SHAFT FURNACES DEVELOPMENT FOR GRANULAR MATERIALS THERMAL TREATMENT

Doc. Ing. Jan Spisak, PhD
Ing. Peter Kosinar
Ing. Branislav Vanko
Faculty of Mining, ecology, process control and geotechnology
Technical University of Kosice

Abstract:

The contemporary shaft furnaces for the production of magnesia sinter have a very good performance indexes, which are, however, quite distant from their technological limitations. Thermodynamic, hydrodynamic and rheological processes don´t run optimally. The purpose of the research was to determine the reasons and optimization measures. One of the significant requirements was to process materials with lower granularity (20-40 mm). The research was focused on the charging system modification, burner system modification, coke utilization in the middle part of the furnace, sinter heat utilization, increasing the insulation. Improvement measures are currently verified in the operational conditions. The result was conceptually new pilot shaft furnace determined for the further research. The basic features of the new shaft furnace are distributed burners enabled the secondary air combustion and thus the homogeneous heat generation through the furnace cross section can be achieved which leads to the significant improvement of homogeneity of temperature distribution through the furnace cross section.)

Keywords: Shaft furnace, thermal treatment, granular material

Introduction:

Shaft furnaces are the most suitable thermal apparatus for the production of magnesia sinter. Its production in shaft furnaces is limited to the charge granulometry with more than 40 mm and also the performance limitations of the existing furnaces. The existing shaft furnaces optimization is aimed at reducing the specific fuel consumption and an increase in performance. Energy costs for the sintered magnesia present a crucial cost item. Limitation on the increasing the magnesia sinter production in shaft

furnaces is mainly caused by the natural granularity of treated magnesite raw materials.

The technical optimization of shaft furnaces is carried out at the level of elements, apparatuses or entire equipment. It has usually an innovative character. The operational optimization ensures the process implementation close to the extreme of the selected criteria. Part of the operational optimization is the control system. The shaft furnaces optimization was carried out by economic, technical, technological and environmental selected external indicators (performance, production quality, environmental impacts, costs and benefits). The optimization conditions constitute the inputs to the process. Implicit limits are used for the process relations reflecting the links between process quantities. Explicit limits specify process boundaries and breaking the boundaries leads to failure. Optimality criteria are used for the assessment of the selected alternatives. For the optimization problems solving are using following methods: direct, implicit and explicit. Their use depends primarily on the task complexity and required solution time.

2. Shaft furnaces for the sintered magnesia production

Generally, the current shaft furnaces are vertical devices of the height 10 - 15 m with internal diameter 1500 - 2500 cm. The shaft furnace profile is adapted to volumetric changes of the material. The magnesite sintering furnace is technologically divided into following zones:

- drying and preheater,
- decarbonisation (caustification),
- sintering involving heating on the sintering temperature,
- sinter cooling.

The shaft furnace charge is composed of lumpy and granular material in the size of 40 - 250 mm. The magnesite charged into the furnace is thermally transformed into the sintered magnesia. Fuel input into the furnaces is performed by burners which are placed on the furnace circumference of the sintering zone. Fuel combustion is performed in the layer of the material in the sintering zone. Flame length depends on diffusion processes between fuel and combustion air. Sinter quality is influenced by the temperatures homogeneity in the sintering zone. A charge lumping occurs in the high temperatures zone. The created conglomerates cause decline of thermal processes inside the furnace. At low sintering temperatures, the degree of sintering does not reach the desired value causing decline of the overall quality of sinter. One of the main disadvantages of the current shaft furnaces is insufficient fuel combustion, which causes high CO content in the exhaust gas, very low proportion of secondary air on the combustion process due to insufficient mixing

with fuels caused low sintering temperature o in the central part of the furnace and large excess of oxygen in the flue gas. The main internal criterion of the shaft furnace operation is maximal temperatures homogeneity through furnace cross section in the sintering zone.



Fig. 1 Shaft furnace – scheme and photo

Proportion of the extracted raw materials which is qualitatively suitable as a charge for the use in the shaft furnaces with chemical composition and granularity composition is slightly below 30 %. Further increasing the magnesia sinter in the shaft furnaces requires their conceptual changes which enables charge processing with low granularity.

