ENERGY OPTIMIZATION OF THE CONVECTIVE DRYING PROCESS OF LEGUMES AND FRUITS THROUGH DUST BALANCE MEASUREMENT

Gheorghe Brătucu[1] Andreea Marin[1] Mădălin Bondoc[1]
[1]Transilvania University of Brasov, Brasov, ROMANIA, e-mail: gh.bratucu@unitbv.ro

Abstract: *The paper presents a model for the optimization of the convective drying process of vegetables and fruits, which takes place in a plant that uses hot air as a dehydrating agent. In the calculation of the mass balance, an example is made of tomatoes, considered common vegetables subjected to the drying process. After the amount of moisture to be discharged from the product under consideration, the hot air needed to absorb the moisture content is calculated. The conclusions of the research are the results of some experimental research that focused on these aspects.*
Keywords: *vegetables and fruits, convective drying, mass balance, optimization*

1. INTRODUCTION

Materials with a fibrous, porous, gelatinous structure of organic nature in which the bonding of moisture to the material is strong, including vegetables and fruits, exhibit high values of equilibrium humidity, the migration of moisture through them through diffusion [1]. The weight of the constant speed drying area is small or is completely missing. If the drying speed is too high, the difference between the superficial moisture and the core humidity can cause irreversible damage to the product by cracking, twisting, flaking [2]. Therefore, the drying rate of these materials is limited, and the heat transfer intensity must not exceed this supportability threshold [6], [7]. The energy optimization of the convective drying process must ensure the highest quality of the finished products, without neglecting the economic aspect of the convective drying process, represented by the energy consumption required for the elimination of water, to the level at which the preservation of the vegetables or fruits is made completely safe . For this purpose, the paper draws the theoretical mass balance of the drying chamber, using the tomatoes for exemplification. Next, the air needs to be determined when drying the vegetables and fruit, taking into account the amount of moisture that is removed by drying.

2. MATERIAL AND METHOD

2.1. Calculation of the mass balance of the drying chamber

The mass balance of the drying chamber is expressed by:

$$G_1 - G_2 = w_1 G_1 - w_2 G_2 = L \cdot (x_2 - x_1) = \Delta W \,, \tag{1}$$

where: G_1 is the mass of wet material, *in kg*; G_2 - mass of dry matter, in *kg*; w_1 - relative humidity of the material at the inlet to the dryer, in *%*; w_2 - relative humidity of the material at the outlet of the dryer, in *%*; L - dry air flow, in *kg / s*; x_1 - absolute air humidity at the dryer entrance and x_2 is the absolute air humidity at the outlet of the dryer, in *%*; ΔW - the amount of moisture emitted from the material, in *kg / s*.
By replacing the terms with known values, for example, for 100 g of tomatoes with an initial humidity of 94% and the final one of 8% at a dry air flow rate of 0.481 kg / s, the amount of moisture emitted from the material is ΔW = 0.009 kg / s.
Decreasing humidity can be calculated with the formula [9]:

$$U = \frac{W_1 - W_2}{100 - W_2} \cdot 100 = 93{,}47[\%]. \quad (2)$$

When there is no material loss, the amount of dry substance remains constant even before and after drying. This aspect can be mathematically expressed by the relationship:

$$G_U = G_1 \frac{100 - W_1}{100} = G_2 \frac{100 - W_2}{100} = 0{,}006[kg]. \quad (3)$$

It follows that G_2 = 0.0065 *kg*.
The values of G1 and G2, respectively, can be expressed as follows:

$$G_1 = G_2 \frac{100 - W_2}{100 - W_1} = 0{,}099[kg],$$
$$G_2 = G_1 \frac{100 - W_1}{100 - W_2} = 0{,}0065[kg]. \quad (4)$$

