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INVESTIGATION ON EFFECT OF POROSITY AND INVOLUTION OF ROLL ON DRYING SPEED

Volodymyr Didukh, Ruslan Kirchuk,
Igor Dudarev, Igor Golovachuk

Lutsk State Technical University
75, Lvivska Str., Lutsk, 43018, Ukraine

Summary. The article proposes an analytical method of defining bulk porosity and involution of material layer in a roll, investigates their effect on drying speed of plant material in the roll in view of energy efficiency. The obtained results show that in the area of the end of constant drying speed, more significant effects of porosity and involution coefficients on the roll drying process are observed.

Key words: bulk porosity, drying speed, energy efficiency, analytytical method

Resulting from unfavourable weather conditions during storage, the plant material in rolls has to be brought to standard humidity through artificial drying. It enables maintaining material quality in the roll and its extended storage. Process of plant material drying is one of the most energy intensive [Didukh *et al.* 2002]. It requires continuous improvement regarding reduction of power inputs, manual labour and creation of new machines and mechanisms of maximum possible process mechanization and automatization. One of the directions of improvement of drying process is improvement of available methods, taking into account material characteristics, its distribution in the package, finding best temperature performance and heat carrier parameters.

The drying methods with the use of in-turn feed of heat carrier and free air (heating-cooling) or heating-rest are spreading. They have different names: impulse (changeable), broken (heating-rest), oscillating (heating-cooling, cycling of feed sides) [Danilov and Leonchik 1986]. Such drying conditions significantly save energy resources through short attachment of a high temperature heat carrier. In result of non-steady conditions and changing the temperature profile on the material surface, heat-transfer coefficient can be 1,5…3,0 times higher than at steady conditions [Danilov and Leonchik 1986]. Package resting or cooling with irregularly distributed material enables transferring humidity among different layers and compensates the temperature providing uniformity of drying [Didenko and Doroshenko 1974, Evminov (ed.) 1980].

Description of plant material drying process in cylindrical packages with the use of oscillating temperature requires further investigations directed on material distribution pattern. Roll bulk porosity is one of the parameters determining penetrability of the roll, i.e. its ability to transmit a certain quantity of the carrier. The bigger the value, the higher the penetrability of the roll is. The bulk porosity value is significantly influenced by the roll density, characteristics if stalks and their distribution in the roll. At increasing material density in the roll, its bulk porosity reduces. Chaotic stalk distribution in the roll results in pores of different size, which are not always interconnected, making the heat-carrier movement more complicated and, consequently, slowing down the drying process.

Roll formation is resulted by rolling of material strip. Though the strip is rolled spirally, it can be assumed that in section, the roll layers have the form of a ring, except for the central part (nucleus). Due to different density, bulk porosity, involution of layers, the ventilation intensity is not similar. It leads to non-uniform drying.

To analyze that task, it is necessary to study the drying process separately in each roll layer. Let us assume that the density, bulk porosity and involution of material layer on the roll height are similar.

Bulk porosity of a material layer in the roll can be defined as follows:

$$\Pi_V = \frac{V_{пор.}}{V_{шар.}}, \tag{1}$$

where:

$V_{пор.}$ – volume occupied by pores in material layer;

$V_{шар.}$ – material layer volume in the roll.

$$V_{пор.} = V_{шар.} - V_{c.cm.} n, \tag{2}$$

where:

$V_{c.cm.}$ – average stalk volume in the material layer;

n – quantity of stalks in the layer .

Assuming that a stalk after being pressed into the roll keeps its round shape or its deformation is slight, a stalk diameter after pressing is approximately equal to the stalk diameter before pressing, we receive:

$$V_{c.cm.} = \frac{\pi d^2_{c.cm.} l_{c.cm.}}{4}, \tag{3}$$

where:

$d_{c.cm.}$ – average diameter of a stalk in material layer;

$l_{c.cm.}$ – average stalk length in material layer.

Volume of the material layer in roll:

$$V_{шар.} = \pi h L_{рул.} \left(2R + h\right), \tag{4}$$

where:

h –layer thickness in roll;

$L_{рул.}$ – layer height equal to roll height;

R – distance from the roll centre to a relevant layer.

Material layer density:

$$\rho_{шар.} = \frac{m_{шар.}}{V_{шар.}}, \tag{5}$$

where:

$m_{шар.}$ – material layer mass .

$$m_{шар.} = m_{с.ст.} n, \tag{6}$$

where:

$m_{с.ст.}$ – average stalk mass in material layer.

