Complex research and innovation program of the raw materials thermal treatment

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Thermal treatment of raw materials takes place in many industries, especially in mining and processing industry. Thermal processes significantly contribute to the total cost of production and their technical and technological level significantly impacts the competitiveness of manufacturing companies in world markets. In the field of thermal treatment of carbonate raw materials, shaft furnaces, rotary kilns and deck furnaces are mainly used. By background optimizing of these aggregates, their rationalization opportunities have been practically exhausted. Further improvement is possible by moving the existing innovation borders or changing to different design solutions.

Key words*: thermal treatment, carbonate raw materials, shaft furnaces, rotary kilns, deck furnaces*

Introduction

In industrial practice, innovation processes are understood as the realization of individual innovations or their parts. They provide a qualitative and quantitative change in products, processes, and structure of production and technical base with all economic and social context. The intention of the research activity of Development and realization workplace of raw materials extracting and treatment (VRP) is through to the needs of industrial practice-oriented applied research, particularly in the thermal treatment of raw materials intensifying transfer of conceptually new knowledge and technology to the Slovak business practice with the aim to help increase its competitiveness on the European and world market.

Thermal treatment of raw materials is currently carried predominantly by heat exchange through the surface layer of the material, or by a transition of the heat-exchange medium through the stationary layer moving on the belt. A specific feature is the shaft furnaces intended for the processing of a coarse-grained batch, wherein the heat-exchange medium counter-currently passes in the vertical direction gravitationally and the batch moving. Another category is devices for thermal treatment of the fine-grained and dusty material, which carried the processes in a fluidized state. Fluidization is carried out either mechanically or pneumatically. [1]

Depending on the granularity, shaft furnaces, rotary furnaces, multilayer, fluidized and fountains furnaces are used in wide range for the thermal treatment of raw materials in the world at present. The dividing of these thermal aggregates can be possibly made according to the granularity of the processed material, as shown in the first part of Fig. 1.

The current main trend in the thermal treatment of raw materials is the emphasis on environmental, energy and overall process efficiency. In compliance with this trend, a comprehensive research and innovation program of raw materials thermal treatment processes is elaborated in our VRP. It contains, in addition to the innovative program for existing thermal aggregates (a complex optimization program of rotary and shaft furnaces), also a broad spectrum of research of conceptually new thermal aggregates, in which furnaces in a thin compact layer, rotary fluidized furnaces, microfluidic furnaces and hybrid furnaces (combined) are developed. The dividing of these thermal aggregates can also be possibly made according to the granularity of the processed input material, as shown in the second part of Fig. 1. [2]

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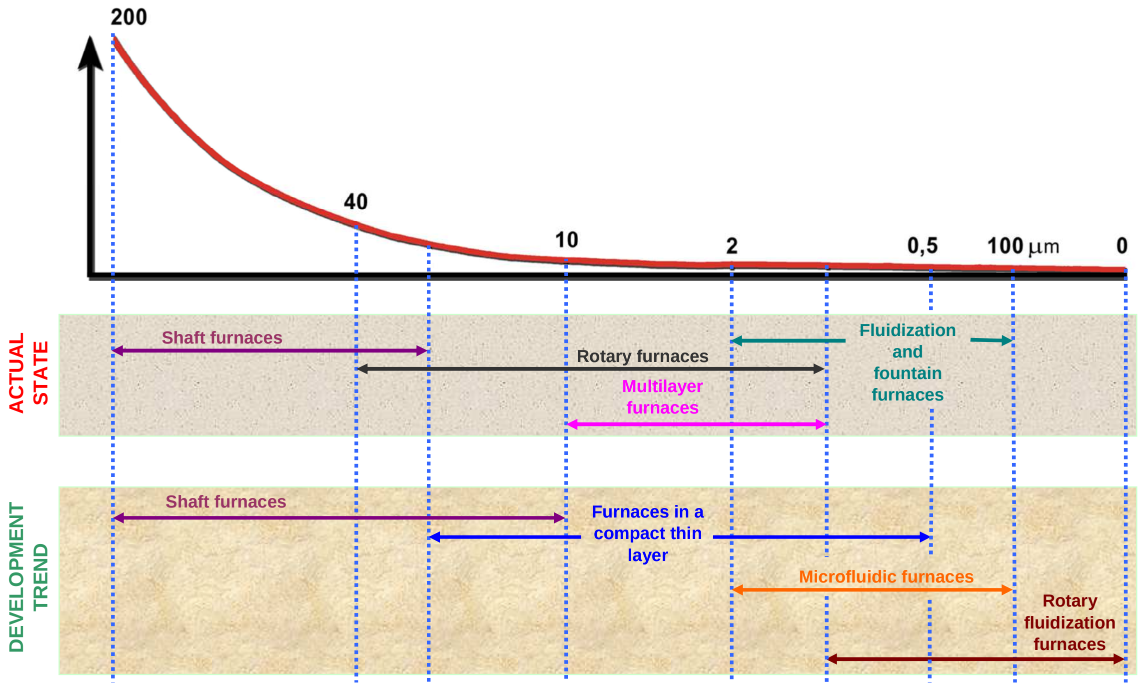


