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EXPERIMENTAL STUDY ON DRYING KINETIC AND ENERGETIC CHARACTERISTICS OF CONVECTION PNEUMATIC DRYER

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Abstract. *The aim of this study is to present a part of the experimental and theoretical research of an industrial pneumatic dryer, in order to determine its energetic characteristics, heat transfer coefficient, as well as the drying kinetics curves. Heat transfer is accomplished through convection thanks to the principle of drying based on direct contact between the heated air and the moist material. During that process, intensive heat and mass exchange take place. Based on the results of the research, the models of drying and energetic characteristics are provided.*

Key Words: *Models of Drying, Energetic Characteristics, Pneumatic Dryer*

1. INTRODUCTION

Convective dryers with pneumatic transport of material are the type of equipment used in factories for industrial processing of grains during the drying process of powder like fine-grained material.

These drying systems have been determined in the studies of the authors provided in the following References: [2], [3], [4], [8], [9], [10], [13]. These dryers provide continual drying of mealy materials with the concentration c_k= (0.05-2) kg material / kg air. Medium size of the particles of the dried material can be 0.05-2 mm. The velocity of the flow of the heated drying agent (air or gas) in the dryer is 10 - 30 [m/s].

The efficiency of these dryers is estimated according to the thermal degree of heat usage in the dryer, which ranges between 65 – 75%, depending on the drying system (direct or indirect drying). The amount of evaporated moisture on the pneumatic pipe is about 400 [kgH_2O/m^3h], according to [10], [16], [18]. The time of drying in these dryers

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lasts for only a few seconds, so that the materials that stand well high temperatures in a short period of drying, for example τ = (1 - 3) s, can be dried there.

The implementation of pneumatic dryers is especially common in food processing industry in the factories for industrial processing of grains (wheat and corn processing using wet method).

Problems of heat transfer are explored in [1],[5], [6], [7], [14], [15].

2. Description of the Experimental Facility

Experimental research is completed in the dryer with pneumatic transport of material, Fig. 1 The dried material is the cornstarch ρ=550 [kg/m^3].

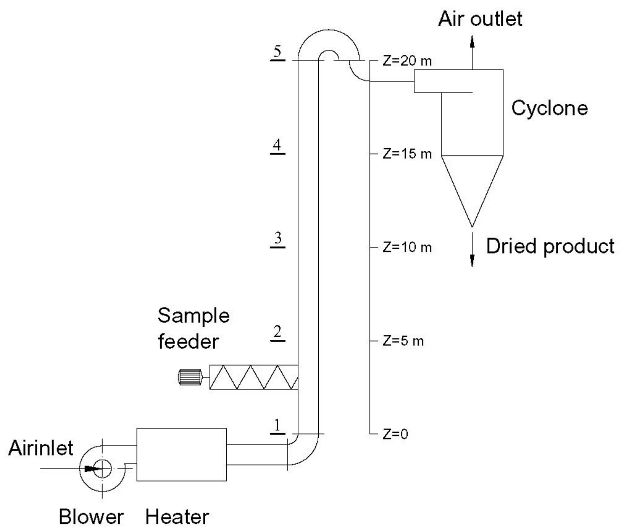

Fig. 1 Scheme of experimental pneumatic dryer: heater with the heating power of Q=2,5 MW, dryer pipe with the diameter d=1.250 mm and height h_L=20 m.

The heating of the drying agents is done using heaters (1). It is accomplished in the direct contact between the warm gases and the moist material.

The dosage of the moist material in the dryer is done using rotation dosage administrator with the help of stationary crawler conveyors (2). The amount of moist material totals m_l = 8000 [kg/h], with the moist w_l=36%. The temperature of the moist material at the inlet of the dryer is t_{W1}=25^{o}C, and the temperature of the dry material at the outlet of the dryer is t_{W2}=40^{o}C.

The moist material is conveyed by warm air – the drying agent using pneumatic pipes of the dryer (3), and it goes into the separator (5) where the separation of the dry material is being conducted, and the warm evaporations go into the atmosphere. During that process the consumption of steam water of m_p = 3.830 kg/h, p= 8 bar for heating the dryer is determined. Table 1 gives mean values of the drying agent – warm air and moist of the dried material.