3. Shaft furnaces technical and operational optimization

An optimal furnace achieves optimum values of the selected performance indexes. Technologically optimal furnace (TOF) is considered as the furnace which operates at the limit of its technological capabilities. Proposed indexes to achieve TOF are achievable by changing the flow conditions, combustion and reducing heat loss. Technical optimization includes technical and technological measures to improve the value of the selected criteria. Technical optimization involves the following steps:

Inserted burners

For secondary air improvement combustion the two-row arrangement of burners (Fig. 2) was proposed. The amount of secondary air reaches approximately 30 % of the total volume of combustion air supplied to the furnace. Unburned secondary air causes a decrease in burning in the central part of the furnace and increasing the flue gas flow rate through the furnace. Due to the increased amount of air the flue dust velocity and the amount of the flue gas is increased. By using secondary air for combustion the volume of flue dust will be reduced by about 50 %. Technical solution lies in two-row arrangement of burners. The bottom row of burners is inserted inside the furnace and ensures fuel penetration into

the center of the furnace. The benefits are achieved by homogeneous distribution of the sintered temperatures through furnace cross section and secondary air utilization for combustion.

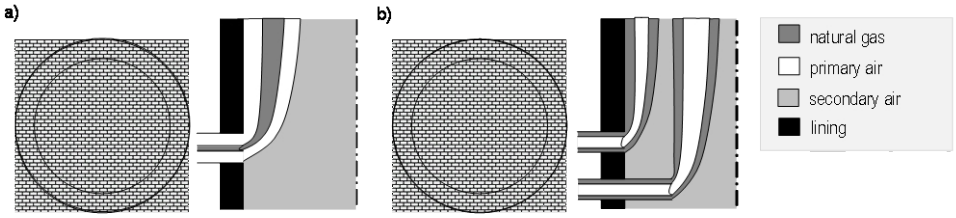


Fig. 2 Flow arrangement in the shaft furnace: a) standard; b) inserted burners

The charging system

The current charging system is implemented by hopper in the middle part of the furnace. In the furnace is formed a cone, by which the coarse-grained charge is sorted to the furnace walls. Fine-grained charge is accumulated in the middle part of the furnace. Changing the charging system is performed by in-building which is used to direct the fine material to the walls of the furnace and coarse-grained material to the middle part of the furnace.

The benefits will be a higher homogeneity of maximum sintering temperatures through the cross section of the furnace. This measure will increase the sinter quality and the furnace performance.

Predictive control system

A predictive control system will provide support of operator activities by objective information about the state of the furnace. A major advantage is that control system will be carried out on the basis of inside information about the process - the principle of white box. The measure will result in a security of the furnace operation near to the technological optimum. Potential deviations will be eliminated by forward interventions.

Co-burning of coke in the shaft furnaces

The solution lies in the supply of coke into the middle part of the furnace, which provides secondary air combustion. Thereby the temperature in the middle part of the furnace will be increased which will stop being critical from the point of the burning quality. Thus is achieved an increasing the performance and quality of sinter.

Reduction in charge granularity

The uniformity of the sintering temperatures through the furnace cross section and the use of heat of sinter were achieved by the change

of the furnace construction. Increased furnace performance, reduced specific fuel consumption and improved sinter quality will be achieved by the measure.

Improving walls insulation of the shaft furnaces

A greater uniformity of sintering temperatures through furnace cross section will be achieved by an increase in isolation in the high temperature part of the furnace and heat generation adequate treatment. The material temperature is moved towards higher values by an increase in isolation and it enables a reduction in fuel consumption. Reducing the loss by 0,46 GJ/h can be achieved a fuel savings of 10 m^3/h. Improving the walls insulation a specific fuel consumption will be reduced and the furnace performance and furnace sinter quality will be increased. Thermal insulation influence was analyzed based on the temperatures measuring of the surface furnace shell No. 14 and the furnace No. 13th. In compared with the furnace No. 14. The furnace No. 13 has an average temperature of the shell 35°C lower than the furnace No14 corresponding to a reduced heat loss by 0,366 GJ/h. The medium temperatures difference in burner´ zone of the furnace is 103°C and their corresponding heat loss of high of 3 m has a value of about 0,26 GJ/h.