Fig. 1. Splitting aggregates by grain of processed material.

Complex optimization of shaft and rotary furnaces

The primary purpose of all innovation processes and measures on a shaft and rotary furnace aggregates is the effort to streamline the burning of the product by reducing the specific consumption of used fuel and energy per unit of production while maintaining standard high quality of production and reduction of environmental impacts. This can be achieved by the application of several innovation and optimization measures, on which proposal and construction the research of VRP focuses. [3]

Shaft furnaces

A complex optimization program of shaft furnaces includes a range of technical (constructional) and operational measures, whose common objective is to streamline their operations. The optimization program contains mainly these measures:

- solutions for the batch filling system, in various modes, according to the particular needs of the furnace, respectively the technological process implemented therein,
- solutions aimed at flue gas pull away, control parameters and the use of their potential,
- targeting a fuel process and the uniform heat generation of the cross section of the furnace,
- solutions aimed at reducing the heat loss of the furnace shell, by proposing more appropriate linings, insulation, use of heated air in the furnace shell,
- solutions for system cooling and sampling of the product,
- solutions for more efficient monitoring and control of the thermal treatment process.

The most interesting solutions of the said portfolio are attributable developed combustion system of fuel cycle working burners, which operational verification is currently underway. This new combustion system of fuel solves one of the most serious problems in the thermal treatment of materials in a shaft furnace, which is the temperature field inhomogeneity in a sintering furnace zone. This problem has a major effect on the quality of the product produced and the actual performance of the furnace, due to the need to abstain longer from the material in the furnace to eliminate the occurrence of unburned originating from areas of the furnace at the lowest temperature. To remedy these shortcomings, the cyclic system was designed by burners, respectively controlled by limiting the supply of the combustion mixture to the burners. This ensures the deflection of the secondary air channel of the axis of the furnace to areas with lower temperatures, and the flame is shifted from the edge of the furnace to the center. A hitherto phase solution was reached to confirm the basic concept of the functioning of the cyclic burners in shaft furnaces. A laboratory model was created (Fig. 2a), which was verified by the principles of functioning of the system and the control system for controlling it. To control work model used a simplified user interface (Fig. 2b), allowing the setting of parameters of cycling primary air supply to the burner system and measure the temperature in the layer of material. [4] Currently, the pilot operational verification regarding SMZ runs in Jelšava.

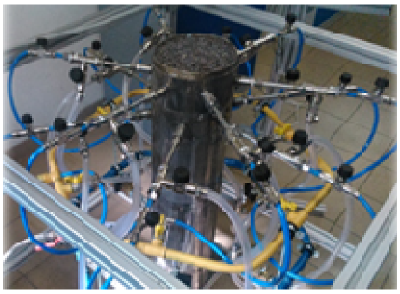
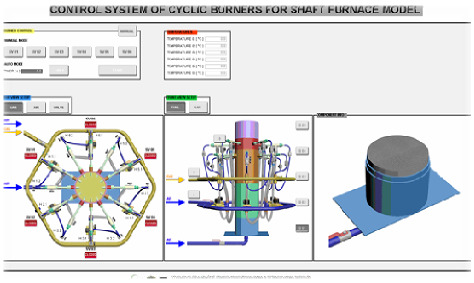
a)  b) 

Fig. 2. A laboratory model of cyclic burners and the sample of a user interface for the cyclical burners controlling.

