**Slavica Prvulović**
Professor
University of Belgrade
Technical Faculty, Bor

**Dragiša Tolmač**
Professor
University of Novi Sad
Techical Faculty “Mihajlo Pupin”, Zrenjanin

**Zvonimir Blagojević**
JP Toplifikacija, Požarevac

**Jasna Tolmač**
Senior Undergraduate of Physics
University of Novi Sad
Faculty of Sciences

# Experimental Research on Energetics Characteristics of Starch Dryer

*Experimental and theoretic researches are presented in this paper and they are implemented on the real industrial equipment of convection dryer for maize starch. The numeric values are given for optimum parameters of drying, energetics characteristics and balances as well as the coefficient of heat transfer.*

*Heat transfer in these systems is accomplished based on the principle of direct contact of dried material and warm air. Then, an intensive transfer of heat and mass is accomplished.*

*This work presents the results of researches which can be useful in designing and construction of such dryers in the food and agri industry. It refers to the technological technical characteristics of the dryer, energy balances and coefficient of heat transfer.*

**Keywords:** *starch, dryer, energy balance, numeric data, heat transfer.*

## 1. INTRODUCTION

The material presented in this paper is of interest to agricultural engineers around the world because it views the problem of drying the corn starch as an agricultural product. This is a wet way of industrial corn refinement, and corn starch only one of products.

Information given in the manuscript about energy characteristics and coefficient of heat transfer can serve engineers for planning of this and similar systems of drying. Experimental results were obtained in realistic industrial installation for drying, place, so they can be useful. Drying places of this type are used by nearly all factories for industrial refinement of cereals in the world. Heat transfer systems of this kind and likewise are introduced in literature [1-6].

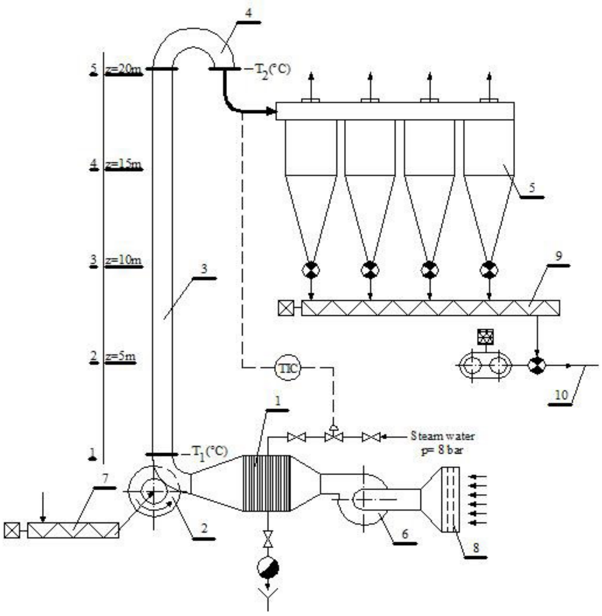
In these dryers, a continuous drying of different kinds of materials is made, the concentration being $c_k$ = 0.05 – 2 kg of material / kg of air. Average particle size of the drying material can be 0.05 – 2 mm. The specific consumption of energy is usually 3500 – 5040 kJ/kg$H_2O$, according to [7,8].

The drying time in these dryers is very short, only several seconds, therefore they can be used for drying of the materials susceptive to high temperatures in a short drying period of time.

## 2. DESCRIPTION OF EXPERIMENTAL PLANT

Experimental research was carried out in the convection pneumatic dryer, Fig. 1. Drying was performed in direct contact of warm gases with the moist material. Based on that, the principle of direct drying is represented here. The drying material is starch.

The dosing of moist material to the dryer is made through the rotation dozer (2) with the capacity of $m_1$ = 8000 kg/h, through the screw conveying system, as given in the scheme of experimental plant in Figure 1. Moist material is transported via hot air – the drying agent through the dryer pneumatic pipe (3), and goes to the cyclones (5) where separation of dried material is made, and the hot gases exit into the atmosphere.