Quantity of stalks in material layer is defined by substitution (4) and (6) into (5) and making conversion:

$$n = \frac{\pi h L_{рул.} \rho_{шар} \left(2R + h\right)}{m_{с.ст.}} . \tag{7}$$

If we accept the assumption that $l_{с.ст.} = L_{рул.}$, which is possible at parallel placing stalks into a roll, substituting (2), (3), (4), (7) into (1) and making conversion, we receive:

$$П_V = 1 - \frac{V_{с.ст.} \rho_{шар.}}{m_{с.ст.}} . \tag{8}$$

By changing $\frac{m_{с.ст.}}{V_{с.ст.}}$ through $\rho_{с.ст.}$, being a conditional density of a stalk, while total stalk volume (with the emptiness) is counted, we receive:

$$П_V = 1 - \frac{\rho_{шар.}}{\rho_{с.ст.}} . \tag{9}$$

Besides bulk porosity, the material layer (roll) penetrability is affected, as already mentioned, by distribution of stalks in the roll and their straightness. These factors can be calculated through involution of the layer (roll) [Sumietov 1980], being a proportion of the distance covered by heat carrier in the layer to the roll height. For the rolls with the parallel placing of stalks of little straightness deviation, assuming that the heat carrier will move along the stalks, the involution of the material layer (roll) can be defined as follows:

$$\xi_{шар.} = \xi_{с.ст.} = \frac{l_{с.ст.}}{L_{с.ст.}} = \frac{l_{с.ст.}}{L_{рул.}}, \tag{10}$$

where:

$\xi_{шар.}$ – involution of material layer (roll);

$\xi_{с.ст.}$ – coefficient of stalk straightness;

$L_{с.ст.}$ – average conditional stalk length in roll equal to a segment connecting two stalk ends.

To define material layer involution at chaotic distribution of stalks in the roll, (10) cannot be applied. In that case, besides stalk straightness and their length, the material layer involution will be affected by randomness of stalk distribution, density of material pressing, pores between stalks, difference in volume, and their interconnection.

Having made the substitution, on the basis of Newton-Richman equation, values of bulk porosity and involution of the material layer into equation, suggested by Lykov [1968], we receive:

$$\boldsymbol{W = W_{к} + (W_{n} - W_{к})e^{-\frac{kt\,П_{v}}{x_{шар.}}}}. \tag{11}$$

where:

$W_{к}$ –final material humidity;

W_{n} – initial material humidity;

k – drying coefficient;

τ – drying time.

For visualization of the introduced statements, the mathematical model of roll drying is suggested. Basing on the investigations [Fedik 1999] as well as own experimental data, the received coefficient values for porosity and involution are received. They are put together in Table 1.

Table 1. Values of porosity and involution coefficients

Porosity coefficient Π_V	0.980	0.977	0.975	0.980	0.977	0.975
Involution coefficient $\xi_{шар.}$	1.000	1.007	1.015	1.015	1.007	1.000

The results of the model-based analysis of flax straw roll drying taking into account the porosity and involution coefficients is shown in Figure 1.

An analysis of the obtained results shows that in the area of the end of constant drying speed, more significant effects of porosity and involution coefficients on the roll drying process are observed. It enables to state the necessity of investigation of roll forming processes and means as one of the energy efficient drying methods. The optimal roll structure with the application of the oscillating temperature modes of drying will enable to significantly reduce the energy costs for post-harvest treatment of agricultural plants.

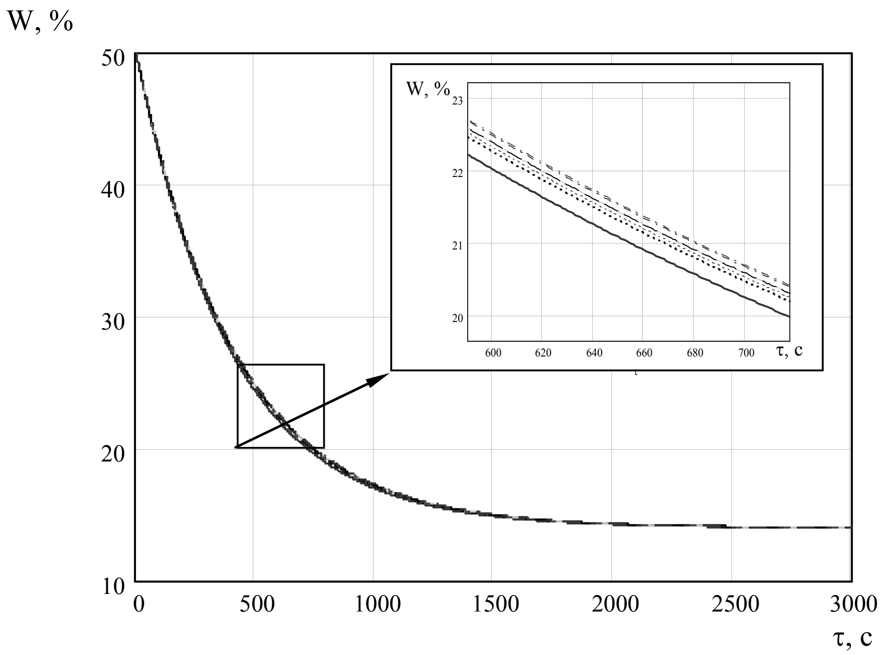

Fig. 1. Graph for flax raw drying including porosity and involution coefficients

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