Drying moisture is the difference between the wet weight and the dry mass:

$$W = G_1 - G_2 = 0{,}0925[kg]. \quad (5)$$

Replacing the value of G_2 from equation (4) in relation (5) gives:

$$W = G_1 - G_1 \cdot \frac{100 - W_1}{100 - W_2} = 0{,}0925[kg],$$
$$or \quad (6)$$
$$W = G_1 \frac{W_1 - W_2}{100 - W_2} = 0{,}0925[kg].$$

Similarly, replacing the value of G_1 gives:

$$W = G_2 - G_2 \cdot \frac{100 - W_2}{100 - W_1} = 0{,}0931[kg]$$
$$or \quad (7)$$
$$W = G_2 \frac{W_1 - W_2}{100 - W_1} = 0{,}0931[kg]$$

2.2. Calculation of air consumption when drying fruits and vegetables

In a lossless drying equipment, the amount of completely dry air passing through the dryer, as well as the amount of completely dry material, remains invariable [3], [4].
Thus, in the case of a stationary process, using the proposed example, the total amount of moisture is composed of:

- moisture of the drying material: $G_1 \cdot \frac{W_1}{100} = 0{,}09306[\%]$;
- humidity of the air at the entrance to the dryer: $Lx_1 = 0{,}36075[\%]$;
- moisture content of dry material: $G_2 \cdot \frac{W_2}{100} = 0{,}00052[kg]$;
- humidity of the air at the outlet of the dryer: $Lx_2 = 0{,}45695[\%]$.

In the absence of losses, the total humidity remains constant and equality is observed:

$$G_1 \frac{W_1}{100} + Lx_1 = G_2 \frac{W_2}{100} + Lx_2 \,. \quad (8)$$

The remote moisture content of the material is:

$$W = G_1 \frac{W_1}{100} - G_2 \frac{W_2}{100} = 0{,}09254[kg] \,. \quad (9)$$

By comparing equations (8) and (9) it follows:

$$W = L \cdot (x_2 - x_1) = 0{,}09254[kg] \,. \quad (10)$$

Thus, the total air consumption required for drying can be expressed with the relation:

$$L = \frac{W}{x_2 - x_1} = 0{,}4627[kg/s] \quad (11)$$

The specific air consumption, *l*, ie the air consumption per 1 *kg* of humidity is:

$$l = \frac{1}{x_2 - x_1} = 5[kg/kgumiditate] \,. \quad (12)$$

3. RESULTS AND DISCUSSIONS

In most cases, drying of wet vegetables and fruits is done with hot gases, air or combustion gases. In the drying installations, the thermal regime changes over time, drying is carried out in a non-stationary regime. For this reason a rigorous analysis of the kinetics of the drying process is complex and to describe the basic laws, it is considered to be stationary drying at the beginning, when the temperature of the drying agent, the relative humidity and the circulation speed remain constant throughout the process drying [5], [8].

The bond between the material and the moisture has an important influence on the drying process. The drying regime is characterized by three parameters: temperature, relative humidity and drying rate. The values of these parameters influence both the duration of the drying process and the quality of the ***material*** to be dried. The drying regime has to be optimized in order to find a minimum drying time with a minimum heat consumption corresponding to the best technological properties of dried vegetables and fruits.

4. CONCLUSION

Based on the experimental research of a colloidal environment, the following conclusions were obtained [6]:

• if the environment is *colloidal*:

- an increase in the drying agent temperature by 50 ^{0}C, leads to a 6 to 8% drying time reduction;
- a reduction in the relative humidity of the drying agent from 85% to 60% leads to a reduction in the drying time of about 8-10%;
- an increase in drying speed from 2 *m / s* to 7.6 *m / s* leads to a reduction in the drying time of 15...18%; by increasing the thickness of the material layer three times it is possible to increase the duration of the drying process by 15...18%;

• if the environment is *capillary - porous*:

- a reduction in relative humidity of the drying agent from 75.8% to 17.7% results in a decrease in the drying rate of almost 4.5 times;
- an increase in the drying agent temperature from 30 to 60 ^{0}C produces an increase in the drying rate in the first period of about 2.5 times.

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