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SPRINKLE DRYING KILN CERAMIC GRANULATE DRYING CHARACTERISTIC AND EXPERIMENTAL MEASUREMENTS OF THE DRYING PROCESS PARAMETERS

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Original scientific paper

The paper deals with technology of production of ceramic granulate that is further used for production of ceramic products. Drying is a wide-spread technological process used in almost every industrial sphere. One of them is ceramic industry. The moisture of the granulate belongs to main parameters influencing its quality. Goal of the measuring was to design the system of manipulation for the process of granulate drying according to achieved dependence.

Keywords: *ceramics, granulate, combustion, moisture*

Karakteristika sušenja keramičkih granulata u peći za sušenje škropljenjem i eksperimentalna mjerenja parametara procesa sušenja

Izvorni znanstveni članak

Ovaj rad se bavi tehnologijom proizvodnje keramičkih granulata, koji se koriste za daljnju proizvodnju keramičkih proizvoda. Sušenje je rasprostranjeni tehnološki proces koji se koristi u gotovo svim industrijskim područjima. Jedno od njih je keramička industrija. Vlažnost granulata pripada glavnim parametrima koji utječu na njihovu kvalitetu. Cilj mjerenja je bio oblikovati mjerni sustav za rukovanje procesom sušenja granulata prema postignutoj ovisnosti.

Ključne riječi: *keramika, granulati, izgaranje, vlaga*

1 Introduction
Uvod

Production of ceramic granulate consists of emulsion preparation, drying and separation of granulate from drying gas. Main part is drying. This process uses a huge amount of heat given by combustion. Heat is brought from heating device to drying chamber. The heat thus obtained is used for drying the emulsion from which the moisture is removed during the process. Moisture belongs to main parameters that impact the quality of produced material. Drying gas that flows from the kiln includes the residuum of dried granulate. This "compound" flows through the system of cyclones where the residual granulate is separated and gas flows to chimney system. Mathematical model of drying kiln that was used for experimental measurements describes and defines the balance equation from which the researched dependence was substantiated. On the basis of these findings the system of control and inspection of drying process was designed. Fig. 1 shows the production scheme for ceramic granulate.

2 Mathematical model of drying kiln
Matematički model peći za sušenje

The goal of the mathematical model of drying kiln is to describe input and output quantities, to find the relations between them and to substantiate the searched dependence of granulate moisture on the moisture of drying gas on output. At the same time this mathematical model allows theoretical description of dependence of output quantities and their impact on input parameters. As the base for creation of mathematical model of drying kiln was used power and material balance of input and output quantities used for drying.

$$\dot{m}_{sp} \cdot h_1 + \dot{m}_{v1} \cdot c_{v1} \cdot t_{v1} + \dot{m}_s \cdot c_{s1} \cdot t_{s1} = \\ = m_{sp} \cdot t_2 + \dot{m}_s \cdot c_{s2} \cdot t_{s2} \qquad (1)$$

Considering the range of problem elaboration, so called theoretical drying kiln was imagined. This type of kiln does not count with heat and material losses. It was assumed that enthalpy of drying gas was the same both on input and output. From the balance equation (1) the researched dependence was obtained in the form of equation (2)[1].

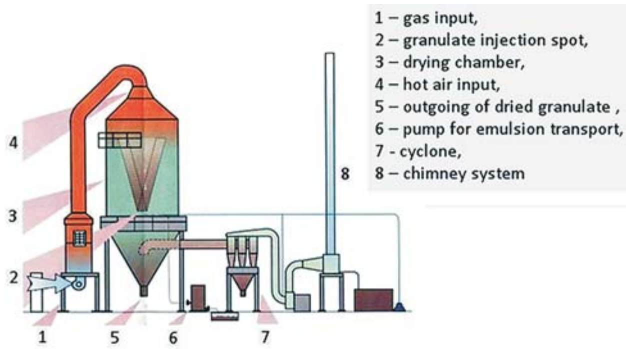

Figure 1 *Scheme of sprinkle drying kiln* [2]
Slika 1 *Shema peći za sušenje škropljenjem* [2]

Description of equation (2):