Rotary furnaces

The complex optimization program of rotary furnaces consists of technical (construction) and operational measures. Optimization program includes the following solutions:

- the self-regulating continuous batch filling system, enabling to operate the height of layers of material in the furnace,
- solutions aimed at flue gas pull away, control their parameters and the use of their potential, which represents the new radial sealing of cold and hot dipped head, intensified dusty chamber, batch preheater in a thin compact layer or fluidized layer,
- solutions to control heat transfer surface area, for example, internals (internal construction parts) and change layer height,
- solutions aimed at fuel combustion processes and control of the temperature profile along the length of a furnace cross-section through the intelligent diffusion furnace burner,
- solutions designed to reduce the heat loss of the furnace jacket, by proposing more appropriate linings, insulation, use of heated air from furnace jacket,
- solutions for a control system for cooling and sampling of the product,
- effective solutions for monitoring and controlling thermal treatment process.

To illustrate the above portfolio of measures, the following solutions were chosen and described in detail:

The self regulating continuous batch dispenser to rotary furnace

The device provides continuous feed to the rotary furnace, self-maintaining of a defined height of the material in the work areas of processing equipment, and eliminates overflow of feed material from the rotary furnace at its dosages. Within the furnace, a damper together with a set of stirrer blades are placed, whose task is to return the undersize material (Fig. 3). This design of the self-regulating dispenser allows continuous dosing of input material into the rotary furnace with eliminating his slump out of technological equipment. A non-slip barrier is achieved by mixing the material in the layer with less thickness. This solution also helps to increase heat transfer rates and a reduction in heat loss of the furnace jacket. At the same time, the change in the form of batch movement contributes to the reduction of mechanical wear of lining. [4]

Fig. 3. Batch dispenser.

The radial sealing of rotary and static contact part of the furnace

Control of the furnace atmosphere prevents the uncontrolled suction of air into the furnace, respectively flue gas channels, so it is essential to ensure the optimal hydrodynamic conditions in the furnace. The existing technical solutions do not allow prolonged contact with a perfect seal rotating furnace jacket and stationary heads (hot dip and cold). A new type of contact with radial seal axial pressure (Fig. 4) provides a method for sealing the gap between the moving and stationary part. The problem of leakage, respectively media penetration in the joint of the two parts of the device, is transferred in the direction of the movable part to the location of the seal, which is designed for moving parts. [4]

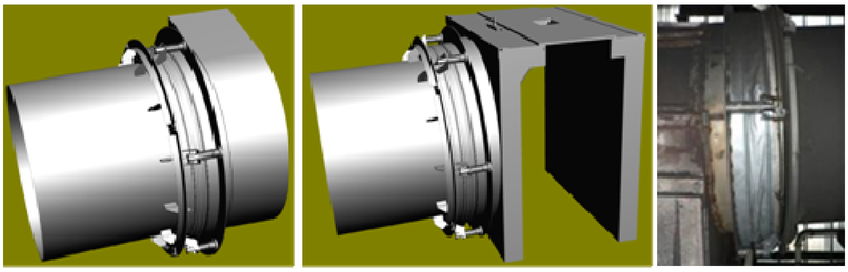


Fig. 4. Radial sealing.

Cooling of the furnace jacket control system

To reduce the heat loss of the furnace jacket, a controlled system for cooling of furnace jacket was designed (Fig. 5). A controlled system for cooling of furnace jacket is a new solution aimed at reducing heat loss of the furnace jacket integrated into the technological process. The proposed solution is also cost-effective and operationally efficient. By the cooling of furnace jacket controlled system of the rotary furnace, the formation of an air gap between the shell and the surroundings of the length of the furnace in which an adjustable quantity of the cooling air discharging is distracted an amount of heat, the temperature of the surface of the jacket does not exceed the limit permissible by design (about 350°C). [5]

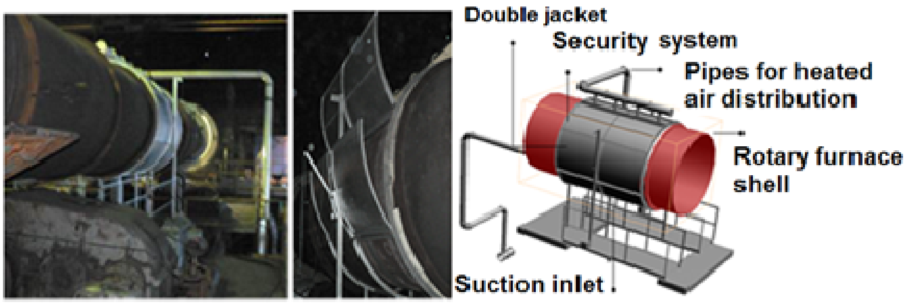


Fig. 5. Cooling of furnace jacket control system.

