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PRODUCTION TECHNOLOGY OF CERAMIC GRANULATE AND MATHEMATICAL MODEL OF DRYING KILN

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Abstract
The paper deals with technology of production of ceramic granulate, that is further used for production of ceramic products. Drying is 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 process of granulate drying according to achieved dependence.
Keywords
ceramics, granulate, combustion, moisture

1. INTRODUCTION

Production of ceramic granulate consist of emulsion preparation, drying and separation of granulate from drying gas. Main part presents drying. This process uses huge amount of heat given by combustion. Heat is brought from heating device to drying chamber. Such made heat is used for drying of emulsion from which the moisture is removed during the process. Moisture belongs to main parameters that impact the quality of produces 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 base of these findings the system of for control and inspection of drying process was designed. Figure 1. shows the production scheme for ceramic granulate.

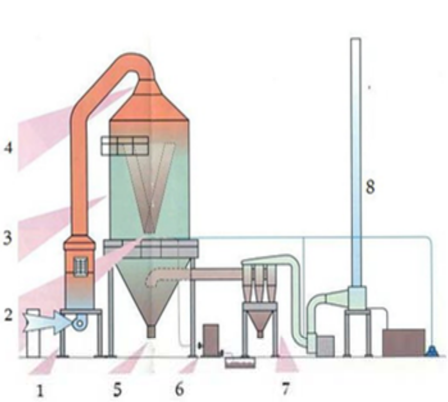


Fig. 1. Scheme of sprinkle drying kiln

2. MATHEMATICAL MODEL OF DRYING KILN

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 searched dependence of granulate moisture on moisture of drying gas on output. At the same time this mathematical model allows theoretical description of dependence of output quantities and their impact to 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.

$$m^{\bullet}_{sp} \cdot i_1 + m_{v1} \cdot c_{v1} \cdot t_{v1} + m_s \cdot c_{s1} \cdot t_{s1} = m^{\bullet}_{sp} \cdot i_2 + m_s \cdot c_{s2} \cdot t_{s2} \qquad (1)$$

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

$$u_2 = \frac{m_{v2} \cdot c_{s2} \cdot t_{s2}}{\{m^{\bullet}_{sp} \cdot [c_{pv} \cdot t_1 + (r_0 + c_{pvp} \cdot t_1)]\} - \{m^{\bullet}_{sp} \cdot [c_{pv} \cdot t_2 + Y_2 (r_0 + c_{pvp} \cdot t_2)]\} + m_s \cdot u_1 \cdot c_{v1} \cdot t_{v1} + m_s \cdot c_{s1} \cdot t_{s1}} \qquad (2)$$

equation description:

$m^{\bullet}_{sp}$	-	Mass flow of drying gas flowing through the kiln	[$kg.s^{-1}$],
i_o	-	Enthalpy of air that inputs the heat device	[$J.kg^{-1}$],
t_o	-	Temperature of air that inputs the heat device	[°C],
Y_o	-	Absolute moisture of air that inputs the heat device	[$kg.kg^{-1}$],
i_1	-	Enthalpy of during gas that inputs the kiln	[$J.kg^{-1}$],
t_1	-	Temperature of drying gas that inputs the kiln	[°C],
Y_1	-	Absolute moisture of drying gas that inputs the kiln	[$kg.kg^{-1}$],
i_2	-	Enthalpy of drying gas that outputs the kiln	[$J.kg^{-1}$],
t_2	-	Temperature of drying gas that outputs the kiln	[°C],
Y_2	-	Absolute moisture of drying gas that outputs the kiln	[$kg.kg^{-1}$],
$m^{\bullet}_s$	-	Mass flow of dry material (solid) through the kiln	[$kg.s^{-1}$],
u_1	-	Mensural moisture of material that inputs the kiln	[$kg.kg^{-1}$],
u_2	-	Mensural moisture of material that outputs the kiln	[$kg.kg^{-1}$],
t_{s_1}	-	Temperature of solid that inputs the kiln	[°C],
t_{s_2}	-	Temperature of solid that outputs the kiln	[°C],
t_{v_1}	-	Temperature of water that inputs the kiln	[°C],
c_{s_1}	-	Specific thermal capacity of solid on input	[$J.kg^{-1}.K^{-1}$],
c_{s_2}	-	Specific thermal capacity of solid on output	[$J.kg^{-1}.K^{-1}$],
c_v	-	Specific thermal capacity of water	[$J.kg^{-1}.K^{-1}$],

3. EXPERIMENTAL PART

Experimental measurements were realized in Ceramtec s.r.o.. This company is branch firm of German company Hoechst CeramTec AG, with seat in Czech Republic in 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 first stage measured quantities and measured spots were selected. After then 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 of granulate weight, thermometer GRYF 209 L for measuring of granulate temperature.

