm{out}}$ and therefore φ_{out} will be constant, too.

The determination of the volumetric heat transfer coefficient

$$\alpha_v = \alpha a$$

may be achieved similarly to σ_v and disregarding the relevant deduction, the bed-height can be expressed by the temperature difference driving force in the following form:

$$H = \frac{\dot{m}_G c_{nG}}{A_q \alpha a} \int_{T_{G\,\mathrm{out}}}^{T_{G\,\mathrm{in}}} \frac{dT_G}{T_G - T_f} = H_{TU} N_{TU} . \tag{14}$$

Here

$$H_{TU}=\frac{\dot{m}_G c_{nG}}{A_q \alpha a} \tag{15}$$

represents the height of the transfer unit expressed by the heat transfer coefficient and

$$N_{TU}=\int_{T_{G\,\mathrm{out}}}^{T_{G\,\mathrm{in}}} \frac{dT_G}{T_G-T_f} \tag{16}$$

means the number of transfer units expressed by the temperature difference driving force.

In case of an adiabatic saturation

$$T_f=T_n=\mathrm{const}$$

and so

$$(N_{TU})_{at}=\int_{T_{G\,\mathrm{out}}}^{T_{G\,\mathrm{in}}} \frac{dT_G}{T_G-T_n}=\ln\frac{T_{G\,\mathrm{in}}-T_n}{T_{G\,\mathrm{out}}-T_n}. \tag{17}$$

The logarithmic mean temperature difference is:

$$\Delta T_{\log}=\frac{(T_{G\,\mathrm{in}}-T_n)-(T_{G\,\mathrm{out}}-T_n)}{\ln\dfrac{T_{G\,\mathrm{in}}-T_n}{T_{G\,\mathrm{out}}-T_n}}. \tag{18}$$

Herewith,

$$(N_{TU})_{at}=\frac{T_{G\,\mathrm{in}}-T_{G\,\mathrm{out}}}{\Delta T_{\log}} \tag{19}$$

hence,

$$H=\frac{\dot{m}_G c_{nG}}{A_q \alpha a}\,\frac{T_{G\,\mathrm{in}}-T_{G\,\mathrm{out}}}{\Delta T_{\log}} \tag{20}$$

Under the conditions established following Eq. (11), the value $T_{G\,\mathrm{out}}$ will be constant. On basis of Eq. (20) the volumetric heat transfer coefficient can be calculated, i.e.:

$$\alpha_v=\alpha a=\frac{\dot{m}_G c_{nG}}{A_q H}\,\frac{T_{G\,\mathrm{in}}-T_{G\,\mathrm{out}}}{\Delta T_{\log}}. \tag{21}$$

From σa and αa, respectively, determined on the basis of Eqs (12) and (21), the value of the psychrometric ratio $\alpha/\sigma c_{nG}$ can be checked, too.

Determination of volumetric transfer coefficients α_v and σ_v, respectively, if air saturation is non-adiabatic

Eqs (5) and (14) can also be written in the following form:

$$\Delta H = H_{TU} \Delta N_{TU} = \frac{\dot{m}_G c_{nG}}{A_q \alpha a} \int_{T_{G\,\mathrm{in}}}^{T_{G\,\mathrm{out}}} \frac{dT_G}{T_f - T_G} = \frac{\dot{m}_G c_{nG}}{A_q \alpha a} \left(\overline{\frac{1}{T_f - T_G}} \right) (T_{G\,\mathrm{out}} - T_{G\,\mathrm{in}}) \tag{22}$$

and

$$\Delta H = H_{YU} \Delta N_{YU} = \frac{\dot{m}_G}{A_q \sigma a} \int_{Y_{G\,\mathrm{in}}}^{Y_{G\,\mathrm{out}}} \frac{dY_G}{Y_f - Y_G} = \frac{\dot{m}_G}{A_q \sigma a} \left(\overline{\frac{1}{Y_f - Y_G}} \right) (Y_{G\,\mathrm{out}} - Y_{G\,\mathrm{in}}) \tag{23}$$

respectively, where the integral mean value is denoted by an over-line. If the value of ΔH is not too high, then:

$$\left(\overline{\frac{1}{T_f - T_G}} \right) \cong \frac{1}{\bar{T}_f - \bar{T}_G} \tag{24}$$

and

$$\left(\overline{\frac{1}{Y_f - Y_G}} \right) \cong \frac{1}{\bar{Y}_f - \bar{Y}_G} . \tag{25}$$