- $\dot{m}_{sp}$ Nucleon flow of drying gas flowing through the kiln, kg/s
- h_0 Enthalpy of air that the heat device inputs, J/kg
- t_0 Temperature of air that the heat device inputs, °C
- Y_0 Absolute moisture of air that the heat device inputs, kg/kg
- h_1 Enthalpy of during gas that the kiln inputs, J/kg
- t_1 Temperature of drying gas that the kiln inputs, °C
- Y_1 Absolute moisture of drying gas that the kiln inputs, kg/kg
- h_2 Enthalpy of drying gas that the kiln outputs, J/kg
- t_2 Temperature of drying gas that the kiln outputs, °C
- Y_2 Absolute moisture of drying gas that the kiln outputs, kg/kg
- $\dot{m}_s$ Nucleon flow of dry material (solid) through the kiln, kg/s
- u_1 Mensural moisture of material that the kiln inputs, kg/kg
- u_2 Mensural moisture of material that the kiln outputs, kg/kg
- t_{s1} Temperature of solid that the kiln inputs, °C
- t_{s2} Temperature of solid that the kiln outputs, °C
- t_{v1} Temperature of water that the kiln inputs, °C

$$u_2 = \frac{\dot{m}_{v2} \cdot c_{s2} \cdot t_{s2}}{\left\{\dot{m}_{sp} \cdot \left[c_{pv} \cdot t_1 + Y_1 \cdot \left(r_0 + c_{pvp} \cdot t_1\right)\right]\right\} - \left\{\dot{m}_{sp} \cdot \left[c_{pv} \cdot t_2 + Y_2 \cdot \left(r_0 + c_{pvp} \cdot t_2\right)\right]\right\} + \dot{m}_s \cdot u_1 \cdot c_{v1} \cdot t_{v1} + \dot{m}_s \cdot c_{s1} \cdot t_{s2}} \quad (2)$$

c_{s1} Specific thermal capacity of solid on input, J/(kg·K)
c_{s2} Specific thermal capacity of solid on output, J/(kg·K)
c_v Specific thermal capacity of water, J/(kg·K)

3 Experimental part
Eksperimentalni dio

Experimental measurements were realized in Ceramtec s.r.o.. This company is a branch firm of German company Hoechst CeramTec AG, with the seat in the Czech Republic city Šumperk. This part consisted of measurement preparation, measuring of selected parameters and data evaluation. Drying was done in sprinkle drying kiln Škoda 100F. Emulsion consisted of 1070 kg of solid and 880 kg of water. After drying there was 861 kg of granulate acquired. In the first stage measured quantities and measured spots were selected. After that the time schedule of measurements was defined. During the measurement the temperature and absolute moisture of drying gas on output and moisture of dried granulate were observed. All values were recorded in tables. Drying took ten hours. Measuring devices were used – hygrometer TESTO 645 for measuring the moisture of drying gas, moisture analyzer Sartorius MA 50, digital weight BP 8100 for measuring granulate weight, thermometer GRYF 209 L for measuring granulate temperature.

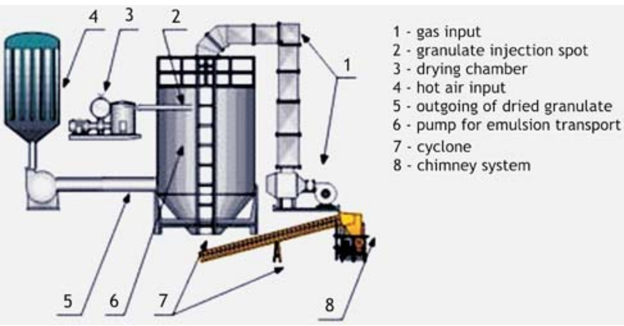

Figure 2 *Scheme of sprinkle drying kiln the Škoda 100F in Ceramtec*
Slika 2 *Shema peći za sušenje škropljenjem Škoda 100F u Ceramtec*

