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MODEL OF MASS TRANSFER WHEN DRYING DIRECTLY – AND COUNTER-CURRENT MODE

Ilkhom Rakhmatov
Department of Physics, Bukhara State University, Bukhara, Uzbekistan
rahmatov.1961@mail.ru

Abstract:The article investigates the drying mode for mass transfer under direct current and counter-current conditions.The scheme and mathematical calculation of drying plants are given. Calculated the moisture content of the drying agent and the drying speed

To study the influence of the drying mode parameters and the method of organizing the movement of the drying agent on the duration of drying, you can use a mathematical model based on the laws of mass transfer of moisture from wet material to wet air. This model is more preferable, since in low-intensity processes there is practically no energy consumption for heating the material. Convective-radiation energy supply at low temperatures of the radiating surface can be considered according to the law of additivity.

A batch chamber dryer can be structurally arranged so that the drying agent moves along a thin layer of dispersed material, that is, the "dried material-dried agent" system can be considered as an ideal displacement chamber. This type is most easily implemented in continuous installations, where options for organizing movement are possible: direct current and counter-current. In this case, the driving force of the mass transfer process between the drying agent and the drying material changes smoothly – from its maximum value to the minimum. When calculating the drying kinetics and analyzing the influence of various parameters on it, it is possible to use kinetic models based on the laws of mass transfer. This possibility is provided in the case of low-temperature drying under soft conditions in a thin layer, when the solution of the external problem is valid without taking into account the non-isothermicity of both the flow and the material layer.

Let's consider the problem statement and its solution for the case of direct flow motion of the drying agent and the drying material [1]

For an element of length dx, the material balance for evaporated moisture is recorded:

$$L\frac{dz}{d\,x} = G\frac{d\omega}{dx} \qquad (1.1)$$

Integrating this expression from the drying agent input to the cross section gives the result:
:

$$L(z - z_1) = G(\omega_1 - \omega) \qquad (1.2)$$

or

$$Z = Z_1 + \frac{G}{L}(\omega_1 - \omega) \qquad (1.3)$$

Using a kinetic model describing the drying kinetics through a generalized drying rate N* in any drying period, write::

$$\frac{d\omega}{d\tau} = N^*N \qquad (1.4)$$

The drying rate in the first period N can be calculated if we assume that it is determined by the conditions of external mass transfer.

Since the driving force along the drying surface is continuously changing, its current value N can be determined by the value of the drying speed at the input of the drying agent and the change in its state along the length:

$$N = N_1 \frac{ln\frac{P_\delta - P_п}{P_\delta - P_s}}{ln\frac{P_\delta - P_{п_1}}{P_\delta - P_s}} \qquad (1.5)$$

where P_S is the partial pressure of water vapor above the surface of the material, equal to the saturation pressure of water vapor at the material temperature; P_π is the local partial pressure of water vapor in the flow of the drying agent $P_{\pi 1}$ is the partial pressure of water vapor in the flow of the drying agent at the inlet; N_1 is the drying rate in the first period at the inlet. The values N_1 and $P_{\pi 1}$are constant and are mode parameters.

The moisture content of the drying agent is related to the partial pressure of water vapor by the ratio:

$$Z = \Psi \frac{\mathrm{P}}{\mathrm{B} - \mathrm{P}} \qquad (1.6)$$

where B is atmospheric pressure Ψ-the ratio of the molecular masses of water brine and dry air. At low partial pressures of water vapor, the dependence is close to linear, so the formula for the local drying rate can be rewritten as follows:

$$N = N_1 \frac{Z_s - Z}{Z_s - Z_1} \qquad (1.7)$$

where Z_S is the moisture content of the drying agent in the state of saturation above the surface of the material with a known temperature; Z_1 is the moisture content of the drying agent at the entrance to the material layer, equal to the moisture content of the atmospheric air. In the second drying period the local drying rate also depends on the local moisture content of the material and it is proposed to calculate it using the formula:

$$N = N_1 \frac{Z_s - Z}{Z_s - Z_1} f(W) \qquad (1.8)$$

where f(w) is a kinetic function of the I kind that sets the formula for the generalized drying rate curve for an infinitesimal portion of the material with strictly constant parameters of the drying agent. With a strictly physical approach, you should use the formula to calculate the local drying rate in the second period

