HIGH-REVOLUTION ROTARY FURNACE FOR FINE-GRAINED MATERIALS HEAT TREATMENT

Doc. Ing. Jan Spisak, PhD
Ing. Dusan Nascak, PhD
Ing. Andrej Hacevsky
Development and realization workplace of raw materials extracting and treatment, Faculty of Mining, ecology, process control and geotechnology
Technical University of Kosice

Abstract

Fine-grained and dust materials create a significant part of the thermally treated substances. The capabilities of materials processing are currently limited, thus making difficult its use. Rotary furnaces are contemporary the most important apparatuses for fine-grained materials processing. Apart from low efficiency, the process has also other limits that hinder their use for the fine-grained fractions heat treatment. The main problem of fine-grained materials processing lies in air tightness or low permeability of processed material layer. The concept of high-revolution rotary furnace was based on the mechanical fluidization of the material by which the homogeneous fluidized material layer through cross-section of the rotary furnace was obtained. Thereby homogeneous heating of individual grains was obtained. The research of mechanical fluidization was realized on the physical model of high-revolution rotary furnace. The pilot furnace design was based on the results of the experiment. The experiments focused on rheological, hydrodynamic and thermodynamic processes were conducted on this pilot high-revolution rotary furnace. The results of the experiments have confirmed correct functionality of the aggregate for the fine-grained materials heat treatment. The principal advantage of the furnace is the fluidization process which doesn’t depend on the flow and combustion processes.

Keywords: High-revolution rotary furnace, thermal treatment, magnesia sintering, fluidization

Introduction:

The mining and thermal treatment of magnesite ores the high quantity of fine granular and powdered substance is generated despite of their very good chemical composition because of their granulometry hardly used and in the majority becomes a waste. Fine granular fractions of raw magnesite are waste product of the separation in heavy suspensions. Another source of fine granular magnesite is flue dust from sintering in rotary and shaft furnaces. The objective is to increase the utilization of fine granular fractions of magnesite ore and the flue dust. The sources of fine granular fractions and possibilities of their treatment are presented in the paper. We mention the structure and properties of magnesite waste, economic and environmental aspects of its use and new concepts of thermal plants. Proposed concepts are based on reducing the amount of dust waste and designing the new technologies which enable effective heat treatment of these materials and thus full-value utilization of this technology. This new development was oriented towards possibilities of improvement of fine granular material thermal treatment.

Treatment of granular materials is connected with the loss of fine fractions, which is mainly regarded as a waste. Their thermal treatment is connected with low effectiveness and efficiency. For the improvement of the contemporary and new developed thermal apparatus physical modelling was used as one of the basic source of knowledge. Modelling approach is based on the similarity principles and the principles of equivalency. The physical modelling for the design of high-revolution rotary furnace was used.

1. High-revolution rotary furnace:

High-revolution rotary furnace is designed for fine-grained and dust materials heat treatment in a mechanically fluidized layer. Mechanical fluidization in a rotary furnace is achieved by increasing the revolutions to such a degree that the material in the furnace is uniformly distributed over its cross section (Fig. 1).

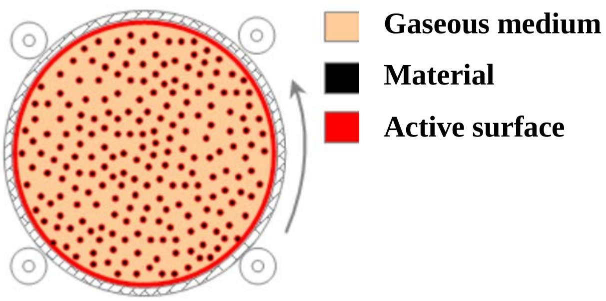

Fig. 1 Mechanical fluidization in the high-revolution rotary furnace

Fluidization of the material is achieved by the balance of centrifugal and gravitational forces. At the critical revolutions the material fills the entire cross section of the furnace. The main advantage of this solution is the intensive heat transfer, for which the optimal conditions are created. The heat exchange surface is significantly increased by fluidization.

Due to the material drop and axial material velocity a high coefficient of heat transfer is reached. The aggregate can be arranged as co-current or counter-current. The material motion is lateral and motion of the flue gas is longitudinal. Technological advantage of high-revolution rotary furnace is that the material movement is not depending on the gas motion. This enables an efficient control of the furnace performance. The heat source can be provided by combustion directly inside the or in the separate combustion chamber.