Let

$$\Delta T_G = T_{G\,\mathrm{out}} - T_{G\,\mathrm{in}} \tag{26}$$

and

$$\Delta Y_G = Y_{G\,\mathrm{out}} - Y_{G\,\mathrm{in}} . \tag{27}$$

On the basis of the afore-said statements we obtain:

$$\frac{\Delta Y_G}{\Delta T_G} = \frac{c_{nG} \sigma}{\alpha} \frac{\bar{Y}_f - \bar{Y}_G}{\bar{T}_f - \bar{T}_G} \cong \frac{\bar{Y}_f - \bar{Y}_G}{\bar{T}_f - \bar{T}_G} \tag{28}$$

and

$$\frac{\Delta Y_G}{\Delta T_G} = \frac{\bar{N} c_{nG}}{\bar{q}} \tag{29}$$

respectively.

During the period of adiabatic saturation the overall heat flux density is used up for moisture evaporation, i.e.:

$$\bar{q} = \bar{N} r \tag{30}$$

therefore,

$$\left(\frac{\Delta Y_G}{\Delta T_G}\right)_{at} = -\frac{c_{nG}}{r} = \frac{Y_n - \bar{Y}_G}{T_n - \bar{T}_G} = \text{const.} \tag{31}$$

This period can be recognized by the following features:

$$T_{G\,\text{out}} = \text{const}, \qquad Y_{G\,\text{out}} = \text{const}$$

$$T_{n\,\text{in}} = T_{n\,\text{out}} = T_n = \text{const}$$

and

$$T_f = T_n, \qquad Y_f = Y_n$$

and

$$\varphi_f = 1.$$

During the period after the adiabatic saturation one portion of the heat flux density is used for moisture evaporation, while the other portion is required to heat the wet material.
Then,

$$q = \bar{N}\Delta h + q_h \tag{32}$$

where Δh represents evaporation and wetting heat. Hence,

$$\frac{\Delta Y_G}{\Delta T_G} = -\frac{\bar{N} c_{nG}}{\bar{N}\Delta h + q_h}. \tag{33}$$

It can be seen that after free moisture has been exhausted value $|\Delta Y_G/\Delta T_G|$ decreases. For this phase the following will be valid:

$$\bar{T}_f > T_{n\,\text{in}}, \qquad \varphi_f < 1$$

The above-mentioned statements are illustrated in Fig. 2.

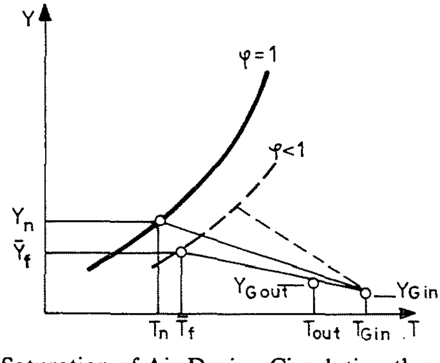

Fig. 2. Saturation of Air During Circulation through Bed

The material balance of moisture is:

$$\dot{m}_G \Delta Y_G = -m_s \frac{d\bar{X}}{dt} \tag{34}$$

from where, the mean moisture content of the bed can be written as:

$$\bar{X}(t) = \bar{X}_0 - \frac{\dot{m}_G}{m_s} \int_0^t \Delta Y_G(t)\, dt\,. \tag{35}$$