Mass flow of drying gas on input

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

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

Combustion of 184,5 kg of CH_4 in ten hours gives 1245,39 kg of combustion gases, what means that mass flow of drying gas on input is 0,034 $kg.s^{-1}$

Mass flow on output:

Amount of drying gas does not change during the drying, it can be only increased by water evaporated from emulsion what presents 0,024 $kg.s^{-1}$. Mass flow of drying gas on output from kiln is 0,058 $kg.s^{-1}$.

Mass 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

- Mass flow of solid on input is 1070 kg of solid/10 hours, gives 0,0297 $kg.s^{-1}$
- Mass flow of water on input is 880 kg of water/10 hours, gives 0,0244 $kg.s^{-1}$

Mass flow of dried granulate:

After measuring of weight of dried granulate per time unit we obtained mass flow of the granulate. On the base of series of five measurements an average value of mass flow was determined. Data are listed in the table No. 1.

Tab. 1 Mass flow of dried granulate

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

Mass flow of dried granulate is 0,023 $kg.s^{-1}$

Calculation of mass flow on output fits on real behavior conditions of drying. As theoretical course of drying was thought, mass 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 table No.2.

Tab. 2 Average values of drying gas on output acquired with measuring device TESTO 645

φ_2[%]	t_2[°C]	$Y_2[kg.kg^{-1}]$
15,76	85,79	63,47

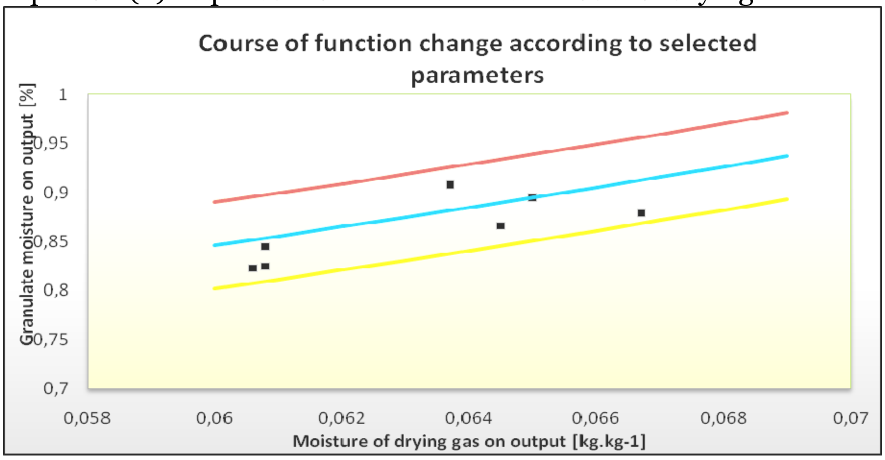
Tab. 3 Measured values of granulate moisture, temperature and moisture of drying gas on output in specific time

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

4. EVALUATION

The goal of this paper was to describe the verification of mathematical model of drying kiln for specific technology. On the base of measured and defined values the dependence of mensural granulate moisture after drying on moisture of drying gas on output was substantiated. This dependence is expressed by equation (1) and showed in graph no.1. mass flow of drying gas on input and output $\dot{m}_{sp}$ was determined from amount of combusted gas and calculation of mass combustion. Absolute moisture Y_2 and temperature t_2 of drying gas on output was found by measuring and moisture of drying gas on input Y_1 was found from diagram *i-Y*. Temperature of drying gas t_1 was elected and measured at measuring spot. Mass flow of solid $\dot{m}_s$ and water $\dot{m}_{v1}$ on input was determined on the base of input values of drying and time of drying. Mass flow of solid on output was determined after weighing of amount of dried granulates per specific time. Mass flow of residual moisture $\dot{m}_{v2}$ was determined from detection of moisture in dried granulate and from mass flow of solid on output. Mensural moisture on kiln input u_1 was determined from proportion of moisture weight to total emulsion weight (water + solid). Thermal capacity of solid either on input and output was determined after similar materials as it was impossible to determine an exact value.

Graph No.1 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.



Graph No.1 Course of function change according to selected parameters

5. CONCLUSION

Listed measurements confirmed that moisture of drying gas on output from kiln is in correlation with granulating moisture. Initiated correlation is rather right described by equation (2) 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.

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