$$N = N_0 \frac{Z_* - Z}{Z_s - Z_0} \qquad (1.9)$$

where Z_* is the moisture content of the drying agent above the surface of the material. The value of Z_* should be searched for, based on the consideration that in the second drying period. In contrast to the first period, the surface temperature of the material is no longer equal to the known adiabatic saturation temperature of the drying agent and is a variable value, and the partial pressure of water vapor above the surface of the material is already less than the saturation pressure. At the surface temperature of the material and is determined by the conditions of internal mass transfer in the material particle. It is obvious that this approach has encountered almost insurmountable computational difficulties. The only reason to change the exact theoretical expression (1.5) to approximate semi-empirical expression (1.4) is mounted Krasnikov law, according to which, at a strictly constant parameters of drying agent, drying speed is a function only of the moisture content of the material, and when you change the parameters of drying agent is a function only undergoes linear homogeneous transformation:

$$\frac{dW}{dt} = -nf(W) \qquad (1.10)$$

Where n is the proportionality coefficient depending on the parameters of the drying agent. Note also that the expression (1.4) is a special case of the expression (1.10) when *f* (W)=1, so you can use the expression (1.10) to calculate the drying rate in both the first and second periods

Then the expression (1.10) can be finally written as:

$$\frac{dw}{d\tau} = -N^* N_1 \frac{Z_s - Z}{Z_s - Z_1} \qquad (1.11)$$

Taking into account (1.3), we get:

$$\frac{dw}{d\tau} = -N^* N_1 \frac{Z_s - (Z_1 + \frac{G}{L}(\omega_1 - \omega)}{Z_s - Z_1} \qquad (1.12)$$

By entering the variables accepted in this case

$$v = \frac{\omega - \omega_p}{\omega_k - \omega_p}; \qquad R = \frac{G}{L} = \frac{\omega_k - \omega_p}{Z_s - Z}$$

$$\chi = \frac{1}{\omega_k - \omega_p}; \qquad \text{and } K_r = \frac{N_1}{\omega_k - \omega_p} = \chi N_1 \tau$$

get:

$$\frac{\partial v}{\partial(\chi N_1 \tau)} = \frac{\partial v}{\partial(K_r)} = N_1^*[1 - R(v_1 - v)] (1.13)$$

Integrating these expressions. Get for direct flow, if there are I and II drying periods:

$$K_{r_{\text{ПР}}} = \chi N_1 \tau = \int_{v_1}^{1} \frac{\partial v}{N_I^*[1 - R(v_1 - v)\,]} + \int_{1}^{v_2} \frac{-\partial v}{N_{II}^*[1 - R(v_1 - v)\,]} \qquad (1.14)$$

If we assume that the change in N* is linear, then:

$$N_I^* = 1 \qquad N_{II}^* = v$$

Then we finally have

$$K_r = \frac{1}{R} ln\left[\frac{1}{1 - R(v_1 - 1)}\right] + \frac{1}{1 - Rv_1} ln\left[\frac{1 - R(v_1 - v_2)}{v_2[1 - v_1 - 1)]}\right] \qquad (1.15)$$

For the case when, dimensionless moisture content$v_1 \geq 1;\ \ v_2 \geq I$

$$K_r = \frac{1}{R} ln\left[\frac{1}{1 - R(v_1 - v_2)}\right] \qquad (1.16)$$

For the case $(v_2 \leq I; \quad v_1 \leq I)$ get:

$$K_{r_{\text{ПР}}} = \frac{1}{1 - Rv_1} ln\left[\frac{v_1[1 - R(v_1 - v_2)]}{v_2}\right] \qquad (1.17)$$

When solving the inverse problem-the problem of finding the moisture content that will be achieved during drying of a certain duration, it will have:

$$v_{\text{ПР}} = [K_r - K_r(I)]exp[-(1 - Rv_1)] \qquad (1.18)$$

when defining $K_r(I)$, use (1.15), assuming $v_2 = I$

The dimensionless current moisture content will be recorded in this case:

$$v_{\text{ПВ}} = \frac{1 + Rv_2}{R + [(1 + Rv_2) - R]exp\left\{\frac{1+Rv_2[K_r - K_r(I)]}{(1+Rv_2)-R}\right\}} \qquad (1.19)$$

