KINETICS OF SESAME DRYING AND ROASTING IN ROTATION-PULSED FLUIDIZED BED APPARATUS

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Abstract

An industrial experiment for investigation of kinetics parameters on sesame drying and roasting in rotation-pulsed fluidized bed dryer has been carried out.

The generalized drying curve has been built. The equation describing drying rate depending on the mode parameters has been obtained.

Introduction

The roasting is a high-temperature process of drying and heating the material accompanied by specific for any object of processing operations at which characteristic consumative qualities have been formed - taste, colour, aroma, chemical composition changes, structure-mechanical indices changes, etc.

The object of investigation of this paper is roasting of wet-separated sesame-seeds designed for the production of ground roasted sesame-seeds in the industrial-type rotation-pulsed fluidized bed apparatus presented in (Djurkov, 1999). The purpose of this study is to investigate the kinetics of sesame-seeds drying by reason of prognostication the apparatus operation at new technological modes and conditions.

Methodology of investigation of the process of sesame seeds roasting in rotation-pulsed fluidized bed apparatus

Two series of experiments have been carried out - 11 in total. The rate-frequency of drying agent recirculation, the initial temperature, the initial material quantity have been varied. The data of conditions at which the separate experiments have been carried out are presented on Table 1 and Table 2.

The experiments have been carried out in the following sequence:

- feeding the working chamber with material; the latter consists of well-strained wet-separated sesame-seeds; before feeding the material should be weighed and a sample for determining the initial moisture should be taken;
- in the process of roasting the drying agent temperatures should be measured at any minute under the gas-distributor t_B and after the material bed t_C with digital thermometers of the firm "Testoterm" with an accuracy of 0.1 ^oC;
- samples of the material should be taken periodically in the chamber for determining the moisture content by using the weighing method;
- calibration of the valve of the output drying agent has been preliminarily done - at fixed three positions of the valve the volume capacity of the outflowing air has been determined, the fan capacity and the rate-frequency of recirculation at a working chamber fed with material and temperature equal to the ambient;
- the roasting continues till reaching of preliminarily accepted air temperature after the bed;
- the duration of the process is measured by a stop-watch.

Table 1

Parameter	Experiments					
	1	2	3	4	5	6
m_i, kg	48	47	47	32	57	48
u_i, kg/kg	0.732	0.73	0.7	0.702	0.687	0.74
m_0, kg	27.27	27.17	27.66	18.8	33.79	27.62
v_A, m^3/s	0.196	0.196	0.245	0.134	0.134	0.134
n	2.3	2.3	1.8	4.1	4.1	4.1
ρ_{SM}, kg/m^3	1.038	0.985	1.016	0.75	0.816	0.841
L_C, kg/s	0.468	0.444	0.448	0.412	0.448	0.462
L_A, kg/s	0.203	0.193	0.249	0.1	0.109	0.113
$N.10^4$, s^{-1}	4.44	6.88	8.22	14.49	7.16	8.39
t_B, ^0C	116.3	158.6	173.9	182.5	182	188
t_C, ^0C	51.8	59.7	61.9	75	71.4	70.3
δt_{max}, K	64.5	98.5	112	107	110.6	117.7
$d_B.10^3$, kg/kg	66.13	102.4	97.18	277.9	225.4	210.6
t_{SB}, ^0C	51.7	59.7	59.9	73.3	70.7	70
$d_{SB}.10^3$, kg/kg	96.6	152.3	154.2	349	293.1	280.9
$d_C.10^3$, kg/kg	92.4	144.5	147.9	344	279.5	262.3
t_{SC}, ^0C	51.0	58.9	59.4	73.2	69.9	68.9
$d_{SC}.10^3$, kg/kg	92.8	144.9	149.3	345.3	280.4	263.2
c_v, kJ/(kg.K)	1.123	1.190	1.181	1.517	1.419	1.392
$\frac{c_v}{r_C}\frac{L_C}{m_o}10^6$	7.32	7.43	7.32	12.59	7.17	8.83
$\frac{N}{\delta t}10^6$	6.88	6.98	7.34	13.48	6.47	7.13
τ, min	34	22	18	11.5	21	20.5
τ_1, min	16	11	9.4	5.2	11.5	9
u_{k1}	0.256	0.235	0.228	0.236	0.206	0.236
k_C	0.075	0.119	0.142	0.172	0.115	0.097
k_B	0.058	0.088	0.089	0.093	0.073	0.041