It can be assumed that

$$\bar{X} \cong \bar{X}_f = X^* \qquad \text{and} \qquad \bar{T}_a = \bar{T}_f$$

Since, with the aid of satisfactory approximation we obtain

$$Y \cong \frac{M_v}{M_G} \frac{p_{vt}(T)}{P} \varphi$$

where

$$\varphi = \frac{p_V}{p_{Vt}}$$

therefore, if the sorption isotherm of lucerne, viz. the following correlation:

$$\varphi(T_a, X^*) = \varphi(\bar{T}_f, \bar{X})$$

are known, we obtain

$$Y_f = \frac{M_v}{M_G} \frac{p_{Vt}(\bar{T}_f)}{P} \varphi(\bar{T}_f, \bar{X}) \tag{36}$$

i.e. Eq. (24) will become:

$$\frac{\Delta Y_G}{\Delta T_G} = \frac{\dfrac{M_v}{M_G} \dfrac{p_{Vt}(\bar{T}_f)}{P} \varphi(\bar{T}_f, \bar{X}) - \bar{Y}_G}{\bar{T}_f - \bar{T}_G}\,. \tag{37}$$

In the afore-said formula there is only one unknown term, $\bar{T}_f$. With the trial and error method, the identity of the right side with the left side of the equation can be achieved, thus the value of $\bar{T}_f$ which yields identity can be determined.

In the knowledge of $\bar{T}_f$, according to Eq. (36), Y_f can be determined, too. With the aid of all these results the volumetric heat transfer coefficient,

$$\alpha_v(t) = \frac{\bar{\dot{m}}_G\, c_{nG}}{\Delta H} \frac{\Delta T_G}{\bar{T}_f - \bar{T}_G} \tag{38}$$

and the volumetric evaporation coefficient, respectively,

$$\sigma_v(t) = \frac{\bar{\dot{m}}_G}{\Delta H} \frac{\Delta Y_G}{\bar{Y}_f - \bar{Y}_G} \tag{39}$$

can also be calculated.

Determination of specific phase contact surface "a"

The general form of the constitutional equation which includes the heat transfer coefficient can be written as:

$$\mathrm{Nu} = A\, \mathrm{Re}^B \mathrm{Pr}^C . \tag{40}$$

In case of heat transport between the packed bed and the fluid, Eq. (40) will turn into:

$$\frac{\alpha d_e}{\lambda_q} = A \left(\frac{\bar{w} d_e}{\nu_G} \right)^B \mathrm{Pr}^C . \tag{41}$$

The equivalent diameter d_e and the specific transport surface a, respectively, furthermore the porosity ξ_p can be written successively, as:

$$d_e = \frac{V_p}{F_e}$$

$$a = \frac{F_e}{V} = \frac{F_e}{HA_q}$$

$$\xi = \frac{V_p}{V} = 1 - \frac{V_a}{HA_q} = 1 - \frac{\Delta V_a}{\Delta HA_q}$$

After substitution of these values into Eq. (41) and a due arrangement, the specific heat transfer surface will be:

$$a = \left[\frac{\alpha_v}{\lambda_G} \left(1 - \frac{\Delta V_a}{\Delta HA_q} \right) \frac{1}{A\, \mathrm{Pr}^C} \left(\frac{\mu_G}{\bar{\dot{m}}_G} \right)^B \right]^{\frac{1}{2-B}} . \tag{42}$$

In Eq. (42) term α_v is already known on basis of Eq. (21) or Eq. (38). The value of coefficient A and exponent B, respectively, must still be determined. This can be achieved by placing only a few lucerne stalks into the measuring apparatus, taking care that covered surfaces should not occur.