Smart diffusion burner

The diffusion burner (Fig. 6) is a device designed to take full advantage of the secondary air in rotary and other facilities. Its main advantage is that it enables the efficient mixing of fuel with air and does not require any primary air. It makes full use of the heat potential of the products, reduce specific fuel consumption, reduce the total gas volume and increase of a specific output device. The diffusion burner has a concept based on the radial arrangement of the flame. The proposed solution enables efficient combustion of the secondary air. Results of experiments confirmed that the developed burner ensures the efficient transfer of heat to the processed material and very good temperature resistance. To verify the functionality of the burner an increased performance of furnaces was achieved at the same fuel consumption. [6]

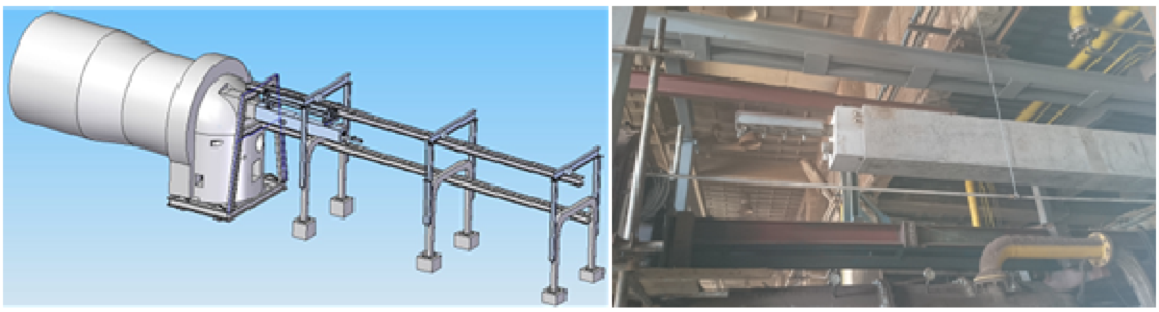


Fig. 6. Smart diffusion burner.

Batch preheater for furnace

Installation of a batch preheater (Fig. 7) will significantly contribute improving of energy side of thermal process in the furnace. This device is the result of joint research development-implementation work of the BERG Faculty of The Technical University in Košice in the cooperation with ATIM, s.r.o. Košice. This is a completely new type of thermal aggregate, to the thermal treatment of granular materials in the thin dynamic layer. Its main contribution is the use of waste heat for preheating the batch to the rotary furnace, and thus significantly increases its performance. [5]

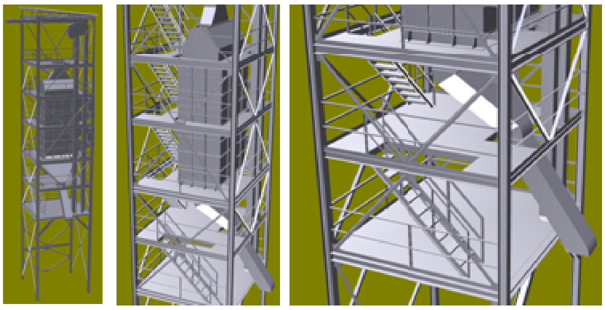


Fig. 7. Batch preheater.

Innovated (new) thermal aggregates

To achieve more efficient processes of thermal treatment, respectively for the thermal treatment of previously untreated fractions, the following conceptually new type of heat aggregates for the processing of raw materials were designed and validated by the research in VRP:

RORP (high-revolution rotary furnace)