**1 – Heat exchanger $Q$ = 2.5 MW; 2 – Rotary feed of moist material; 3 – Dryer pipe diameter $d$ = 1250 mm, height $h_z$ = 20 m; 4 – Dryer head; 5 – Cyclones diameter $d_c$ = 1750 mm; 6 – Centrifugal fan $V$ = 65000 $m_n^3$/h, $\Delta p$ = 3500 Pa, $N$ = 90 kW; 7 – Helical conveyor for bringing of moist material; 8 – Filter; 9 – Helical conveyor; 10 – Pipe of pneumatic transportation**

**Figure 1. Scheme of convection pneumatic dryer**

During drying, the determined steam water is $m_p$ = 3830 kg/h. Average values of the results of measuring the drying temperature are: $T_1$ = 150 °C, $T_2$ = 50 °C, and the material humidity is: $w_1$ = 36 %, $w_2$ = 13 %.

Based on the above, the energy balances can be useful when showing the dryer condition diagnosis, according to the literature [9-12].

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Correspondence to: Dragiša Tolmač
Technical Faculty “Mihajlo Pupin”,
Đure Đakovića bb, 23000 Zrenjanin, Serbia
E-mail: dragisat@gmail.com

Table 1, contains average values of the results of measuring the air temperature – the drying agent and moisture of dried material and time of drying.

**Table 1. Average values of the results of measuring the drying temperature, the material moisture and the time of drying**

| Measuring place, according to the Figure 1 | Time of drying, $t$ [s] | Moisture of the dried material, $w$ [%] | Temperature of the hot air, $T$ [°C] |
|---|---|---|---|
| 1-1 | 0 | 36 | 150 |
| 2-2 | 0.365 | 24 | 115 |
| 3-3 | 0.731 | 18 | 89 |
| 4-4 | 1.096 | 15 | 71 |
| 5-5 | 1.463 | 13 | 50 |

## 3. DETERMINATION METHOD OF ENERGY BALANCE

The discrepancy in the air enthalpy at the inlet and at the outlet of the dryer is according to [11,13-17]:

$$\Delta H = H_1 - H_2 = C_p \left(T_1 - T_2\right) . \tag{1}$$

Quantity of evaporated water:

$$W = m_1 \left(1 - \frac{100 - w_1}{100 - w_2}\right) . \tag{2}$$

Total heat quantity:

$$\dot{Q}_U = \dot{Q}_w + \dot{Q}_S + \dot{Q}_g , \tag{3}$$

$$\dot{Q}_U = m_p \cdot r . \tag{4}$$

Quantity of drying air:

$$V_L = \frac{\dot{Q}_U}{\Delta H} . \tag{5}$$

Specific consumption of energy:

$$q = \frac{\dot{Q}_U}{W} . \tag{6}$$

Thermal degree of utilization:

$$\eta_T = \frac{T_1 - T_2}{T_1} = \frac{\dot{Q}_U - \dot{Q}_g}{\dot{Q}_U} . \tag{7}$$

Total heat power of drying:

$$Q_U = h_t \cdot A \cdot \Delta T_{sr} . \tag{8}$$

Total coefficient of heat transfer:

$$h_t = \frac{Q_U}{A \cdot \Delta T_{sr}} . \tag{9}$$

Heat for drying, i.e. its convective part consists of the heat for water evaporation ($Q_w$) and heat for heating of the drying material ($Q_S$), meaning, without heat losses ($Q_g$):

$$\dot{Q}_{conv} = \dot{Q}_w + \dot{Q}_S . \tag{10}$$

During convective drying the following equation of the heat transfer is applied as well:

$$\dot{Q}_{conv} = h_c \cdot A \cdot \Delta T_{sr} . \tag{11}$$

## 4. RESULTS AND DISCUSSION

Experimental research on the convection pneumatic dryer, Fig. 1., was aimed to determine the energy balance, specific consumption of energy, thermal degree of utilization and other relevant parameters of drying, according to the literature [15,18-20]. The results of the energy balance are given in the Table 2.