Experimental results

The results from the measurements are presented on Table 1 (Experiments from 1 to 6) and Table 2 (Experiments from 7 to 11). These tables indicate the average temperature values of the drying agent before t_B and after the material bed t_C , the maximum utilized temperature drop of δt_{max}, for the first roasting period. In it has been indicated as follows:

– the output of the drying agent circulating through the chamber L_C;
– the output of the eliminated waste drying agent L_A;
– drying rate N;
– moisture content d_B, calculated by the formula:

$$d_B = d_A + \frac{\Delta \dot{U}}{L_A} = d_A + \frac{m_o N}{L_A}; \qquad /1/$$

– the moisture content of the wet air leaving the drying chamber, calculated by the formula:

$$d_C = d_B + \frac{\Delta \dot{U}}{L_C}; \qquad /2/$$

– the duration of drying at the separate experiments τ and the duration of drying to the end of the second sector, which coincides with the first period of drying τ_1.

Table 2

Parameter	Experiments				
	7	8	9	10	11
m_i, kg	48	42.5	45	43	57.8
u_i, kg/kg	0.696	0.698	0.698	0.698	0.698
m_0, kg	28.3	25.03	26.5	25.34	34.04
v_A, m^3/s	0.196	0.134	0.134	0.134	0.196
n	2.3	4.1	4.1	4.1	2.3
ρ_{SM}, kg/m^3	0.985	0.805	0.774	0.826	0.923
L_C, kg/s	0.444	0.442	0.425	0.454	0.416
L_A, kg/s	0.193	0.108	0.104	0.111	0.181
$N.10^4$, s^{-1}	6.3	8.9	9.69	8.5	6.19
t_B, ^0C	143	145.5	167.1	158.5	158.6
t_C, ^0C	58.4	69	71.8	68.6	69.3
δt_{max}, K	84.6	76.5	93.3	89.9	95.3
$d_B.10^3$, kg/kg	97.9	214.3	254.9	205.3	124.4
t_{SB}, ^0C	58.3	68.7	71.8	68.6	62.1
$d_{SB}.10^3$, kg/kg	140.3	260.2	315.2	258.4	174.9
$d_C.10^3$, kg/kg	138	264.7	315.3	253.2	175.1
t_{SC}, ^0C	58.1	69.0	71.8	68.3	62.2
$d_{SC}.10^3$, kg/kg	138.2	264.7	315.4	253.4	175.7
c_v, kJ/(kg.K)	1.182	1.399	1.474	1.382	1.231
$\frac{c_v}{r_C}\frac{L_C}{m_o}10^6$	7.07	9.42	8.96	9.42	5.73
$\frac{N}{\delta t}10^6$	7.45	11.63	10.16	9.45	6.50
τ, min	31	17	21	20	25.5
τ_1, min	12	8	9	9	12
u_{k1}	0.235	0.256	0.186	0.231	0.241
k_C	0.067	0.0128	0.089	0.107	0.097
k_B	0.033	0.094	0.09	0.094	0.056

Kinetics of drying. Processing and a general conclusion of the experimental results

Because of the small number of moisture measurements at the separate experiments it is not possible to work with the individual drying curves. According to the data from the experiments the generalized drying curve has been built - Fig. 1. The drying rate for the first period N has been determined by means of the individual drying curve according to the curve slope within the period τ=4÷10min.