The high-revolution rotary furnace is prepared for the thermal treatment of fine-grained and dusty material in a mechanically fluidized layer. The mechanical fluidization is carried out by increasing the speed to the extent that the material in the furnace is evenly distributed over the cross section of the furnace. Fluidization of the material is achieved at the equilibrium of centrifugal and gravitational forces. At the critical speed, the material fills the entire cross section of the furnace. Thus, achieving the optimum conditions for the transfer of heat, as it significantly increases the heat exchange area. As a result of falls and the rotational speed of the material, the heat transfer coefficient increases. Aggregate can be configured as co-current or countercurrent. Given the local flow, it is a transverse movement of the material and the longitudinal movement of combustion gasses. Regarding heat transfer, essential factors are affecting heat transfer, the grain size and filling of the furnace. Their direct use affects the size of the exchange surface between the material and the hot gas. The technological advantage of the high-revolution furnace is that the movement of the material is independent of the movement of gasses, which allows efficient control of the performance of the furnace. A heat source for the high-revolution furnace may be provided directly in the combustion space of the furnace or in a separate combustion chamber. The limiting factor is the maximum flow rate, near which the material is carried away by flue gasses.

In mechanical fluidization, the residence time of fine particles in the layer is the longest and relative speed the lowest. This is because the movement of fine particles in the radial direction due to gravitational and centrifugal forces is slower than with larger particles. The heat transfer compared to the conventional furnace is increased about 25 times, which allows reducing the dimensions furnaces about ten times. Improved performance has a significant impact on the use of heat due to the drop in temperature of outgoing flue gasses and the reduction of the size of the furnace shell with a product heat recovery. Conceptually, the furnace can be classified as a high-intensity working thermal aggregate. Diagram of the high-revolution rotary furnace is in Fig. 8. [7]

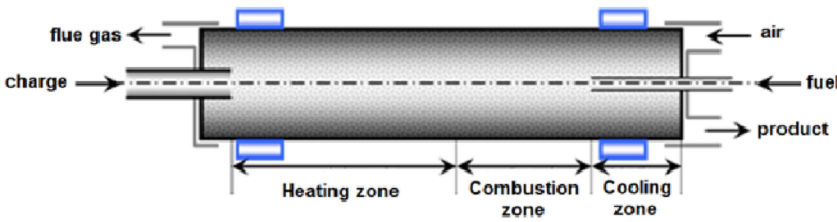


Fig. 8. RORP scheme.

The research program focused on the mechanical fluidization, and its use for thermal processing of raw materials began on a cold laboratory model of RORP (Fig. 9). The model consisted of organic glass and had a diameter of 240 mm and a length of 1.5 m. On the model, the speed was controlled in the range of 0-50 rpm. The goal was to investigate the effects of the thickness of the material bed to the size of critical speed at which it occurs, and the fluidization of the fluidization effect of the pressure loss in the furnace.

Fig. 9. RORP laboratory model.

The result of laboratory research was the knowledge that the particles carrying away are directly dependent on the speed of the flowing medium. The experimental data obtained show that the furnace can operate at the flue gas velocity of about 1 $m.s^{-1}$. The maximum carrying away of dust particles determines the flow of gaseous medium and thus the possible power unit per unit area of its cross-section. The ratio of the media is determined by the planar cross section of aggregate. Heat and engineering-technical parameters were verified by the experimental RORP model (Fig. 10).

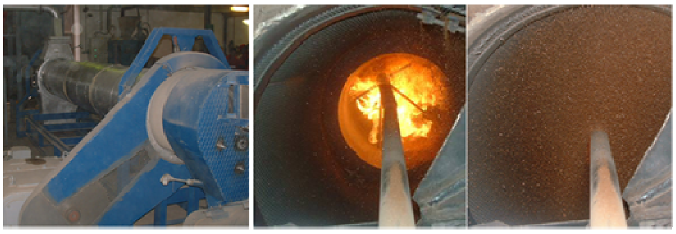


Fig. 10. RORP experimental model.

Implementation of the pilot operating RORP (Fig. 11) was performed by preparation of the technical project. The project was developed based on previous research, supplemented by mathematical simulation. Based on the results of simulations of various scenarios of furnaces, construction elements and the support part of the equipment were designed and manufactured. The pilot operational RORP, compared to conventional rotary furnaces, has increased the speed of rotation several times (classical rotary furnaces – 0,4 rpm; RORP - max. 42 rpm).

Fig. 11. Pilot RORP.