**Table 2. Energy balance of convection pneumatic dryer**

| No. | Energy drying parameter | Symbol and measure unit | Energy value parameter |
|---|---|---|---|
| 1 | Air temperature at the inlet of dryer | $T_1$ [°C] | 150 |
| 2 | Quantity of evaporate water | $W$ [kg/h] | 2115 |
| 3 | Total heat quantity | $Q_U$ [kJ/h] | 7846650 |
| 4 | Drying heat power | $Q_S$ [kW] | 2180 |
| 5 | Specific consumption of energy | $q$ [kJ/kg – w] | 3710 |
| 6 | Quantity of drying air | $V_L$ [$m_n^3$/h] | 60358 |
| 7 | Specific quantity of evaporate water | [kg/m$^2$h] | 26.90 |
| 8 | Specific quantity of evaporate water | [kg/m$^3$h] | 86.20 |
| 9 | Air temperature at the outlet of dryer | $T_2$ [°C] | 50 |
| 10 | Thermal degree of utilization | $\eta_T$ [%] | 67 |

Based on the research, the total heat force of drying of $Q$ = 2180 kW is acquired as well as the specific consumption of energy $q$ = 3710 kJ/kg of evaporable water. According to the literature [1,13,21], a specific consumption of energy in convection drying amounts to 3650 – 5040 kJ/kg of evaporable water. According to the data from literature [22], specific consumption of energy amounts to $q$ = 3642 – 5283 kJ/kg of evaporable water.

Based on the results of energy balance and those of the drying parameters measuring, according to the literature [16,19], a total coefficient of the heat transfer is determined to be during convection drying $h_t$ = 277 W/m$^2$K, Tab. 3. Based on the results of research, the mass air flow amounts to 0.450 kg/m$^2$s, the drying capacity is 5885 kg/h, and the air temperature at the dryer inlet is 150 °C. According to the literature [21], the mass air flow is 0.289 kg/m$^2$s, the drying capacity is 1152 kg/h, at the drying temperature of 90 °C.

According to the research [1,24], on the convection pneumatic dryer, the value of the total coefficient of heat transfer during drying of corn starch is 308 W/m$^2$K, and during drying of potato starch the coefficient of heat transfer is 290 W/m$^2$K.

**Table 3. Total coefficient of heat transfer ($h_t$)**

| Total quantity of heat (heat power), $Q_U$ [kW] | Drying surface*, $A$ [m$^2$] | Mean difference of temperature, $\Delta T_{sr}$ [°C] | Total heat transfer coefficient, $h_t$ [W/m$^2$K] |
|---|---|---|---|
| 2180 | 78.50 | 100 | 277 |

*According to [14,23] drying surface is equal to interior surface of drying pipe ($A = d \cdot \pi \cdot h$; $d$ = 1250 m – pipe diameter; $h_z$ = 20 m – pipe height).

The objective of this part of research is to determine the character of heat transfer in such complex dynamic model, considering that the heat transfer comprises a phenomenon of heat transfer by convection, conduction and radiation. Based on the results of research, the value of the coefficient of heat transfer by convection has been determined, Tab. 4.

**Table 4. Coefficient of heat transfer by convection ($h_c$)**

| Heat power for water evaporation, $Q_w$ [kW] | Heat power for mat. heating, $Q_S$ [kW] | Heat power of heat transfer by convection, $Q_{conv}$ [kW] | Surface drying, $A$ [m$^2$] | Mean difference of temp., $\Delta T_{sr}$ [°C] | Coeff. of convection heat transfer, $h_c$ [W/m$^2$K] |
|---|---|---|---|---|---|
| 1482 | 66 | 1548 | 78.5 | 100 | 188 |

A coefficient of heat transfer under the dynamic conditions of the dryer operation (non-equal dosing of material to be dried, oscillations in the initial moisture content, temperature of drying, heat flux, etc.) depends on a greater number of different values which characterize the heat transfer.