Approximation dependence of the type below has been sought for:

$$u = u_o \exp(-kN\tau), \qquad /3/$$

corresponding to the Likov's model - a linear measurement of the drying rate as a function of material moisture content - /4/:

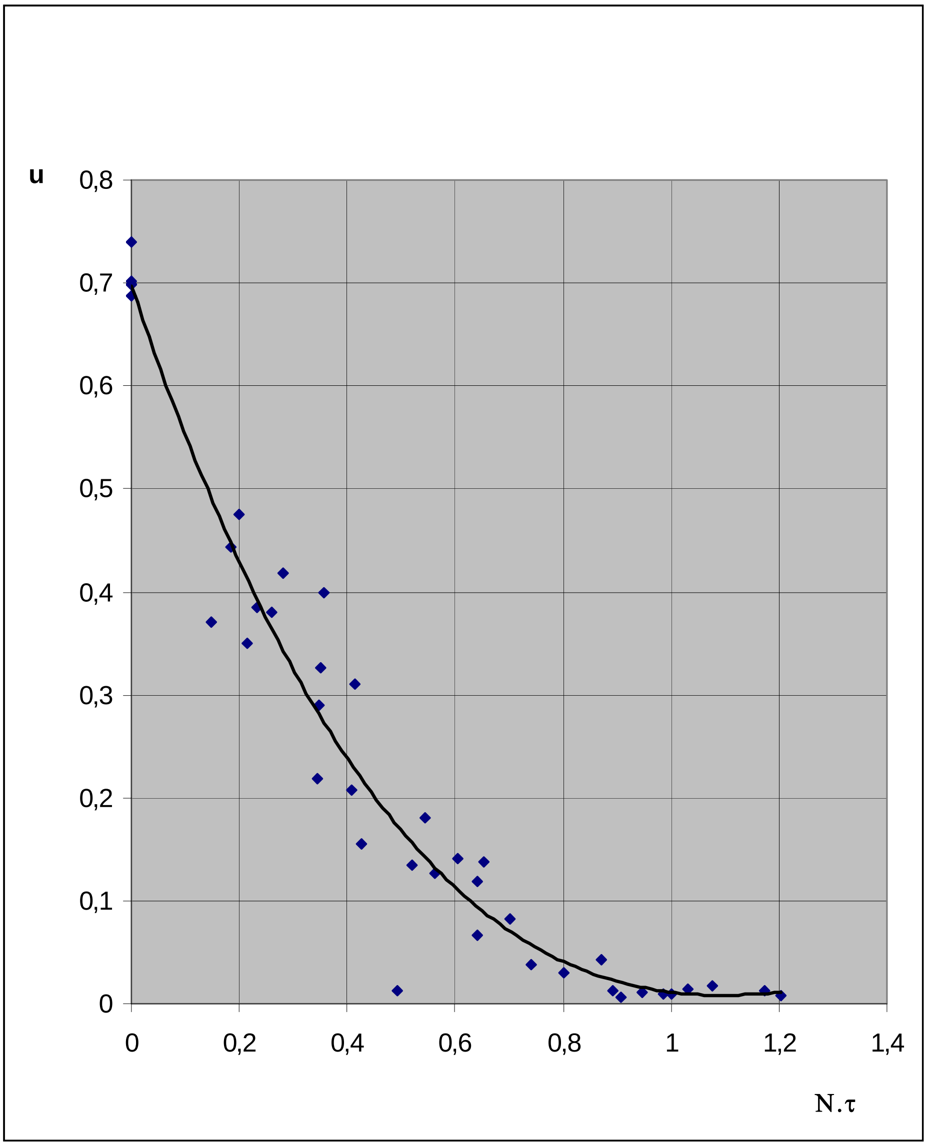

Fig. 1

$$u = 0.7\exp(-3.65N\tau). \qquad /4/$$

The equation /4/ describes the experimental data with some considerable deviations. A better description has been obtained when Olshansky's model has been used (Elenkov, 1995):