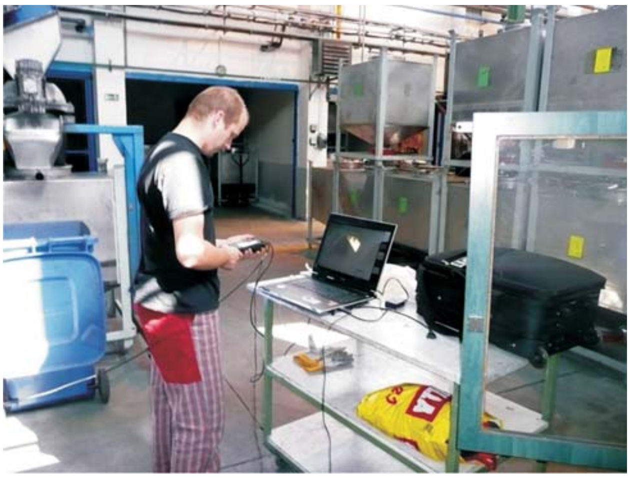

Figure 3 *Measurement of mensural moisture of material that the kiln outputs and absolute moisture of drying gas that the kiln outputs*
Slika 3 *Mjerenje mjerne vlage materijala koji izlaze iz peći i apsolutne vlage plina za sušenje koji izlazi iz peći*

Nucleon flow of drying gas on input:
Nucleon flow of combustion gases on input was determined on the basis of the amount of combusted gas and from combustion equation. During drying 150 m^3 of CH_4 was combusted.
Methane combustion:

$$CH_4 + 2O_2 + N_2 \rightarrow CO_2 + 2H_2O + N_2 \quad (3)$$

Combustion of 184,5 kg of CH_4 in ten hours gives 1245,39 kg of combustion gases, which means that nucleon flow of drying gas on input is 0,034 kg/s.

Nucleon flow on output:
Amount of drying gas does not change during drying, it can be only increased by the water evaporated from emulsion which presents 0,024 kg/s. Nucleon flow of drying gas on output from kiln is 0,058 kg/s.

Nucleon flow of solid and water:
Compound of solid and water (emulsion) is injected into drying kiln:

1070 kg of solid + 880 kg = 1950 kg of emulsion

! Nucleon flow of solid on input is 1070 kg of solid/10 hours, giving 0,0297 kg/s
! Nucleon flow of water on input is 880 kg of water/10 hours, giving 0,0244 kg/s.

Nucleon flow of dried granulate:
After measuring the weight of dried granulate per time unit we obtained nucleon flow of the granulate. On the basis of a series of five measurements an average value of nucleon flow was determined. Data are listed in Tab. 1.

Table 1 *Nucleon flow of dried granulate*
Tablica 1 *Nukleonski tok osušenog granulata*

	Weight, g	Time, s
1.	694	30
2.	673	30
3.	672	30
4.	668	30
5.	695	30
Σ	680	30

Nucleon flow of dried granulate is 0,023 kg/s

Calculation of nucleon flow on output corresponds to real behavior conditions of drying. As theoretical course of drying was thought, nucleon flow of granulate (solid) is the same on the output.

Measurement of moisture of drying gas on output:
Measured values were taken in two minutes intervals and recorded in computer. Average values of temperature t_2, relative φ_2 and absolute Y_2 moisture of drying gas on output from kiln acquired during measurements are listed in Tab. 2.

Table 2 *Average values of drying gas on output acquired with measuring device TESTO 645*
Tablica 2 *Prosječne vrijednosti plina za sušenje na izlazu utvrđene mjernim uređajem TESTO 645*

φ_2, %	t_2, °C	Y_2, kg/kg
15,76	85,79	63,47

***Table 3** Measured values of granulate moisture, temperature and moisture of drying gas on output in specific time*
***Tablica 3** Izmjerene vrijednosti vlage granulata, temperature i vlage plina za sušenje na izlazu u određeno vrijeme*

No.	Measuring time	Granulate moisture, %	Granulate temperature, °C	Temperature of drying gas on output, °C	Moisture of drying gas on output, g/kg
1.	9:10	0,825	35	86,50	60,80
2.	9:21	0,845	35	85,80	60,80
3.	9:34	0,823	35	86,30	60,60
4.	9:44	0,772	35	86,40	61,70
5.	10:07	0,907	35	86,30	63,70
6.	10:18	0,866	35	85,60	64,50
7.	10:27	0,894	35	85,00	65,00
8.	10:36	0,879	35	85,30	66,70