For flowing agents drying (heat air) through pneumatic pipe of dryer $V$ = 60358 m$_n^3$/h, and diameter of pipe dryer $d$ = 1250 mm, the quick rate transport is $v$ = 13.67 m/s. Taking the length (height) into consideration, the pneumatic pipe drying is $h_z$ = 20 m, and time for drying is $t$ = 1.463 s.

The Figure 2 presents drying curves which demonstrate dependency of humidity changes on the time of drying. In the beginning of drying period, dependency of moisture changes and drying time is almost linear in character, where adequate time period of drying is $t$ = 0 – 0.70 s. It is the first drying period and its drying rate is constant, $z$ = 10 m. In the second drying period, at time interval $t$ = 0.70 – 1.463 s, dependency of moisture changes and drying time is not linear in character, which is demonstrated by the polynomial of the second order. In the end of drying, the content of balanced moisture is $w_2$ = 13 %, $z$ = 10 – 20 m.

The Figure 3 presents drying curves rates. The first stage of drying rate is constant but in the second period the drying rate is falling. When material moisture is reduced to the balanced moisture $w$ = 13 %, moisture evaporation rate is d$w$/d$t$ = 0.074 (kg – w / kg – dried solid).

The Figure 4 presents thermal drying curves. Dependency changes of thermal drying agents and time of drying is demonstrated by polynomial of the second order. In the drying process, on the occasion of pneumatic transport of drying material the degree of concentration has a relative small value, $c_k$ = 0.104 (kg material / kg air), so it can considered from the aspect of transport of pure agents drying. Thermal drying curves, Fig. 4, may have thermal approximate linear character. In the beginning of the period drying temperature of drying agents is 150 °C and in the end of drying it is 50 °C.