$$-\frac{du}{N.d\tau} = \kappa.u^n \qquad /5/$$

By means of the values recorded from Fig. 1, of u for $N.\tau$ from 0 to 1.2 through 0.1 interval, the following parameters has been calculated:

$$\psi = \frac{\Delta u}{N.\Delta\tau} = \frac{u_{i-1} - u_{i+1}}{N\left(\tau_{i+1} - \tau_{i-1}\right)} \qquad /6/$$

which has been accepted as a mean reduced drying rate in the range τ_{I-1}, τ_{I+1} and at moisture content of u_i. Fig. 2 has been built after the calculation data.

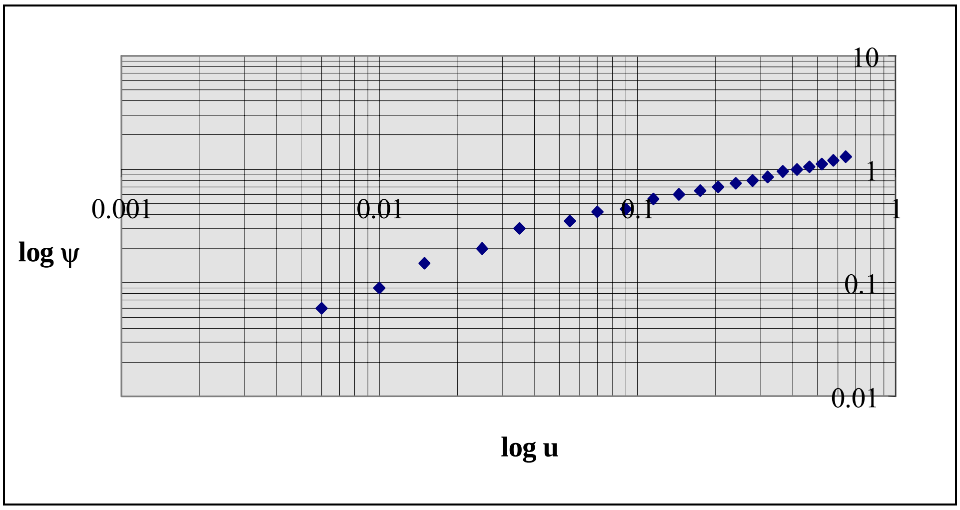

Fig. 2

It can be seen that for moisture contents of about 0.025 the points lie on a straight line that can be described by an equation:

$$\psi = \frac{\Delta u}{N.\Delta \tau} = 1.551 u^{0.5}. \qquad /7/$$

After u = 0.025 the curve is broken - the slope of the curve increases - the moisture evaporation is accelerated because of the seeds temperature increase.

From the equation /5/ by means of integration the equation of the generalized drying curve can be obtained:

$$u = \left(0.837 - 0.776 N\tau\right)^2, \qquad /8/$$

that is valid in the range 0.75> u >0.025 or for 0< $N.\tau$<0.88.

The equation /8/ has been utilized for engineering computations in case a way has been indicated for drying rate N determination, depending on the mode parameters. Having in mind the temperature curve type commented in (Djurkov, 1999), especially in their second sector, it can be stated that in this period a process of adiabatic air saturation with moisture can be observed.

That can be affirmated by the fact that the values of the calculated t_{SB} coincide practically with the measured temperatures t_C (Table 1 and 2). The intensity of evaporation can be determined by the degree of drying agent cooling - $\delta t_{\max} = t_B - t_C = t_B - t_{SB}$, and not by the kinetics of the outer heat - and mass-exchange:

$$r_C.\Delta\dot{U} = r_C m_o N = L_C c_v \left(t_B - t_C\right) \qquad /9/$$

or

$$\frac{N}{\delta t} = \frac{c_v}{r_C}\frac{L_C}{m_o} \qquad /10/$$

On Fig. 3 in binary logarithmic coordinate system the values of $N/\delta t$ and $c_v.L_C/r_C m_o$ taken from Tables 1 and 2 have been shown.