Forthecase$v_1 > 1,\ v_2 \geq 1\ \ и v > 1$the resulting solutions have the form:

$$K_{r_{\text{ПВ}}} = \frac{1 - R(1 - v_2)}{R} ln\left[\frac{1 - R(v - v_2)}{1 - R(v_1 - v_2)}\right] \qquad (1.20)$$

$$v_{\text{ПР}} = \frac{1}{R}\left\{(1 + Rv_2) - [(1 + Rv_2) - Rv_1]exp\left[\frac{K_r}{1 + Rv_2 - R}\right]\right\} \qquad (1.21)$$

If the dimensionless moisture content meets the condition$v < 1$at the same time $v_2 < 1,\ \ v_1 \ll 1$, that:

$$K_{r_{\text{ПВ}}} = \frac{1 - R(1 - v_2)}{1 + Rv_2} ln\left\{\frac{v_1[1 - R(v - v_2)]}{v[1 - R(v_1 - v_2)]}\right\} \qquad (1.22)$$

$$v_{\text{ПР}} = \frac{v_1(1 + Rv_2)}{(1 + Rv_1) - R(v_1 - v_2)exp\left\{\frac{K_r(1+Rv_2)}{(1+Rv_2)-R}\right\}} \qquad (1.23)$$

When the counterflow is considered:

$$K_{\text{ПВ}} = \chi N_{max} = \chi N_{v=1} = N_1 \frac{1 - R(1 - v_2)}{1 - R(v_1 - v_2)} \qquad (1.24)$$

Drying speed:

$$\frac{\partial v}{\partial K_{r_{\text{ПР}}}} = \frac{1 - R(v - v_2)}{1 - R(1 - v_2)} \qquad (1.25)$$

For the case $v_1 > 1 \quad и v_2 \geq 1$have:

$$v_{\text{ПР}} = (v_1 - 1) + \frac{1}{R}\exp(RK_r) \qquad (1.26)$$

By$v_1 \leq 1,\ \ v_2 = v < 1$,

$$v_{\text{ПР}} = \frac{v_1 - (1 - Rv_1)}{exp[K_r(1 - Rv_1)] - Rv_1} \qquad (1.27)$$

The drying rate in the counter-flow period can be determined using:

$$-\frac{dv}{dK_{r_{\text{ПР I}}}} = [1 - R(v_1 - v)] \qquad (1.28)$$

For the second period we have

$$-\frac{dv}{dK_{r_{\Pi P\,II}}} = v[1 - R(v_1 - v)] \qquad (1.29)$$

It is obvious that using the above approach, you can get similar solutions for the case of counterflow.

However, as it is clear from the considered statement of the problem, the unevenness of the drying speed, which in a real drying chamber, may not be taken into account in the resulting solutions.

Dimensionless drying time for counterflow$K_{r_{\Pi B}}$for the case$v_1 \geq 1. v_2 < 1 и v \leq 1$can be obtained by solving the original equation (1-15):

$$K_{r_{\Pi B}} = \frac{1 - R(1 - v_2)}{R} ln\left[\frac{1 - R(1 - v_2)}{1 - R(v_1 - v_2)}\right] +$$

$$+\frac{1 - R(1 - v)}{1 + R(v_1 - v_2)} ln\left\{\frac{1 - R(v - v_2)}{v(1 - R(1 - v_2))}\right\} \qquad (1.30)$$

This expression of the drying rate in the first period allows us to calculate the effect of drying parameters on its duration.

When drying in the period of falling speed, the change in the drying speed can be determined:

$$\frac{dv}{dK_{r_{\Pi P\,II}}} = \frac{v[1 - R(v - v_2)]}{1 - R(1 - v_2)} \qquad (1.31)$$

$$\frac{K_{r_{\Pi P}}}{K_{r_{\Pi B}}} \qquad (1.32)$$

The obtained expressions allow us to make numerical comparisons of the efficiency of organizing the relative movement of the drying agent and the material (direct flow and counter flow), comparing the dimensionless time (1.32)

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SHORT BIODATA OF ALL THE AUTHOR

Ilkhom Rakhmatov has a higher Education. in 1983, he graduated with honors from the Bukhara State pedagogical Institute. Performs research work to optimize the teaching of technical disciplines. Works on calculations and creation of new generations of drying plants for drying medicinal plants.