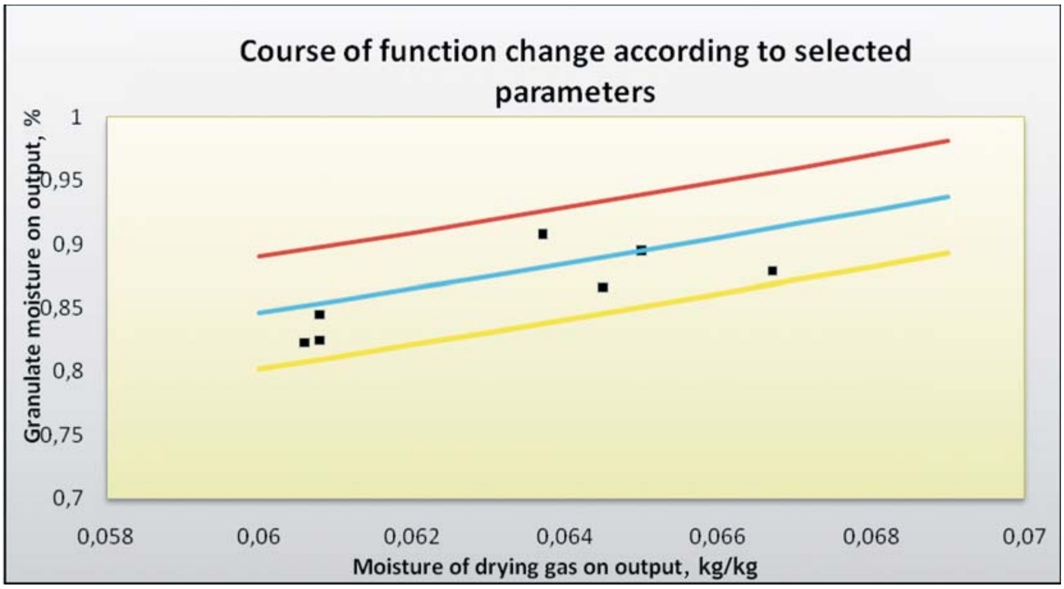

***Figure 4** Course of function change according to selected parameters*
***Slika 4** Tok promijene funkcije u odnosu na odabrane parametre*

4 Evaluation
Ocjena

The goal of this paper was to describe the verification of mathematical model of drying kiln for specific technology. On the basis of measured and defined values the dependence of mensural granulates moisture after drying on moisture of drying gas on output was substantiated. This dependence is expressed by equation (1) and shown in Fig. 4. Nucleon flow of drying gas on input and output $\dot{m}_{sp}$ was determined from the amount of combusted gas and calculation of nucleon combustion. Absolute moisture Y_2 and temperature t_2 of drying gas on output was found by measuring while moisture of drying gas on input Y_1 was found from diagram h-Y. Temperature of drying gas t_1 was elected and measured at measuring spot. Nucleon flow of solid $\dot{m}_s$ and water $\dot{m}_{v1}$ on input was determined on the basis of input values of drying and time of drying. Nucleon flow of solid on output was determined after weighing the amount of dried granulates per specific time. Nucleon flow of residual moisture $\dot{m}_{v2}$ was determined from detection of moisture in dried granulate and from nucleon flow of solid on output. Mensural moisture on kiln input u_1 was determined from the proportion of moisture weight to total emulsion weight (water + solid). Thermal capacity of solid either on input or output was determined according to similar materials as it was impossible to determine an exact value.

Graph (Fig. 4) shows maximal and minimal average relative change of the function. Detected inaccuracy 5 % presents the influence of inaccuracy of determining the parameters (mass flow of solid, specific thermal capacity of solid and granulate temperature). More parameters from equation (2) can only be determined with definite accuracy. So called sensible function was used for expressing the impact of this inaccuracy to total function value. Such sensible function describes the change of function called by inaccuracies while measuring the parameter. Listed measurements proved that moisture of drying gas on output from kiln is in correlation with granulate moisture. Initiated correlation is rather right described by equation (2) acquired from mathematical model of drying kiln.

5 Conclusion
Zaključak

The given measurements confirmed that moisture of drying gas on output from kiln is in correlation with granulate moisture. Initiated correlation is rather right described by equation (1) acquired from the mathematical model of the drying kiln. Realized experiments confirmed the possibility of using the continuous measuring of moisture of drying gas on output from kiln for controlling the granulate moisture, eventually to control the drying process.

6
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