After the method of least squares a linear regression equation has been obtained of which follows the exponential function of:

$$\frac{N}{\delta t} = 0{,}903\left(\frac{c_v L_C}{r_C m_o}\right)^{1{,}055} \qquad /11/$$

The exponential function is near the linear one which confirms the supposition that the heat - and mass-transfer can be observed at conditions of balance task and their intensity can be determined by the temperature drop $\delta t = t_B - t_{SB}$ available, mainly.

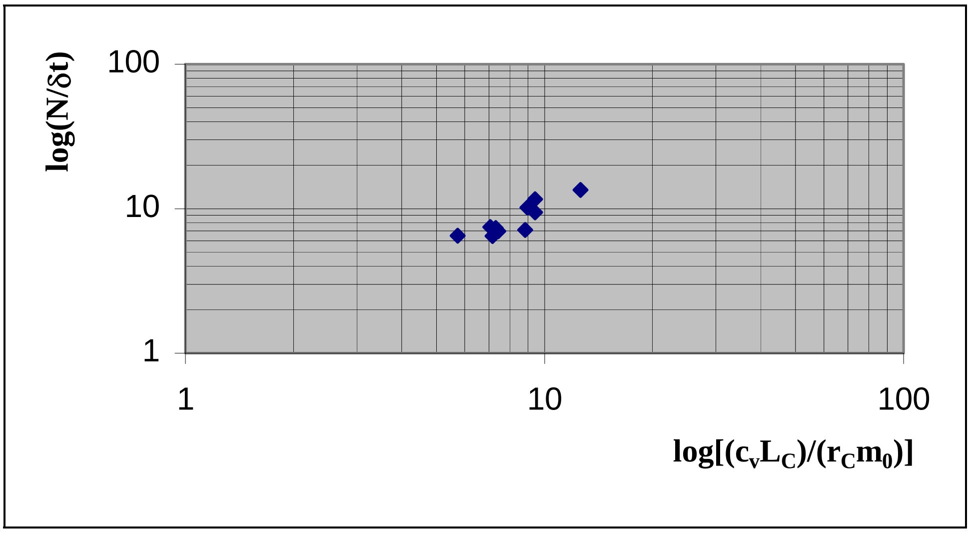

Fig. 3

Kinetics of heating and roasting of the material.

The speed of heating the material and the maximum temperatures that have been reached at the end of the process, are parameters themselves having a considerable significance for the carrying out of the roasting process.

From Fig. 2 – 12 (Djurkov, 1999) it can be seen that at the second stage, the drying agent temperatures before and after the bed have changed almost linearly in a function of a time.

Having in mind the strongly developed heat- and mass-transfer surface of the bed, the high speed of flowing around of the separate grains and the low values of Bio's criterion, it can be considered that the material mean temperature in the bed θ and that of the drying agent leaving it t_C are equal. Consequently, θ will also be a linear function of time.

$$\theta = t_C = t_{SC} + k_{C.}\tau_{II} \qquad /12/$$

Tables 1 and 2 show empirically the obtained values of the coefficients before the argument τ_{II} - k_B and k_C, determining the temperature growth rates t_B and t_C at the second stage of sesame roasting.

$$\tau_{II} = \tau - \tau_I, \qquad /13/$$

where: τ_I is the duration of drying till the beginning of the second stage.

From Tables 1 and 2 the experimentally obtained duration of drying at the first stage can be recorded, as well as the values of the first critical moisture content u_{kI}, calculated by using equation /8/. By the mean value of u_{kI} = 0.232, the mean value of the product $N.\tau_I = 0.458$, can be determined, as well, which allows the duration of the first drying period to be calculated, depending on the drying rate.