Apart from insulating layer (sibral 1 cm) the burner asymmetry caused drop in flue gas and material temperature by the furnace wall had also influence on the reduction in heat loss of the furnace No.13.

When isolating the whole furnace, the heat loss would decrease by about 20 % and in burner´s parts the heat loss would decrease by approximately 40 %. Without an isolation of the burner´s part in the height of 3 meters, the reduction in heat losses would be decreased by approximately 50 %. An isolation of the burner´s part is in terms of the process more significant as it directly affects the maximum sintering temperatures. On the furnace no. 13 there were increased the maximum sintering temperatures not only by the isolation, but also due to burner asymmetry.

4. Results:

4.1 Combustion system adjustment

The combustion system adjustment has been experimentally verified on the shaft furnace. Only lower burners were constructional adjusted which had a reduced diameter due to the possibility of insertion through the existing holes. The attempt was conducted on the shaft furnace No. 11 in SMZ Jelšava.

During the shaft furnace No.11 general repair the casings for an insertion of the new burners were installed in the walls below the upper row of the existing burners (Fig. 3). There were radially placed 3 pieces

of burners under burners No. 2, 4 and 6, later identified as DH2, DH4 and DH6. The burners were inserted with front overlapping of 35 cm beyond the inside wall of the furnace.

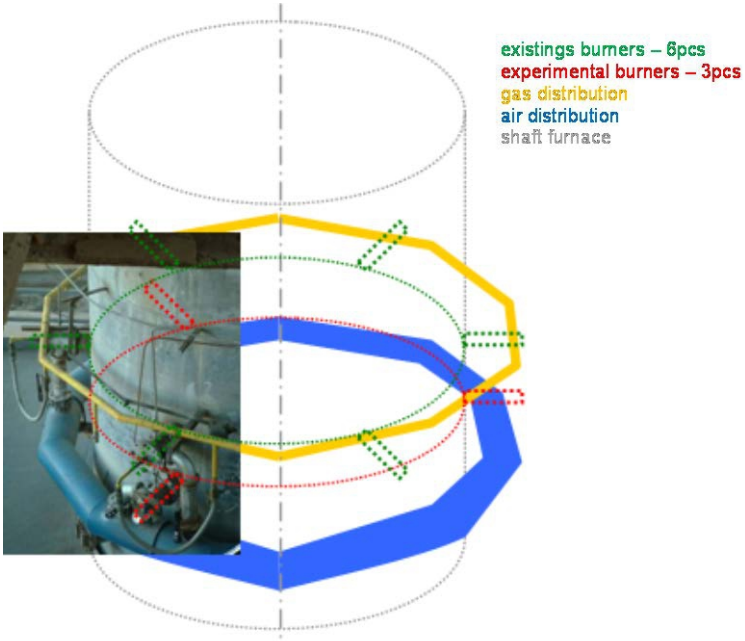


Fig. 3 Layout of original and experimental burners

The purposes of the experiment were the following findings:

- intensity of fuel and secondary air mixing,
- possibility of the flammable mixture transport deeper to the furnace axis by the inserted burners,
- inserted burners functionality and lifetime (Fig. 4).