The limiting factor is the maximum gas flow velocity causing that the material is drag by the flue dust. The process basic indicator is the mean residence time of particles in the furnace layer, which depends on the particles sizes, the bulk density, particles velocity and the velocity of the gaseous medium. As a result of gravitational forces a lateral movement of the fine particles in the layer is slower and their relative rate is lower. Heat transfer in compared with the classic rotary furnace is increased by about 25 times. It permits reduction of the furnace dimensions by around ten times. Increased performance has a significant impact on the use of heat due to temperature decrease of outgoing flue gases and reduced size of the furnace shell with complete use of product heat. Conceptually, the furnace can be classified as the high-intensity thermal aggregates. The high-revolution rotary furnace scheme is shown in Fig. 2.

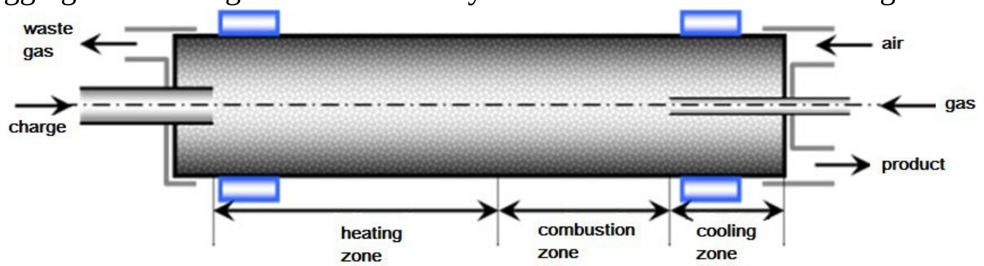

Fig. 2 High-revolution rotary furnace scheme

1.1 High-revolution rotary furnace mathematical modelling

A mathematical model was developed on the primary principles to simulate high-revolution furnace. The model includes rheological, hydrodynamic and thermodynamic processes. For the numerical solution method was used an elementary balance method using spare partial models. Identification and calibration of the model was carried out by physical models. The mathematical model was designed as one-dimensional. Across the width of the furnace, the material is considered as homogeneous, and its movement is imitated by piston flow. Flow model of gaseous medium enables a modelling in co-current and counter-current (Fig. 3).

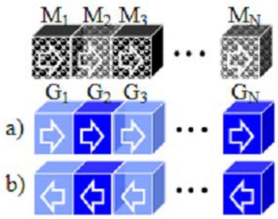

Fig. 3 Material flow and gaseous medium flow a) co-current, b) counter-current

1.2 Process characteristics

Determination of high-revolution furnace parameters was executed on the isothermal model of high-revolution rotary furnace. The most important parameters are the critical revolutions layer thickness and material outflow depending on the furnace diameter. Influence of material layer thickness on the critical revolutions size at which fluidization occurs is shown in Fig. 4.

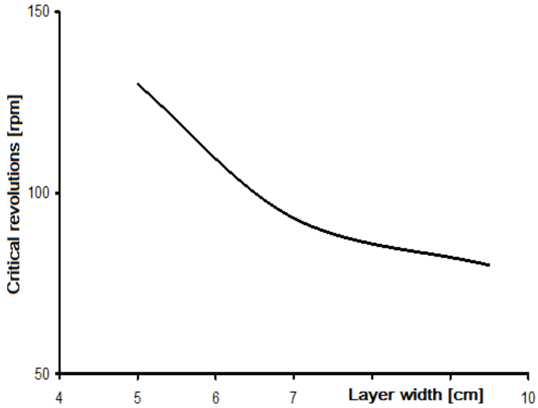

Fig. 4 Dependence of the critical revolutions on the layer thickness

The dragging of particles depends on the flowing medium velocity (Fig. 5). The experiment result shows that the efficient furnace operation is achieved during the gas flow velocity to 1 $m.s^{-1}$. The maximal dragging of dust particles determines a gaseous medium flow and thus possible apparatus performance per surface unit of its cross-section. The apparatus surface cross section is determined by the ratio of the media.

Thermal and constructional and technical parameters were verified on the pilot high-revolution rotary furnace pilot model. In the Fig. 6c is shown a view of a pilot high-revolution rotary furnace. In the Fig. 6a is a view from the inside of the furnace at low speed. In the Fig. 6b is a view during normal operation when there is a fluidized layer.