Table 1 Mean values of measuring results of drying temperature and material moisture

Measuring place, according to Fig. 1	1-1	2-2	3-3	4-4	5-5
Temperature of hot air, T°C	150	115	89	71	50
Moisture of dried material, w (%)	36	24	18	15	13

3. Determination of Energetic Characteristics

During the drying processes, considerable amounts of heating energy are consumed. Energy balances of the drying facility present a starting point for the rationalization of the drying process. An important energetic parameter for determination of the dryer's energy balance is the heat transfer coefficient. Using References [4], [12], [18], [19], [20], [21], [22], [23], the following relations of the energetic parameters are derived:

The discrepancy in the air enthalpy at the inlet and at the outlet of the dryer is:

$$\Delta h = c_p (T_1 - T_2) \quad kJm_n^{-3} \tag{1}$$

Quantity of evaporated water:

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

Total heat quantity:

$$\dot{Q}_U = m_p \; r \; \eta_T \quad kJh^{-1} \tag{3}$$

The quantity of air:

$$V_L = \frac{\dot{Q}_U}{\Delta h} \quad m_n^3 h^{-1} \tag{4}$$

Specific energy consumption:

$$q = \frac{\dot{Q}_U}{W} \quad kJkg^{-1} \tag{5}$$

Thermal degree of utilization:

$$\eta_T = \frac{T_1 - T_2}{T_1} = \frac{\dot{Q}_U - \dot{Q}_g}{\dot{Q}_U} \tag{6}$$

Total heat power of drying:

$$Q_U = k_u\, A\, \Delta T_m \; [W] \qquad (7)$$

Total coefficient of heat transfer:

$$k_u = Q_U / (A\, \Delta T_m) \quad [Wm^{-2}K^{-1}] \qquad (8)$$

4. Results And Discussion

The experimental research projects carried out for an industrial dryer with the pneumatic transport of material, Fig. 1, had, as their objective, determination of energy balance, specific energy consumption and thermal degree of utilization, as well as the drying kinetics curves [12], [13]. The results of the energy balance are given in Table 2.

In the process of experimental drying, total drying power has been determined in relations to Q_U=2.180 kW and it presents the starting data for upgrading the dryer. Mean specific consumption of energy equals q = 3.710 [kJ/kg w], in Table 2. According to References [4], [8], [10], [17], specific energy consumption during convective drying ranges between 3.550 – 4.800 [kJ/kg w], in similar drying systems.

Table 2 Energy balance

No.	Energy drying Parameter	Symbol and Measure unit	Energy value Parameter
1	The quantity of evaporated water	W $kg\, h^{-1}$	2.115
2	Drying heat power	Qu kW	2.180
3	Total heat transfer coefficient	k_u $Wm^{-2}K^{-1}$	278
4	Specific energy consumption	q $kJ\, kg^{-1}$	3.710
5	Quantity of drying air	V_L $m_n^3h^{-1}$	60.358
6	Thermal degree of utilization	η_T %	67

For the flow of the drying agents (warm air) through the pneumatic pipe of the dryer: V = 60.358 [$m_n{}^3$/h], with the diameter of the pipe of the dryer d=1.250 [mm], the speed of the transport v=13,67 [m/s] is gained. Taking into consideration that the length, i.e. the height of the pneumatic pipe of the dryer is h_L=20 [m], the time of drying is τ= 1,463 [s].

Based on experimental and theoretical research [12], [13], [18], the following results and correlation equations of the drying kinetics curves are derived:

$$w = 35{,}485 - 2{,}414z + 0{,}065z^2 \qquad (9)$$

$$dw / dt = 0{,}692 - 0{,}051z + 9{,}897z^2 \qquad (10)$$

$$T = 148{,}942 - 6{,}937z + 0{,}102z^2 \qquad (11)$$

$$dw / dt = -1{,}342 + 0{,}131w - 0{,}002w^2 \qquad (12)$$

With the empirical equations obtained by the experimental research, the character of the drying process is defined in the most comprehensive way.

In Figs. 2 and 3, the drying curve and the drying rate curve are shown.