Performed experiments fully confirmed the validity of the principle of mechanical fluidization and functionality of the high-revolution furnaces. The combustion systems using the diffusion burner allows effective secondary use - cooling air for combustion. [7]

Microfluidic furnace

In microfluidic furnace (Fig. 12.), the material is fluidized in a through-air style in countercurrent flow of the material. The device consists of a number of chambers, which have the character of a perfect blending. Therefore, the material can be seen in each as well homogenized. From a thermodynamic point of view, it is the optimal maximum number of chambers, as with an increasing number of process chambers are close to the net countercurrent. The Proper function of the microfluidic layer is subject to a continuous flow of material. This parameter can affect the size and shape of the hole interconnecting individual chambers.

The gaseous medium at the inlet to the reactor chamber provides fluidization of material located at the bottom of the chamber. The fluidized material is drifting to the top of the chamber, where it recirculates and the material from the higher located chamber is added to it. Gaseous medium progress to higher located chamber. Each chamber is an autonomous reactor whose input-output section must be set to specific process conditions, as the number of media for each chamber is not individually adjustable.

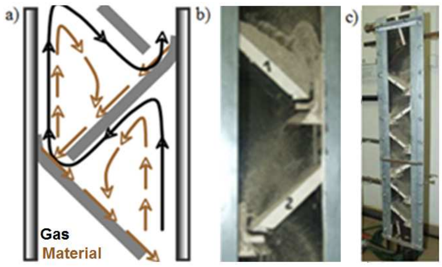


Fig. 12. Laboratory model of the microfluidic furnace) process mechanism b) detail of the process chamber c) model facility.

Specific to the microfluidic layer is the fact that the secondary combustion air is used, and it is possible to multi-stage combustion in several combustion chambers when the burning media in the next combustion chamber are combustion gasses from the previous combustion chamber. For low-temperature processes, for example, the drying process cannot be done directly in the combustion chamber of the material and separately in the combustion chamber. The high-temperature combustion process can be performed directly in the material section. The physical and mathematical modeling was used to build the prototype of the microfluidic furnace. For physical experiments, the experimental equipment was used. The experimental microfluidic furnace has nine fluidization chambers, ensuring of drying, heating, calcining and cooling of the material. The burner is positioned in the seventh chamber. The calcination of magnesite experiments were conducted in the furnace. Filling the chambers depends on the rheological and hydromechanical conditions in individual chambers. Fig. 13 shows the temperature course of the experiment. [7]

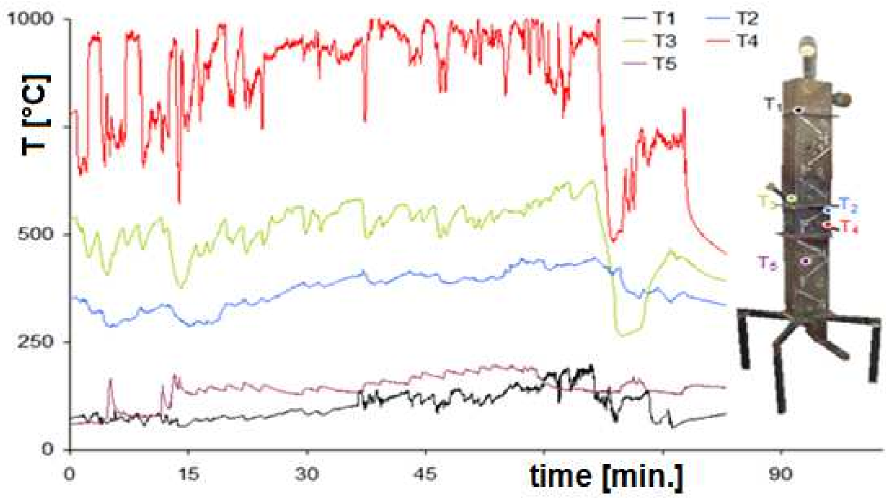


Fig. 13. The course of temperatures.

The verification of operation and operating parameters were carried out in the furnace, and the results were used to calibrate the mathematical model. The verification of operation has included the confirmation of the self-regulation movement of a material through the furnace, which is fully confirmed. For operational parameters, the power density and thermal efficiency were detected. The specific power ranged from 652 kg of product per 1 m^3 device. The specific gas consumption was 126,7 m^3/t. Using the pre-calibrated mathematical simulation model, the microfluidic pilot scale/semi-operational furnace was designed (Fig. 14).