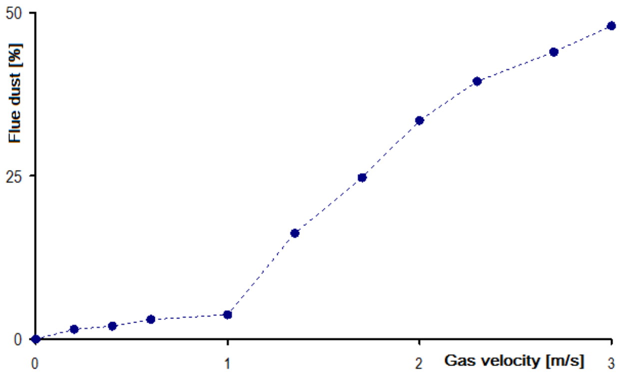

Fig. 5 Dependence of the dust particles amount on the gas velocity in high-revolution rotary furnace

Fig. 6 An inside look into the high-revolution rotary furnace a) low revolutions b) standard operation c) pilot plant equipment

2. Pilot high-revolution rotary furnace:

The pilot high-revolution furnace proposal (Fig. 7) was carried out on the basis of simulations and conducted experiments. The furnace has the following parameters: length, diameter, number of revolutions (length 5 m and inner diameter 1,4 m). Compared with classic rotary furnaces, the number of revolutions was increased by several times (classic rotary furnaces: about 2 - 3 rpm, high-revolution rotary furnace: max. 42 - 1 rpm^{-1}, operating: 28 to 34 rpm^{-1}).

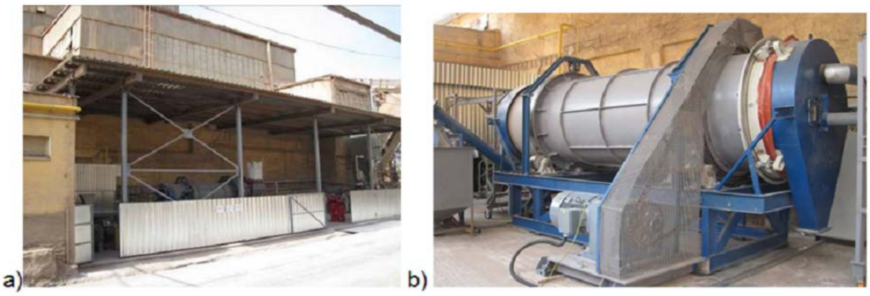

Fig. 7 Pilot high-revolution rotary furnace a) workplace b) furnace

2.1 Experimental verification

Chromium ore drying

An experimental verification was performed on the chromium ore drying process on the pilot furnace. Before the drying there were found courses of temperatures (Fig. 8) and operation parameters. The drying process of the made apparatus was operationally verified on the basis of the parameters. The experiment lasted three days, with an average performance of 2,7 $t.h^{-1}$ and the effective drying time of 9 hours a day. Total dried chromium ore – 64 t. The average flue gas temperature during the experiment was 130°C. Temperature of the dried chromium ore from the cooler was 115°C and the maximum temperature in the furnace in the burner area ranged from 140 to 150°C.

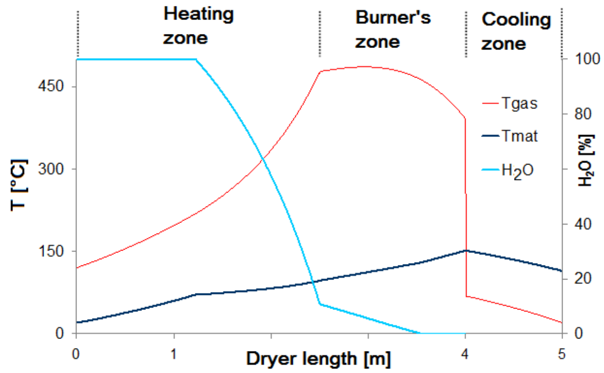

Fig. 8 Simulation results of chromium ore drying

Dehydration of the material based on $Mg(OH)_2$

The chemical composition of input material based on the $Mg(OH)_2$ (Tab. 1) was carried out by analytical methods AAS combination of prepared solutions component analysis and by optical quantification methods. Control of chemical composition was realized by the mobile spectrometer Niton XL3 Goldd.

