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Results Research of Energetics Characteristics of Convection Drying

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

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

This paper 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, energetic balances and coefficient of heat transfer.

Keywords: energy balance, drying , numeric data, heat transfer

0 INTRODUCTION

In principle, convection dryers can be used for drying of meal-like and fine-kernel materials. Simple construction and relatively low consumption of energy has enabled successful application of convection dryers in the above stated industrial branches and starch. Application of convection pneumatic dryers is represented especially in the food industry in the factories for industrial processing of grains (processing of wheat and corn based on the wet milling).

Heat transfer systems of such of kind and likewise are introduced in literature [2] to [4], [6], [8], [9], [12], [14] and [18].

In these dryers, a continuous drying of loose materials is being made, the concentration being ck = (0.05 to 2) kg of material / kg of air. Average particle size of the drying material can be (0.05 to 2) mm. The initial moisture of the drying material can be w1= (35 to 40) %, and the remaining moisture after drying is usually w2 = (10 to 15)%. The specific consumption of energy is usually (3500 to 5040) kJ / (kg H_2O).

Efficiency of convection dryers is evaluated according to the thermal degree of utilization which is within the limits of (66 to 75)%, depending of the drying system (indirect or direct drying). The drying time in these dryers is very short, only several seconds, therefore they can be used for drying of the materials susceptible to high temperatures in the short drying period of time.

1 MATERIAL AND METHOD

Experimental research is made in the convection pneumatic dryer, Figure 1.

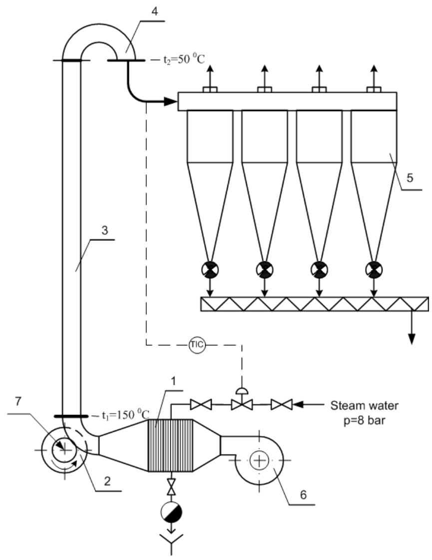

Fig. 1. *Scheme of experimental drying equipment (1 – heat transmiter, 2 – rotation dozer of moist material, 3 – dryer pipe, 4 – dryer head, 5 – cyclones, 6 – centrifugal ventilator, 7 – bringing of moist material))*

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Table 1. *Characteristics convection pneumatic drying*

Position	Name of equipment and characteristics
1	Heat transmiter, heat power Q = 2,5 MW
3	Dryer pipe, diameter d = 1250 mm, height 20 m
5	Cyclone separator, diameter Dc = 1750 mm, height: cylindrical part of the cyclone is 2620 mm, conical part of cyclone is 3500 mm
6	Centrifugal ventilator: V = 65000 $m_n^3h^{-1}$, p = 3500 Pa, N = 90 kW
7	Rotating dozer, N = 22 kW, n = 650 min^{-1}
4	Dryer head

Drying is performed in the direct contact of warm gases with the moist material. Based on that, the principle of direct drying is being represented here. The drying material is starch.

Dosing of moist material to the dryer is made through the rotation dozer (2) with the capacity of m_1 = 8000 kgh^{-1}, through the screw conveying system, as given in the scheme of experimental equipment in Fig. 1. In the Table 1, the characteristics of convection pneumatic dryer are given.

Moist material is being transported via hot air – the drying agent through the dryer pneumatic pipe (3), it passes through the dryer head (4) and goes to the cyclone separators (5) where separation of dried material is being made, and the hot gases exit with the help of ventilator (6), into the atmosphere (see Fig. 1). The dried material is being transported from the cyclone via screw conveyors and through a separate line of transport up to the material warehouse department.

During drying, the determined steam water is m_p= 3830 kgh^{-1}. Average values of the results of measuring the drying temperature and the material humidity are: t_1=150 °C, t_2=50 °C, w_1=36%, w_2= 13%.

Energetic balances show appropriate relations between the total invested energy, utilized energy and heat losses during the drying process. Based on the above, the energetic balances can be useful when showing the dryer condition diagnosis. According to the Lambić [6], Prvulović [10], Tolmać [17].

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

$$\Delta H = H_1 - H_2 = c_p\left(t_1 - t_2\right) \tag{1}$$

Quantity of evaporated water (kgh^{-1}):

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

Total heat quantity:

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

$$\dot{Q}_U = m_p \cdot r \quad kJh^{-1} \tag{4}$$

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:

$$Q_U = h_u\, A\, \Delta\, t_{sr} \tag{8}$$

Total coefficient of the heat transfer:

$$h_u = Q_U / (A\ \Delta t_{sr}) \quad (9)$$

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):

$$\dot{Q}_{conv} = \dot{Q}_W + \dot{Q}_S \quad (10)$$

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

$$\dot{Q}_{conv} = h_c A \Delta t_{sr} \quad (11)$$

2 RESULTS AND DISCUSSION

Experimental research on the convection pneumatic dryer, Fig. 1, was aimed to determine the energetic balance, specific consumption of energy, thermal degree of utilization and other relevant parameters of drying, according to the reference by Prvulović [9]. The results of the energetic balance are being given in the Table 2. The total heat force of drying of Q_d = 2180 kW, is being acquired as well as the specific consumption of energy q = 3710 kJ kg^{-1}, of evaporable water. According to Heβ [2], Prvulović [8] and Tolmać [18], a specific consumption of energy in convection drying amounts (3650 to 5040) kJ kg^{-1}, of evaporable water. According to the data from reference Islam [3], specific consumption of energy amounts q = (3642 to 5283) kJ kg^{-1}, of evaporable water.