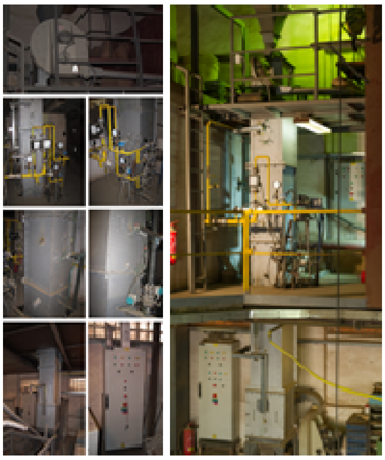


Fig. 14. The semi-operational microfluidic furnace.

The furnace has nine chambers again, and the burner is again placed in the 7th chamber from the top. The number of chambers of the zones of the process depends on the nature of the process. This furnace is designed for caustic magnesite. Through the last chamber, the air is fed to the process. Fluidizing chambers are built of refractory materials with thermal insulation and outer jacket.

The newly developed device has been successfully tested and functionally suitable for the thermal treatment of fine fractions magnesite. A hydromechanical fluidization in microfluidic furnace appears to be the technically operationally effective solution. [7]

ITA (integrated thermal apparatus)

Integrated thermal apparatus represents an innovative and unique technology in the world of thermal treatment of raw materials, based on the principle of cross transition of the gaseous medium through a dynamic thin layer of granular material. The principle of the dynamic thin layer is based on a gravitational movement through a porous medium which volume, respectively surface, is in contact with a gaseous or liquid medium. Devices based on this principle can serve for purposes of technology (heating, drying, etc.), energy (combustion of lump materials) and ecology (solid capturing dust, waste combustion...).

Thermal treatment is performed in a crosswise motion of a gas or liquid medium through a layer. A significant advantage of this solution is the fact that in contact with the operating medium, all grains directly arrive at the layer, thereby achieving a high intensity of the process. Devices based on the technology of the ITA are over traditional devices several times smaller size. Using the principles intended to minimize overall energy consumption in the process of the border near the technological optimum. The technology of the ITA may use, besides already mentioned, the use for the treatment of gaseous or liquid media, or the dust removal and flue gas desulfurization and the like.

In the devices operating on the principle of a compact thin layer, there needs to be a permeable layer. Breathability allows the passage of gas through the media layer. When permeability of the layer is reduced, while maintaining a flow rate, this generates channels that disturb homogeneous passage through a layer gaseous medium, and, therefore, the best of the process. For technological purposes, the velocity of about 0.3 ms^{-1} is suitable. The base profile of the furnace in a compact thin film having two layers is shown in Fig. 15. [7]

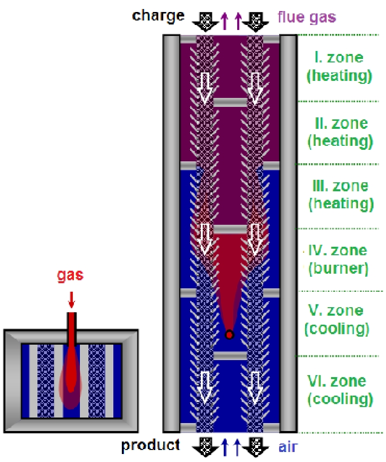


Fig. 15. Hydromechanical profile of the furnace in a compact thin layer.

The development of this device consists of several stages. As a first, the elemental model was created. The aim of the elemental model of the ITA was to verify the flow of a thin layer of granular material. The process requirement was to have a material flow of a piston nature. The aim was also to determine the optimal layer thickness in the aggregate and save the lamellas that have affected the flow of the material itself. It was also necessary to establish the slope of the lamellas in the aggregate.

The next stage was the construction of a laboratory model. The aim of experiments on laboratory model was to verify the discovery of knowledge from the elementary model of piston flow of material in the aggregate, design of technical solutions input and output of the material in the aggregate, the design of the burner and its location in the aggregate and partial thermodynamic processes were verified. ITA laboratory model has been constructed according to Fig. 16.