Tab. 1 Material composition dehydrated in the high-revolution rotary furnace

Composition	Ratio [%]
H_2O	33
$Mg(OH)_2$	53,65
$Ca(OH)_2$	6,45
SiO_2	0,92
Al_2O_3	0,27

Fe_2O_3	5,71

The simulation course for wet material dehydration based on the $Mg(OH)_2$ is shown in Fig. 9. During thermal heating, free water evaporation arises as first. In the temperature range from 150 to 400°C, the decomposition of $Mg(OH)_2$ during formation of MgO and water vapor $H_2O(g)$ is happened. Although in real conditions the decomposition of $Mg(OH)_2$ is only performed from about 300°C, the presence of impurities may this temperature decrease. Decomposition of $Ca(OH)_2$ is carried out in the temperature range from about 400 to 550°C. The content of Fe_2O_3, SiO_2 and Al_2O_3 in the air atmosphere in the process of material heating based on $Mg(OH)_2$ is not changed.

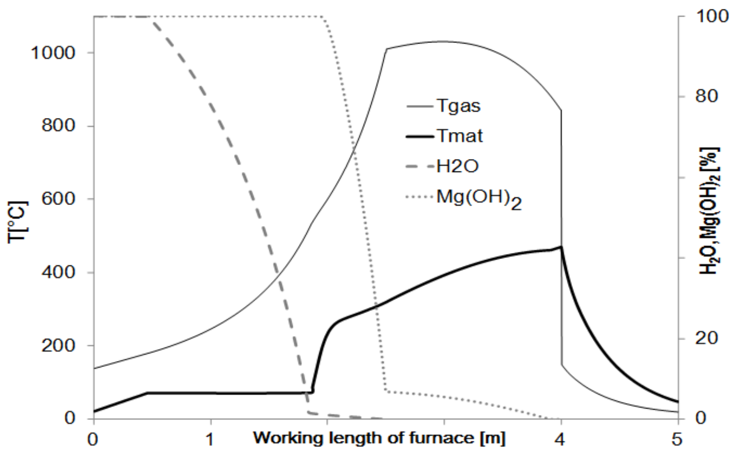

Fig. 9 Simulation of dehydration of magnesium hydrate in the pilot high-revolution rotary furnace

Conclusion:

Functionality of the high-revolution rotary furnace was experimentally verified by simulations. The executed experiments on a pilot furnace confirmed the validity of the mechanical fluidization principle and high-revolution rotary furnace functionality. The combustion system based on diffusion burner allows effectively use secondary cooling air for the combustion. Proposed shell furnace controlled cooling of a new concept is characterized by low heat loss transferred to the surroundings. Using internal protective layer the lining weight and the wear was reduced. Reduction of the lining weight will lead to reduction of energy consumption for the furnace drive. Mechanically fluidized layer allows a qualitative increase in heat transfer due to increasing the heat exchange surface, which is close to the surface of the individual particles and increase in the heat transfer coefficient. Diffusion burner allows working with secondary combustion air only and cooling process can be fully integrated into the thermal apparatus. Thereby the efficiency of apparatus is significantly increased. The concept of controlled cooling of the furnace shell allows the use of heat from the shell to heat a combustion air and reduce heat losses through shell.

Reducing the heat losses through the furnace shell was achieved by increasing the surface temperature and the use of heated air in the combustion process. Developed sandwich structure of the shell furnace enables to achieve increasing thermal resistance. The fourth innovative element was radial seal of the furnace based on rolling friction. This new conceptual solution enables to achieve high- effective sealing with very low energy consumption to overcome resistance by friction and long-term lifetime. Granular and dust materials heat treatment in high-revolution rotary furnace in comparison with classic technologies enables to make this process more efficient. For the high-revolution furnace analysis and design of drying process a mathematical model was created. The model adequacy of the simulated process was verified. The model functionality was verified by simulations. The calibration was executed on the experimental high-revolution rotary furnace. After the model calibration the particular alternatives were simulated. By comparison of the simulation results it was concluded that the digital model is adequate to the real process since the results were almost identical. The model permits to optimize the process in the design phase and during the operational phase.

Acknowledgement:

This work was supported by the Slovak Research and Development Agency under the contract No. SUSPP-0005-09.

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