Upon the k_C value have an effect the process of moisture separation and heat-transfer intensity, that determine the change of the temperature fall worked out:

$$\frac{\delta t}{\delta t_{\max}} = f\left[\left(\frac{\alpha.F}{m.c}\right),\left(\frac{du}{d\tau}\right)\right], \qquad /14/$$

as well as the drying agent temperature change, that at a constant air-heater power depends on the heat-accumulating ability of the unit as a whole and on the atmospheric air parameters.

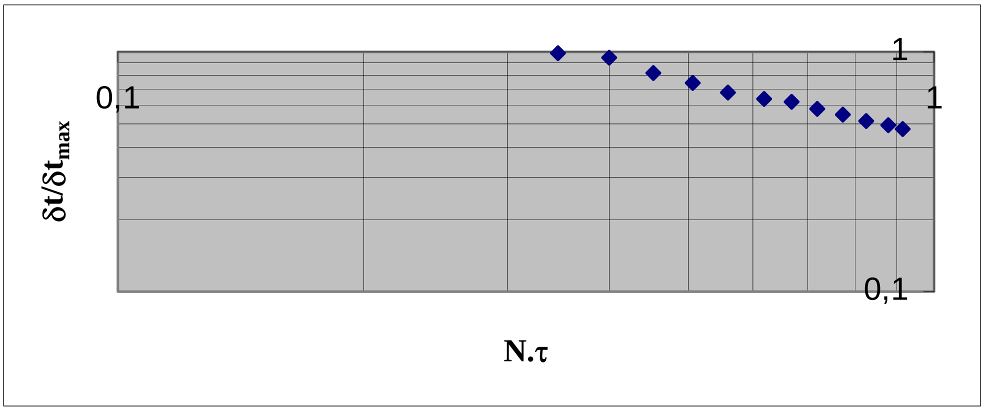

Fig. 4

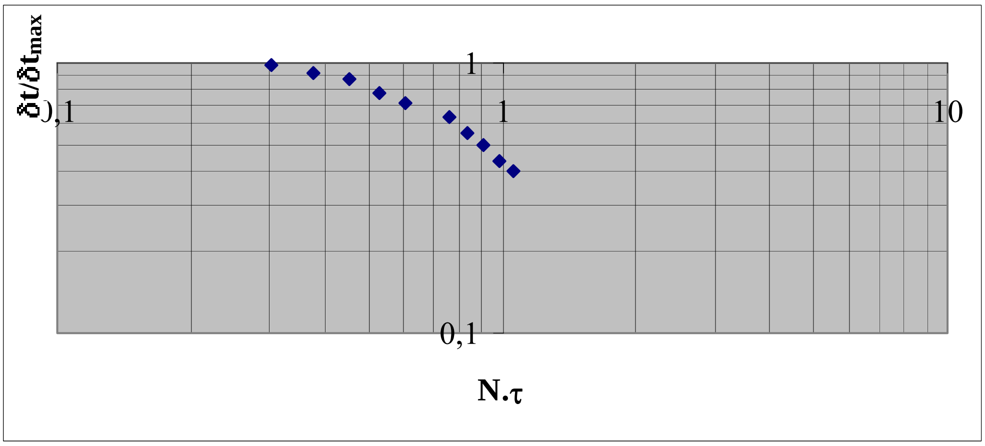

Fig. 5

The effect of the drying rate upon the relative temperature fall worked out $\frac{\delta t}{\delta t_{\max}}$ at the second drying period has been studied. On Fig. 4, 5and 6 as an illustration the dependency of $\frac{\delta t}{\delta t_{\max}} = f(N.\tau)$ for experiments № 1, 7 and 10 has been shown. The calculated from the linear regression models A and n in equation of the type:

$$\frac{\delta t}{\delta t_{\max}} = A.(N.\tau)^{-n} \qquad /15/$$

have been stated in Table 3.