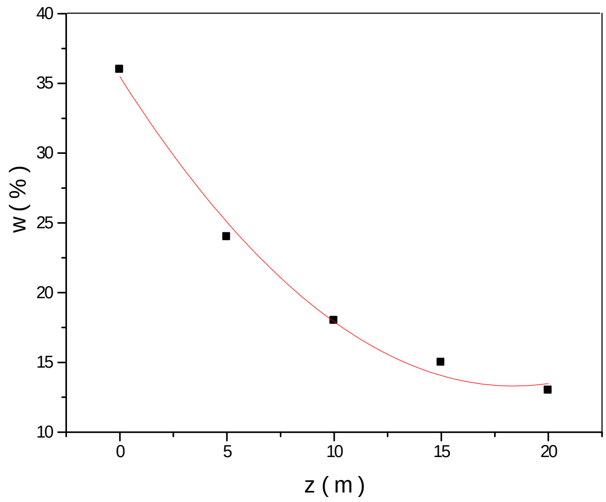


**Figure 2. Drying curves**

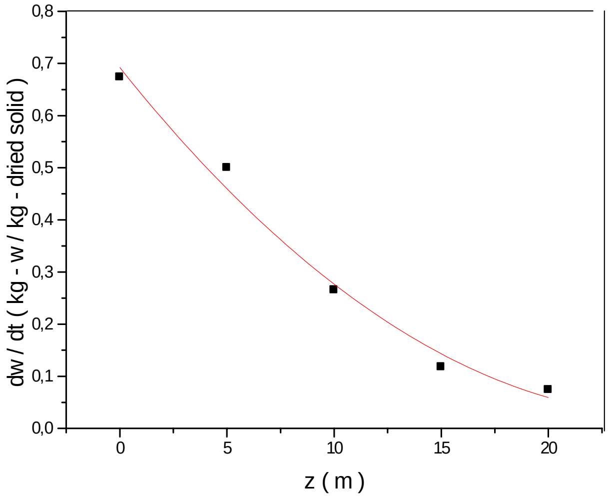


**Figure 3. Drying rate curves**

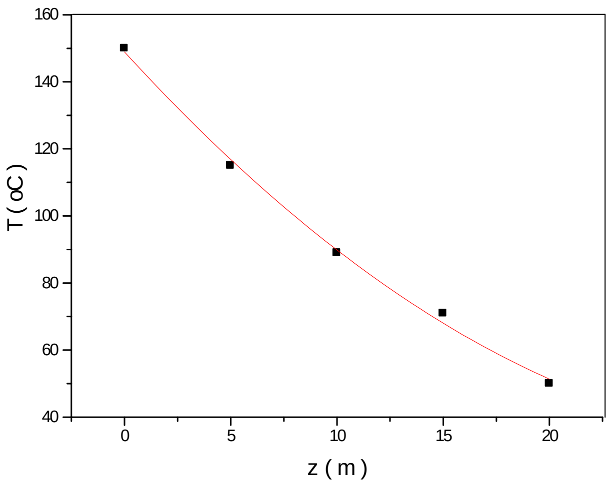


**Figure 4. Thermal drying curves**

By using the theory of correlation – method of the least squares [23,25], in processing the experiment data the following empiric equations were derived:

- dependency equation of moisture material from the time of drying, Fig. 2:

$$w = 35.485 - 2.414\,z + 0.065\,z^2 \qquad (19)$$

- dependency equation of drying rate from time, Fig. 3:

$$\mathrm{d}w/\mathrm{d}t = 0.692 - 0.051z + 9.897z^2 \qquad (20)$$

- equation of thermal drying curves, Fig. 4:

$$T = 148.942 - 6.937\,z + 0.102\,z^2 \qquad (21)$$

Empiric equations based on experimental research define the character of drying process course. Dependency change of drying rate and moisture material is shown in Figure 5.

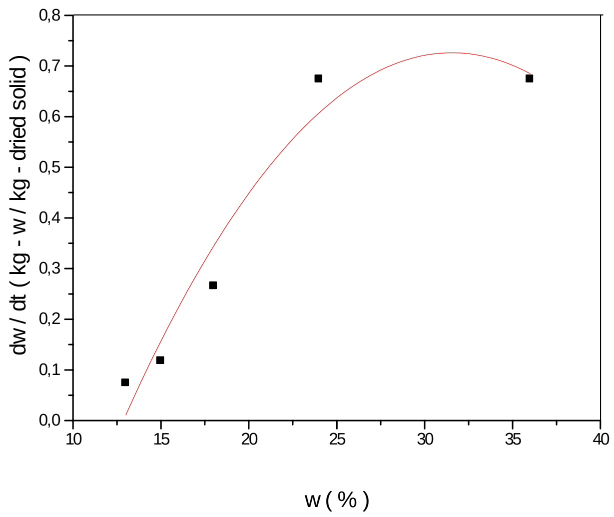


**Figure 5. Drying rate and material humidity dependency**

By applying the correlation theory, the least squares method, on research results, a correlation equation is derived:

- equation of drying rate and moisture material dependency, Fig. 5:

$$\mathrm{d}w/\mathrm{d}t = -\,1.342 + 0.131\,w - 0.002\,w^2 \qquad (22)$$

In the beginning of the period of drying, the surface of colloid moisture material covered by a thin layer of water has the same feature as when moisture free. Due to the contacts of colloid moisture material with heat drying agents, the process of liquid evaporation starts. In that case, in the first period of drying, liquid evaporation is accelerated, taking physical bound moisture into consideration, Fig. 5, but in the second period, the rate of drying is visible lower, taking physical-chemistry bond moisture into consideration.

## 5. CONCLUSION

Energy balance of the dryer can serve for evaluation of energetics condition of the dryer as well as for reviewing of the possibility of rational consumption of energy. This work presented the experimental and theoretic research of relevant parameters of drying on the convection pneumatic dryer in the agri and food industry. Based on the analysis of energy balance, the heat force of drying has been determined $Q_U$ = 2180 kW, specific consumption of energy $q$ = 3710 kJ/kg of evaporable water, as well as the thermal degree of utilization $\eta$ = 67 %.