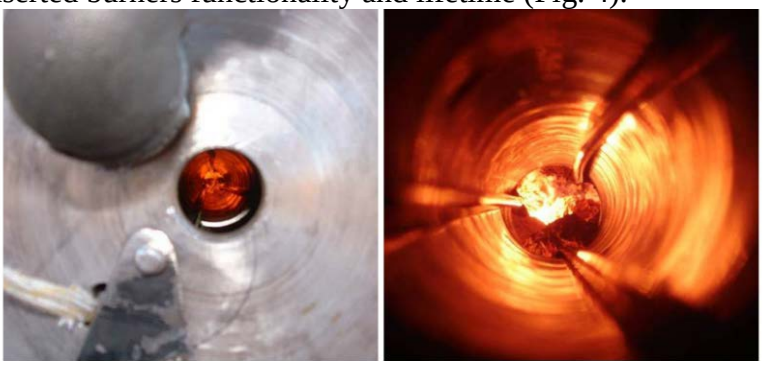


Fig. 4 Combustion of the bottom burners during the experiment

The operating experiment results confirmed that it can be effectively controlled the flow distribution, mixing and combustion process by the change in the construction and arrangement of the burners. An achievement of higher maximum temperature uniformity in the furnace cross section creates an opportunity to improve furnace insulation

and increase the amount of secondary air. It also affects the sinter granularity, thereby contributing to improved heat exchange in the cooling part of the furnace. The achieved reduced specific fuel consumption can be used in order to increase a performance, thereby increasing the effectiveness of the proposed solution.

During the experiment there were achieved the following benefits:

1. manufacturing and technology indexes
- a production increase by 1,36 %,
- decrease in specific fuel consumption by 3.13 Nm^3/t of product,
- decrease in consumption of primary air by 91.8 Nm^3/t of product, secondary (cooling) air consumption is maintained,
- the poor quality of production decline by 4 %, while maintaining product quality,

2. operational indexes
- it was achieved a better distribution of gas through the furnace cross section in the burning zone and thereby balancing the temperature and quality in the furnace radius from 95 to 99 %,
- the proportion of conglomerates decreased by 33 % and output granularity decreased from 120 to 100 mm, which helps reduce a grate wear,
- the temperature of the flue gas in the furnace top increased by 51°C and the resistance of the charge according to the under pressure on the suction by 0.3 kPa, indicating a better charging heating in the furnace axis while the temperature on the grate slightly felled slightly
- the furnace wall temperature by extending the combustion zone towards to the furnace axis decreased in burning zone by 95°C and in calcining zone by 182°C,
- oxygen content was decreased in the flue gases, which is a consequence of the increase in cooling - secondary air combustion.

3. ecological indicators
- reducing the average CO content in the flue gases by1880 ppm,
- reducing the volume of flue gases corresponding to reduction in fuel consumption and combustion air,
- reducing the heat and the temperature load of working surrounding and environment by reducing the heat losses through the furnace walls.

4.2 Combustion in the shaft zone with oxygen using

The co-combustion of oxygen (Fig. 5) in the shaft zone of the ITA apparatus was verified by the models. Two diffusion burners located on the opposite sides of the zone were used for the process of natural gas combustion with a secondary air. In place of their common intersection at the level of 100 mm above the diffusion burner there was placed oxygen supply, which was ensured by Laval nozzle operating in pulse mode. Significance of oxygen was to increase the temperature in the middle part of the apparatus cross-section, which results in the thermal field homogenization along cross-section zone.

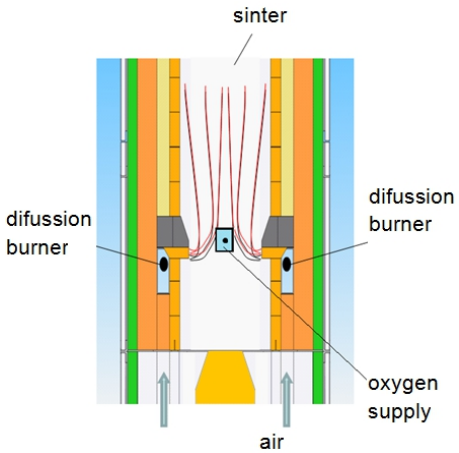


Fig. 5 Model combustion in the shaft zone using oxygen

5. Discussion:

The basic requirement for a new shaft furnace (Fig.5) is the possibility of the input magnesite raw material processing in the range of granularity 20 - 40 mm. The significant benefit is the replacement of the rotary furnace by shaft one. Thereby a reduction in natural gas specific consumption by about 100 m^3 per tone of sinter is achieved. The proposed design solutions have a significant impact on the furnace fundamental indexes: specific capacity, fuel consumption, reliability, impact on the environment. Increasing the specific capacity is affected by reducing the granularity causing an increase in heat surface area by about 64 times. Aperiod of over burn is shortened by about 5 times by reducing the degree of grain massiveness. The hydraulic resistance of charge will be reduced by dust caustic suction and thus a new product will be created. The temperature gradients will be grown between the flue gases and the charge by using pre-heated secondary air. There will be achieved a shortened flame length and regulated excess air by diffusion combustion. A new profile of the furnace has no limitations in terms of intersection