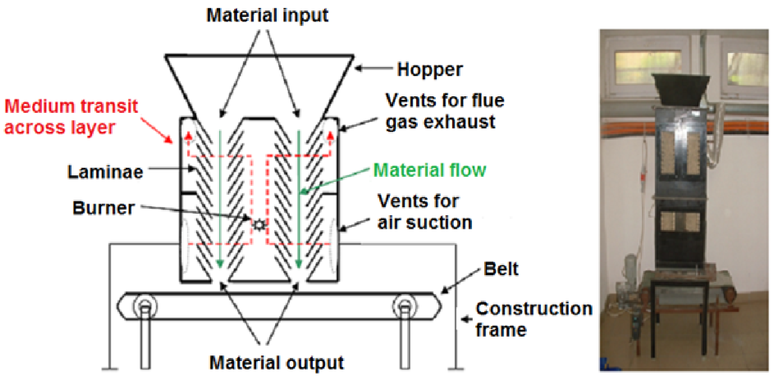


Fig. 16. Laboratory model.

In later stages, the research was focused on the design and position of pilot installation. At the draft in addition to physical modeling, also mathematical was used. A mathematical simulation model was created, in which various settings options for the device were verified. Validation was aimed to clarify the relationships for calculating the coefficient of heat transfer, the decomposition of carbonates and the determination of threshold values for carrying out the process in a cohesive layer. Subsequently, it passed to the construction of facilities. The pilot plant is made up of six segments, hoppers, conveyor belt, fan the inlet air to the aggregate, combustion products ventilator, four burners, a cyclone, the flue gas analyzer and quantity of thermocouples (Fig. 17).

Based on the results of a marketing survey, there were operated over 100 heat aggregates only in Slovakia, which can be replaced in the future by using this technology. E.g., over the prior process of caustification magnesite in a rotary furnace, using ITA, this process is mainly to reduce consumption of natural gas and electricity consumption. [7]

Fig. 17. ITA.

The innovated shaft furnace

Based on lessons learned from existing research and work with a shaft furnaces and their optimization, there was created the concept of new shaft furnace for processing a charge of lower granularity. On the creation of this furnace, we take into account a series of several innovative modifications and design solutions. Design solutions have a significant impact on the basic indicators of plant: power density, fuel consumption, reliability, environmental impact.

The increase of specific performance is affected by reducing the grain size to 20-40 mm, which enjoys an increase heat-exchange area. Time of blowout decreased by the massiveness of grains is cut. It will reduce the hydraulic resistance of the charge by the suction of proportion dust caustics. At the same time, a new product arises. Using preheated secondary air raises the temperature gradients between flue gasses and burden. Diffusive combustion is achieved by shortening the length of the flame and regulated by excess air. A new profile of the furnace has no limitations regarding penetration of combustion gases inside the furnace. The specific volume of the furnace can be varied according to requirements on the overall performance without restriction. There is also the possibility of parallel solutions, respectively extension. Physical experimental model (Fig. 18a) of the newly revised type of shaft furnace is designed to verify the rheology and flow in the shaft furnace, intended for a batch of lower granularity. The main problem of development is to achieve homogeneous flow through the cross section of the furnace as well as the generation of heat. For this reason, the profile of the furnace and the secondary air supply to the burner chambers were adjusted. Preliminary experiments confirmed the developed concept in which the particle size of the charge can be reduced below 40 mm, to ensure the uniform cross section of the firing furnace.

On the basis of the present research, it was conceived a proposal of pilot upgraded shaft furnace, which is currently in the process of building, shortly before completion (Fig. 18b). [7]

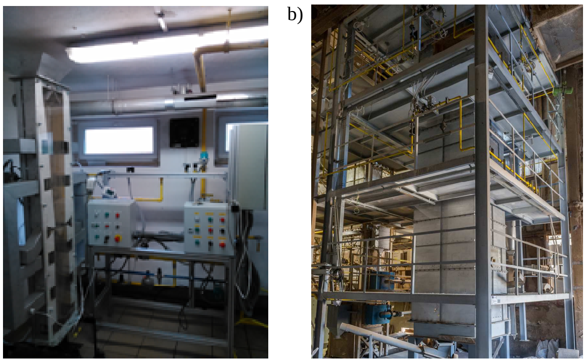


Fig. 18. The innovated shaft furnace a) model, b) pilot plant.

Conclusion

The future of the raw material industry is in increasing its efficiency through the implementation of technical, technological, system and material innovation, which are and will be based on knowledge. By practical applications mentioned in the paper, optimization measures respectively innovative technologies can achieve this.

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