Based on the results of research of energy balance and the results of measuring the temperature of the drying agent, the total coefficient of the heat transfer is determined in the convection dryer in the amount of $h_t$ = 277 W/m$^2$K, and the coefficient of the heat transfer by convection $h_c$ = 188 W/m$^2$K. The effects of the heat losses during drying are expressed through the separate value $h_t - h_c$ = 89 W/m$^2$K, so called coefficient of the heat transfer for the heat losses together with the outlet air and the heat transfer by conduction and radiation through the dryer pipe. In such a way, the effects of the heat transfer are determined as well as the basic parameters of the heat transfer.

Specific consumption of energy and quality of dried material are basic data which characterize the results of drying on the convection dryer. Following and control of these parameters in the drying process, the optimum consumption of energy is provided as well as the quality of dried material. Scientific contribution to the work and research are simple methods of determining the energy balance and heat transfer coefficients, application of thermodynamics. So the complex system of calculating kiln with the potential propagation of moisture is avoided. The results of research can be also used for: determination of dependence and parameters of the heat transfer during convection drying, as well as in designing and development of convection dryers. The acquired results of research are based on the experimental data from the industrial dryer. Based on that, the results of research have a value of use, i.e. they are useful to the designers, manufacturers and beneficiaries of these and similar drying systems as well as for the educational purposes.

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## NOMENCLATURE

| | |
|---|---|
| $h_t$ | total coefficient of heat transfer [W/m$^2$K] |
| $h_c$ | coefficient of convection heat transfer [W/m$^2$K] |
| $H$ | enthalpy [kJ/kg] |
| $T_1$ | air temperature at the inlet of dryer [°C] |
| $T_2$ | air temperature at the outlet of dryer [°C] |
| $C_p$ | specific air heat [kJ/m$_n^3$K] |
| $W$ | quantity of evaporated water [kg/h] |
| $m_1$ | quantity of moist material [kg/h] |
| $m_p$ | quantity of steam water [kg/h] |
| $w_1$ | the material moisture at the inlet of dryer [%] |
| $w_2$ | moisture of the dried material at the outlet of dryer [%] |
| $\Delta T_{sr}$ | mean difference of temperature [°C] |
| $t$ | time drying [s] |
| $Q$ | heat quantity [kJ/h] |
| $A$ | drying surface [m$^2$] |
| $r$ | heat specific evaporation [kJ/kg] |
| $q$ | specific consumption of energy [kJ/kg – w] |
| $V_L$ | quantity of drying air [m$_n^3$/h] |
| $\eta_T$ | thermal degree of utilization [%] |

## ЕКСПЕРИМЕНТАЛНО ИСТРАЖИВАЊЕ ЕНЕРГЕТСКИХ КАРАКТЕРИСТИКА СУШАРЕ СКРОБА

**Славица Првуловић Драгиша Толмач, Звонимир Благојевић, Јасна Толмач**

У раду је приказано постројење конвективне сушаре са пнеуматским транспортом материјала, која се користи за сушење кукурузног скроба у прехрамбеној индустрији. Експериментална мерења и испитивања су извршена на индустријском постројењу конвективне сушаре у процесу производње.

Изложен је део експерименталних и теоријских истраживања везаних за технику и примену методе конвективног сушења. Приказани су резултати мерења параметара сушења. На основу резултата

испитивања и мерења одређени су релевантни параметри процеса.

Прорачун и димензионисање ових сушара врши се по приближној методи састављања енергетског биланса. У оквиру овог рада дат је приступ решавању овог проблема путем термодинамичког модела. Тако су дефинисани коефицијенти преноса топлоте, топлотна снага сушења, термички степен искоришћења и енергетске карактеристике процеса код овако сложеног система у условима рада сушаре.