Based on the results of energetic balance and results of the drying parameters measuring, according to the reference by Prvulović [9], a total coefficient of the heat transfer is determined to be during convection drying h_u = 295 Wm^{-2}K^{-1}, Table 3. Based on the results of research, the mass air flow amounts 0.450 kg s^{-1}m^{-2}, the drying capacity is 5885 kgh^{-1}, and the air temperature at the dryer inlet is 150°C. According to the literature Lin [5], the mass air flow is 0.289 kgs^{-1}m^{-2}, the drying capacity is 1152 kgh^{-1}, at the drying temperature of 90°C.

According to the research by Heβ [2] and Tolmać [12], on the convection pneumatic dryer, the value of the total coefficient of heat transfer during drying of corn starch is 308 Wm^{-2}K^{-1} , and during drying of potato starch the coefficient of heat transfer is 295 Wm^{-2}K^{-1}.

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, Table 4.

Table 2. *Energetics balance of convection pneumatic dryer*

Energetics drying parameter	Sign	Measure unit	Energetics value parameter
Air temperature at the inlet of dryer	t_1	˚C	150
Quantity of evaporable water	W	kgh^{-1}	2115
Total heat quantity	Q_u	kJh^{-1}	7.846650
Drying heat power	Q_d	kW	2180
Energy specific use	q	kJkg^{-1}	3710
Quantity of drying air	V_L	m$_n^3$h^{-1}	60358
Specific quantity of evaported water		kgm^{-2}h^{-1}	26.90
Specific quantity of evaported water		kgm^{-3}h^{-1}	86.20
Air temperature at the outlet of dryer	t_2	˚C	50
Thermal degree of utilization	η_T	%	67

Table 3. *Total coefficient of heat transfer (h_u)*

Drying heat power	Volume of pipe drying place	Drying surface*	Middle log. difference of temperature	Total heat transfer coefficient
Q_d	Vk	A	Δt_{sr}	h_u
kW	m^3	m^2	^oC	$Wm^{-2}K^{-1}$
2180	24.53	7850	94	295

*According to [2], [9], [14] drying surface is equal to interior surface of drying pipe (A = d π h ; d = 1,25 m - pipe diameter ; h = 20 m - pipe height).

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

Heat power for water evaporation	Heat power for material heating	Heat power of heat transfer by convection	Surface drying	Mean logarithmic difference of temperature	Coefficient of convection heat transfer
Q_w	Q_s	Q_{conv}	A	Δt_{sr}	h_c
kW	kW	kW	m^2	^0C	$Wm^{-2}K^{-1}$
1	2	3	4	5	6
1482	66	1548	78.5	94	210

Based on the results of research of energetic balance and the results of measuring the temperature of the drying agent, the total coefficient of the heat transfer is being determined in the convection dryer in the amount of h_u = 295 $Wm^{-2}K^{-1}$, and the coefficient of the heat transfer by convection h_c = 210 $Wm^{-2}K^{-1}$. The effects of the heat losses during drying are expressed through the separate value $h_u - h_c$ = 85 $Wm^{-2}K^{-1}$, 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 being determined as well as the basic parameters of the heat transfer.

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

3 CONCLUSION

Energetic balance of the dryer can serve in evaluation of energetic condition of the dryer as well as in reviewing of the possibility of rational consumption of energy. This paper 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 energetic balance, the heat force of drying has been determined Q_d = 2180 kW, specific consumption of energy q = 3710 $kJkg^{-1}$ of evaporable water, as well as the thermal degree of utilization η = 67%.

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. A significant share of the energy during drying is forwarded to transfer of heat to the material, necessary for evaporation of moisture and heat for breaking of connection forces of moisture with the basis of the material to be dried.

The results of research can be used also 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.

4 NOMENCLATURE

h_u	$Wm^{-2}K^{-1}$	total coefficient of heat transfer
h_c	$Wm^{-2}K^{-1}$	coefficient of convection heat transfer
H	$kJkg^{-1}$	enthalpy
t_1	°C	air temperature at the inlet of dryer
t_2	°C	air temperature at the outlet of dryer
C_p	$kJm_n^{-3}K^{-1}$	specific air heat
W	kgh^{-1}	quantity of evaporated water
m_1	kgh^{-1}	quantity of moist material
m_p	$kg\ h^{-1}$	quantity of water steam
w_1	%	the material moisture at the inlet of dryer
w_2	%	moisture of the dried material at the outlet of dryer
Δt_{sr}	°C	mean logarithm difference of temperature
Q	kJh^{-1}	heat quantity
A	m^2	drying surface
V_k	m^3	volume of dryer pneumatic pipe
r	$kJkg^{-1}$	specific heat of evaporation
q	$kJkg^{-1}$	specific consumption of energy
V_L	$m_n^3h^{-1}$	quantity of drying air
η_T	%	thermal degree of utilizatoin

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