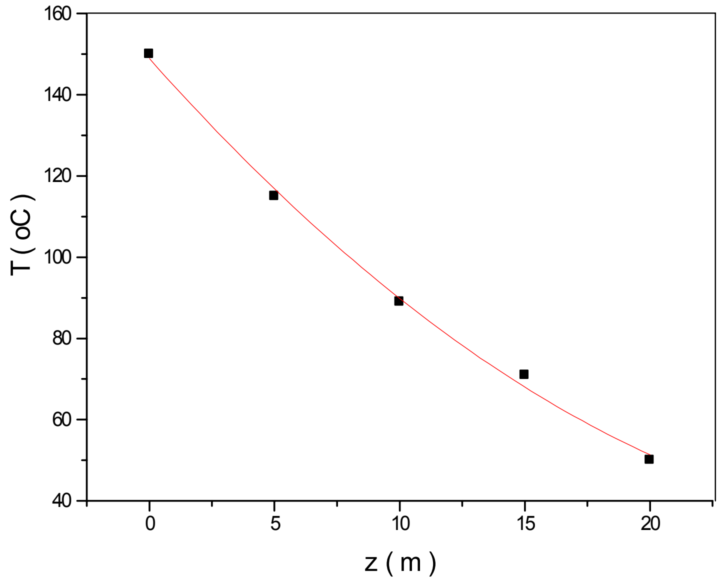

Fig. 2 Drying curve

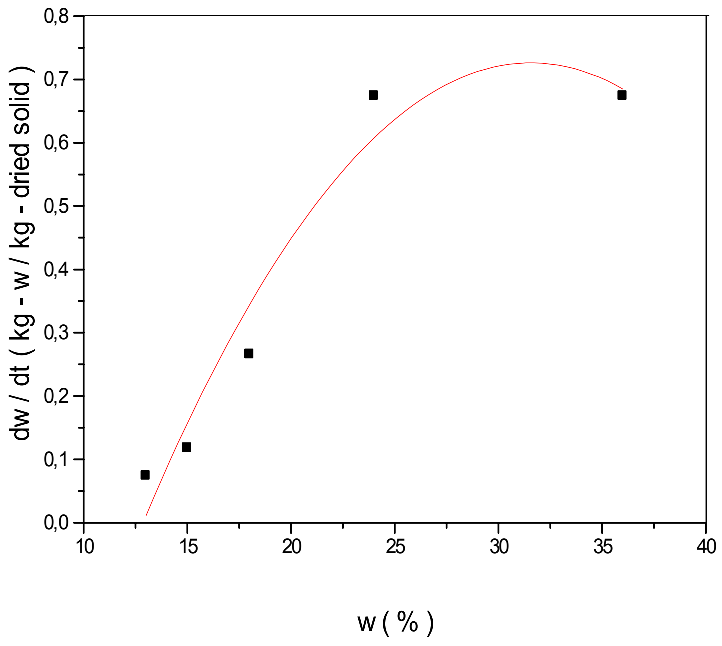

Fig. 3 Drying rate curve

At the beginning of drying, the surface of the particles of the moist material is covered with a very thin layer of water, which has the same characteristics as if it were moisture free. Due to the contact between the surfaces of the particles of the moist material with the warm drying agent, the process of liquid evaporation starts. During that process the liquid evaporates faster at the beginning (the first period of drying), since it is physically and mechanically bound moisture, Figs. 2 and 3. In the second period of drying, the speed of drying falls down rapidly since it is physically and chemically bound moisture at this moment.

CONCLUSION

According to the given research the heat energy of drying Q=2180 kW, specific energy consumption q=3710 kJ/kg of the evaporated water, and thermal degree of utilization η_T = 67 % are gained. Based on the energy balance complete heat transfer coefficient k_u=278 W/ (m^2K), according to [10], has been determined. The obtained results of the research are based on experimental data from the real industrial dryer. Based on that, the results of the research have an applicable value, i.e. they may be useful to the designers, producers and users or the same or similar drying systems just as they can be used for educational purposes.

The experimental and theoretical research of the relevant parameters of the heat transfer aim at a more complete energetic description of the problems of convective drying, in order to supplement the knowledge acquired so far on these and similar drying systems.

NOMENCLATURE

k_u - total coefficient of heat transfer, W/ (m^2K)
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^3K)
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, %
ΔT_{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
η - thermal degree of utilization

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EKSPERIMENTALNA STUDIJA KINETIKE SUŠENJA I ENERGETSKIH KARAKTERISTIKA KONVEKTIVNE PNEUMATSKE SUŠARE

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U ovom radu prikazan je deo eksperimentalnih i teorijskih istraživanja na industrijskom postrojenju pneumatske sušare, u cilju određivanja energetskih karakteristika, koeficijenta prenosa toplote kao i krivih kinetike sušenja. Prenos toplote ostvaruje se konvekcijom, zahvaljujući principu sušenja na bazi direktnog kontakta zagrejanog vazduha i vlažnog materijala. Pri tome se ostvaruje intenzivna razmena toplote i mase. Na osnovu rezultata istraživanja dati su modeli sušenja, kao i energetske karakteristike.

Ključne reči: *modeli sušenja, energetske karakteristike, pneumatska sušara*