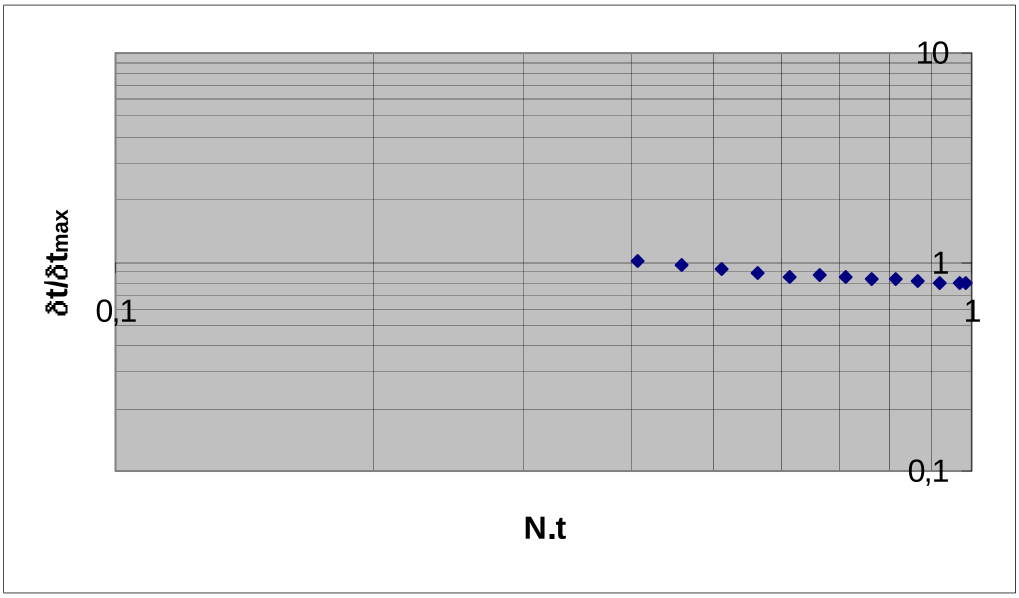

Fig. 6

Table 3

	1	2	3	4	5	6	7	8	9	10	11
A	0.35	0.47	0.35	0.48	0.40	0.37	0.37	0.30	0.40	0.30	0.37
n	0.732	0.696	0.756	0.712	0.714	1.00	0.773	0.206	0.314	0.185	0.418

As it can be seen the coefficient A values vary in a comparatively small range 0.38 ± 0.08. The deviation in A are due probably to the differences in material moisture, with which it enters the second drying period.

The exponent n for experiments № 1 – 7 (n_{mean} = 0.77) defers considerably from n for experiments № 8 – 11 (n_{mean} = 0.28). An explanation of that circumstance can be sought for in the difference between the atmospheric air parameters, utilized during the process of drying. Experiments № 8 – 11 have been carried out at an atmospheric air temperature of 15 ^{o}C and moisture content of 0.008 kg/kg, while the experiments № 1 – 7 at temperature of 7.1 ^{o}C and moisture content of 0.0055 kg/kg. The greater energy consumption for heating the sucked atmospheric air leads to a lower rate of temperature growth of the drying agent before the bed t_B.

Notation

c_v - specific heat capacity of the wet air at constant volume, J/(kg.K)
d - air humidity, kg water/kg humid air
k - constant
L - drying agent flux, kg/s
m - mass, kg
n - rate of re-circulation
N - drying rate, s^{-1}
r - heat of evaporation, J/kg
t - temperature, ^oC
u - water content, kg/kg
$\Delta Ú$ - evaporated water, kg/s
v - specific volume, m^3/kg

Greek symbols

α - heat transfer coefficient, W/(m^2K)
δ - difference
ρ – density, kg/m^3
τ – drying time, s
θ - temperature of the material, ^oC

Subscripts

i - initial
o - absolutely dry material

References

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