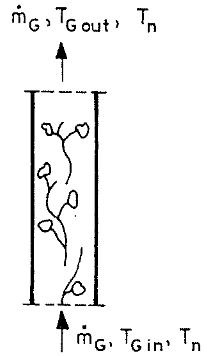

Fig. 3. Drying Model of Lucerne Stalks

During the period of adiabatic saturation, considering Eq. (21), the heat transfer coefficient can be calculated as:

$$\alpha = \frac{\dot{m}_G c_{nG}}{F_e} \quad \frac{T_{G\,\mathrm{in}} - T_{G\,\mathrm{out}}}{\Delta T_{\log}}$$

According to this correlation α can be measured, since in this case the geometric surface, F_e, is measurable as well as the rest of the variables.

In case of this model

$$d_e = \frac{V_p}{F_e} = \frac{V}{F_e} \qquad a = \frac{F_e}{V} \qquad \xi_p = 1$$

Thus, the constitutional equation Eq. (40) will become:

$$\mathrm{Nu} = \frac{\alpha V}{\lambda_G F_e} = A \left(\frac{\bar{\dot{m}}_G V}{\mu_G F_e} \right)^B \mathrm{Pr}^C .$$

Provided that the exponent of the Prandtl number is a known value, i.e.

$$C = 1/3$$

the following formula

$$\frac{\mathrm{Nu}}{\mathrm{Pr}^C} = A \left(\frac{\bar{\dot{m}}_G V}{\mu_G F_e} \right)^B = A\,\mathrm{Re}^B \tag{43}$$

can be obtained. The alteration of $\bar{\dot{m}}_G$ will result in different values for the left side of Eq. (43), although these values plotted as a function of Reynolds' number in a logarithmic co-ordinate system, will range practically along a straight line. From the slope of the straight line, exponent B can be obtained and from its value assumed for $\mathrm{Re}=1$, coefficient A can be determined.

All these recognitions enable the determination of a. In order to establish the twŏ-component model, the specific contact surface a must be separated into two parts, according to the following definition:

$$a=\frac{F_{e\,\mathrm{st}}+F_{el}}{V}=\frac{F_{e\,\mathrm{st}}}{V}+\frac{F_{el}}{V}=a_{\mathrm{st}}+a_{l}\,. \tag{44}$$

Since the geometric surface of lucerne leaves is much larger than that of the stem, the effect of an error made in the course of determining a_{st} is of a lesser significance than it would be when determining a_l. Furthermore, we have assumed that during the drying process the phase contact surface of the stem, which can be taken into consideration from the point of view of mass and heat transfer, does not deviate considerably from its geometric surface, while the leaves, which overlap and cover each other, respectively, to a rather high degree in the course of the shrinkage of the bed, have a much smaller phase boundary, than their geometric surface. In the light of all these facts, the geometric surface can be sobstituted for a_{st} considering the specific contact surface a, calculated according to Eq. (44), hence

$$a_{\mathrm{st}}=a_{\mathrm{st}\,g} \tag{45}$$

and as far as the leaves are concerned, the following correlation will be valid:

$$a_l=a-a_{\mathrm{st}\,g} \tag{46}$$

The specific transport surface a can also be determined from the mass transfer coefficient σ_v, according to the abovementioned deduction, but in this case we must start from the constitutional equation of mass transfer.

Determination of the constitutional equation of heat transfer between lucerne bed and fluid

In order to determine the specific surface of the lucerne bed as related to time, according to the considerations described in the previous chapters, the heat transfer coefficient related to the "own" surface of lucerne and the relevant constitutional equation, respectively, have to be determined. In order to determine the constitutional equation, drying experiments have been carried out, applying a loosely arranged lucerne bed of known drying surface in such a way, that during the measurements the surface remained unchanged and the drying air reached the whole lucerne surface. This could be achieved by placing little lucerne into the bed, about four or five stalks only, tied to a small rod. Before placing the lucerne into the bed, the drying surface was measured. The measurements have been carried out with lucerne, of a moisture content exceeding X_{cr} when, $T_f = T_n$. The measurements were of short duration. We only waited until steady state set in, then the instruments were read and air velocity changed to another value ($\dot{m}_G$).