of flue gases inside the furnace. The specific volume of the furnace can be changed according to the overall performance requirements without restriction. There are parallel solutions or extension possibilities. Reduction in specific fuel consumption is achieved by using heat of sinter and reduction in losses through the furnace shell. Heat of sinter will be used to heat the secondary air. Conceptual solution enables the furnace to reduce the heat potential of sinter by its cooling below 100°C. The secondary air will be used as a combustion air. Heat losses will be reduced by increasing the insulation of the furnace shell. Reducing the maximum temperature in the sintering zone there can be improved an isolation without exceeding the maximum sintering temperatures. The basic influence on the increase in the sinter quality has a burning uniformity through the furnace cross-section. Ensuring an intersection of gases inside the furnace will be achieved by the secondary air supply to the burners and reducing the thickness of the material layer. The medium temperatures of burning and sinter formation and unburned material removal can be reduced by balancing the sintering temperatures. A major impact on the reliability has the mechanical part of the furnace. The new concept of taking the sinter from the furnace enables to remove the Gruber grate which will be replaced by four-active feeder. The desired material flow through the furnace is reached by adjusting the furnace profile. The heat generation balancing along a cross section of the furnace is achieved by changing the burner system. This prevents the formation of conglomerates that have a significant impact on the reliability of the furnace operation and the sinter cooling. Adjusted furnace profile and a burner system (section extension, heat generation balancing by diffusion combustion in the layer) have a character of an internal control. The furnace top structural solution will lead to the self-regulated batching. Adjusted furnace section will allow better access for the operating interventions which will be provided with a new system of monitoring and prediction control of the combustion process. Reduction of CO and NO_x in the flue gases will be achieved by control of excess air and burning intensity by maximizing the primary flame. Distributed burning improves the quality of burning at lower temperatures of combustion reducing the NO_x creation and thus is achieved the reduction of the secondary flame proportion. Combustion quality is inversely proportional to the proportion of the secondary flame. The amount of flue dusts in the flue gas is reduced by full use of secondary air for combustion. This will lead to reduce the average amount of flue gases per ton of the product. Unloading of dust fractions at the place of formation (caustification) there is obtained the final product of desired quality of overburn and is prevented its mixing with the raw material dust particles. Using the ITA profile in the suction zone will lead to decline in the flue gas

velocity below abduction velocity. The furnace input and output designed by a new concept of continuous self- regulating charging and by a new concept of continuous sinter collection will ensure a perfect hydraulic seal of the furnace top, remove the need of charging control system and failures arose from this control system and continuous product collecting. This has a positive impact on the continuity of the material flow in the furnace and the creation of conglomerates. Technological parameters of the proposed furnace obtained by simulations are shown in Tab. 1.

Tab. 1 Comparison of technological parameters of the reference and the proposed shaft furnace

Title	**Existing shaft furnace**	**New shaft furnace**	**Units**
Furnace cross section	3,14	3,14	m^2
Working height of the furnace	12	12	M
Power consumption of natural gas	360	360	m^3/h
Specific output of cross section	0,76	1,02	t/m^2
Specific consumption	150	113	m^3/t
Sinter temperature OUT	700	50	°C
Sinter weight	2400	3200	kg/h
Flue gas temperature OUT	200	140	°C
Flue gas volume	7000	7150	Nm^3/h

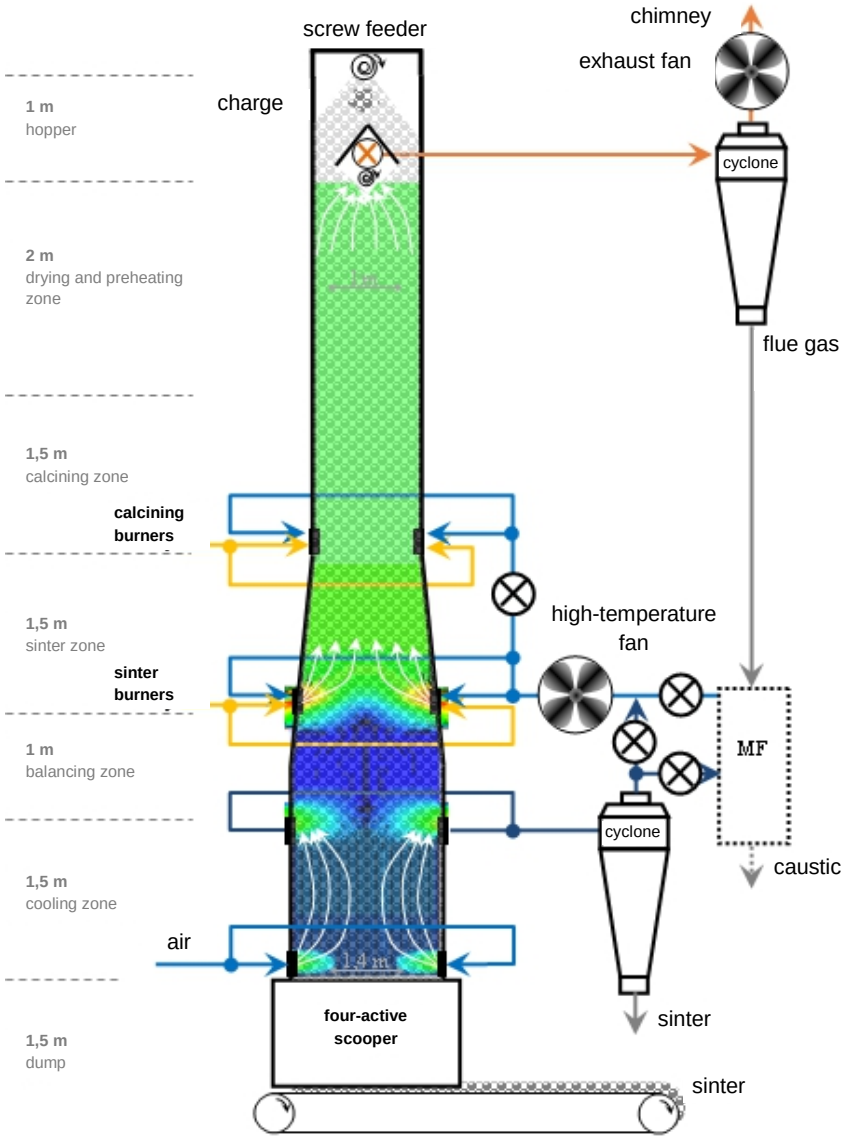


Fig. 6 Scheme of innovated shaft furnace

Conclusion:

In the article there have been presented the shaft furnaces current state and development capabilities in order to produce a magnesite sinter via technical and operational measures. The shaft furnaces innovation has been aimed at the existing and new shaft furnace development. Proposed technical and operational measures can significantly contribute to the improving their operation. The technical measures are aimed at improving the current shaft furnaces possibilities and the new shaft furnace design. An operational

optimization will be provided by the control system in a real time according to the selected criteria optimality.

An economic optimization is a means to increase the process economic indexes that underpin an economic efficiency of the company as a whole. It should influence the process operation in such a way that the production process should be control by one single index online - cost ratio per 1 tone of magnesite sinter continuously or at current production cycle or for a certain period of time. The new shaft furnace proposal for magnesite treatment of granularity 20 - 40 mm has undergone several stages of development. A key issue is to ensure the necessary permeability of the charge by reduction in dust. The proposed alternative solutions will be verified by simulations and pilot plant.

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