On basis of the measured results, we have plotted $\mathrm{Nu}/\mathrm{Pr}^C$ as a function of Re on a logarithmic scale and the measurement results yielded a straight line. According to the data taken from references, the exponent of the Prandtl number was concerned as $C = 1/3$ for evaluation purposes.

On basis of Fig. 4, the constitutional equation of heat transfer can be written as:

$$\mathrm{Nu} = 6.26 \cdot 10^{-4}\, \mathrm{Re}^{0.84}\, \mathrm{Pr}^{0.33}\,. \tag{47}$$

In the knowledge of α the evaporation coefficient σ can be calculated according to the following equation:

$$\frac{\alpha}{\sigma c_{nG}} = 1\,. \tag{48}$$

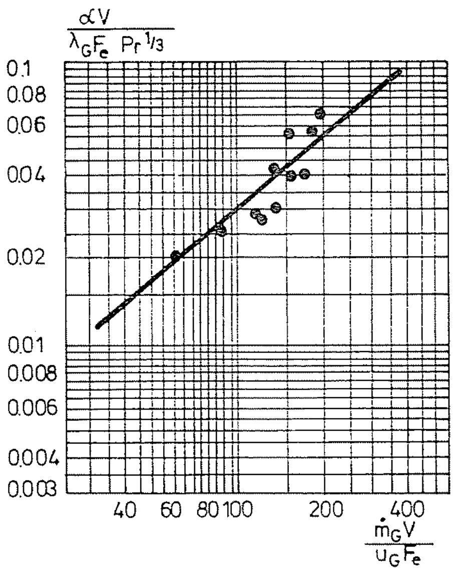

Fig. 4. Determination of Constants in the Constitutional Equation of Heat Transfer

Experimental determination of the specific contact surfaces

In the course of evaluation of the through-circulation drying measurements, the volumetric heat and mass transfer coefficients, as well as the specific transport surface and from their knowledge the heat transfer coefficient, respectively, have been determined as a function of drying time and moisture content of the material. The evaluation was carried out as described at the beginning of the paper.

A typical result is demonstrated in Fig. 5 which clearly shows that the heat transfer coefficient is approximately constant throughout the drying process of the lucerne bed, while the specific phase contact surface (of leaves) decreases considerably if the moisture content decreases.
The detailed description of the experimental measurements and the presentation of the results can be found in Ref. [4].

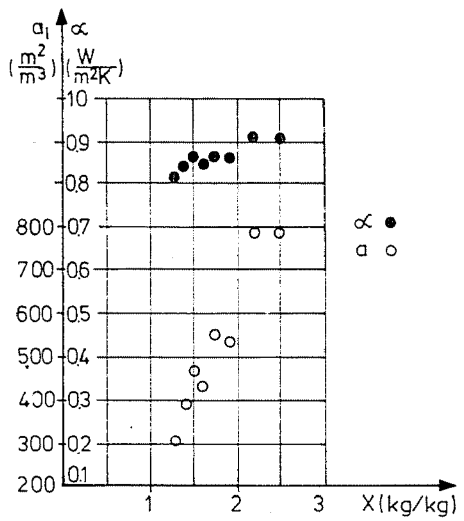

Fig. 5. Variation of Heat Transfer Coeff. and Specific Phase Contact Surface of Leaves During Drying of Bed

Computational simulation of drying of a lucerne bed

In order to follow the course of the drying process, a two-component model had to be elaborated. The detailed discussion of the model can be found in Refs. [1, 6]. Let us offer here only the result of applying the transport coefficients and specific contact surfaces determined by the previously

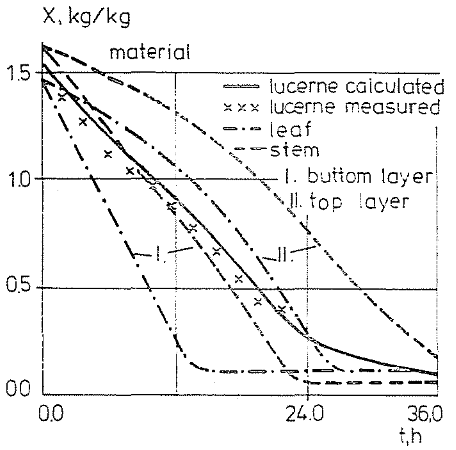

Fig. 6. Drying Curves of Lucerne

described measuring method. Until the definitely determined variation (see: Fig. 5) of the transport coefficient(s) and phase contact surface(s) was not taken into consideration when applying the mathematical model, an agreement of calculated and experimentally obtained results could not be spoken of.

The formation of the curves showing the weight losses of a lucerne bed of $H=0.3$ m, height packed with lucerne reaped in May, during the through-circulation drying is illustrated in Fig. 6. The mass flow of circulating air was: $\dot{m}_G=0.171$ kg/m^{2}s.

The detailed discussion of the numerical solution of the mathematical model can be found in Refs. [6, 7].

According to Fig. 6, it becomes evident that the measured and calculated values agree satisfactorily, proving the validity of the introduced method which has been applied in order to determine the transport coefficients and specific contact surfaces.

Symbols

A, B, C — constants
A_q — empty cross-section
a — specific surface
c — specific heat
d_e — equivalent diameter
F_e — phase contact surface
H — height

Δh — evaporation and wetting heat
M, m — mass
$\dot{m}$ — mass flow intensity
m_G — mass flow density of air
N — drying rate
P — pressure
p — partial pressure
q — heat flux density
r — evaporation heat
T — temperature
t — time
V — volume
w — gas velocity
X — mass ratio
Y — moisture content of air

Subscripts (referring to:)

a — material
at — adiabatic
emp — empty
f — surface
G — gas
g — geometric
h — heating up
in — in
L — water
l — leaf
log — logarithmic
n — wet
O — initial value
o — overall
out — out
p — pores
s — dry
st — stem
U — unit
TU — transfer unit
V — vapor
v — volumetric
$*$ — equilibrium

Superscript

— — average (mean value)

Greek letters

α — heat transfer coefficient
Δ — difference
ξ — porosity
λ — heat conductivity coefficient
σ — evaporation coefficient
φ — relative moisture content of air
ρ — density
ν — kinematic viscosity
μ — dynamic viscosity

Non-dimensional numbers

Nu — Nusselt number
Re — Reynolds number
Pr — Prandtl number

References

1. IMRE, L.—MOLNÁR, K.: Two-Component Model of a Lucerne Convective Bed Dryer. Proc. 3rd Int. Drying Symposium, Drying R. Ltd. Wolverhampton, Vol. 2 pp. 73—78. 1982.
2. IMRE, L.—KISS, L.—KÖRNYEY, T.—MOLNÁR, K.: Digital Simulation of a Solar Hay-Drying System. The 2nd Int. Symp. on Drying. Montreal, Canada. 1980.
3. IMRE, L.—KISS, L.—KÖRNYEY, T.—MOLNÁR, K.: Numerical Analysis of Convective Solar Dryers. Numerical Methods Conference, Padova, Italy. 1981.
4. SZENTGYÖRGYI, S.—MOLNÁR, K.: Drying Characteristics of Lucerne (Report), Techn. Univ. Budapest. 1982.
5. FARKAS, I.—IMRE, L.—KISS, L.—MOLNÁR, K.: Application of Numerical Methods for Simulation of Solar Rural Dryers (in Hungarian) KAMM 3, Professional Boundary Meeting. Košice (Czechoslovakia) — Miskolc (Hungary) 1980.
6. IMRE, L.—MOLNÁR, K.—FARKAS, I.: Some Aspects of the Intermittent Solar Drying of Lucerne. Solar Drying and Rural Development. Bordeaux. 1983.
7. IMRE, L.—FARKAS, I.—KISS, L.—MOLNÁR, K.: Numerical Analysis of Solar Convective Dryers. Third Int. Conf. on Numerical Methods in Thermal Problems. Seattle, USA. 1983.

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