Shaft Furnace Sintering Temperature Homogenization by the Coke Charging

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ABSTRACT: In terms of specific energy consumption, heat treatment of magnesite in shaft furnaces is a very difficult process allowing reaches the desired characteristics of processed magnesite substances only in increased energy consumption. The main reason is nonuniformity of sintering temperatures in the cross section of the shaft furnace. The lowest sintering temperature is achieved in the centre of the furnace. The reason is that no fuel is directly given to the middle of the furnace due to potential flow and transfer of heat from the surrounding layers is very limited. The new concept is based on the use of coke charged to the central part of the furnace. The considerable balancing of the maximum temperature is reached by combustion of coke by secondary air passing through the central part of the furnace. The results of experiments confirmed the possibility of using coke, achieving a substantial improvement in the shaft furnace work.
KEYWORD: shaft furnace; magnesite; sintering; calcinations; coke; clinker

1 INTRODUCTION

The raw magnesite reached in SMZ, a.s. Jelsava is used to produce sintered magnesia or caustic magnesite, i.e. magnesium oxide – periclase with iron oxide, calcium oxide and silicon oxide, contained in the relevant mineral forms (Košinár 2011). The basic products of processing magnesite of all manufacturing companies are:

- sintered (dead-burnt) magnesia,
- caustic calcined magnesia,
- partially calcined magnesite (Koštial 2012)

Refractory magnesia products are applied in the production and processing of metals, especially steel, such as furnace linings and containers used for operating iron slags at high temperatures. Magnesite ($MgCO_3$) is decomposed into MgO and CO_2 by heat treatment at temperature of 399 ℃. Magnesite begins to be unstable from temperature of about 250 ℃ for the presence of CO_2 in the atmosphere. For $CaCO_3$ are responsible temperatures 883/537 ℃. Both processes are endothermic (Repiský & Vikorová 2008).

$$MgCO_3(s) = MgO(s) + CO_2(g) \quad \Delta H = 121{,}0\ kJ.mol^{-1}\ (298\ K)\ \ 93{,}9\ kJ.mol^{-1}\ (893\ K) \qquad (1)$$

$$CaCO_3(s) = CaO(s) + CO_2(g) \quad \Delta H = 178{,}4\ kJ.mol^{-1}\ (298\ K)\ \ 166{,}0\ kJ.mol^{-1}\ (1173\ K) \qquad (2)$$

1.1 *Shaft furnace*

Crucial aggregates for the production of sintered and caustic magnesia for the company SMZ, a.s. Jelšava are rotary and shaft furnaces. Burden of the shaft furnaces consists of raw material with 40 to 150 mm grain size and concentrates with grain size from 40 to 100 mm charged in a ratio of 67 %: 33 %. In terms of chemical composition, quality standard of two basic types of burden for the shaft furnaces is given in Table 1 (Košinár 2011).

Table 1. Charge parameters for shaft furnaces.

	min. %	max. %		
SF charge	**MgO**	**CaO**	**Fe_2O_3**	**SiO_2**
S 40 –150 mm	42	3	3,8	0,5
K1 40 – 100 mm	43,5	2,4	3,9	0,4

Shaft furnace as countercurrent thermal aggregate is technically divided into 4 zones:

- drying and preheater– 2 - 3 m – burden heating to 350-600 ℃,
- decarbonization – high 2 – 4 m, at material temperature 600 – 1200 ℃,
- sintering – high 2 – 3 m, periclase formation and sintering at temperature 1500 - 1700 ℃,
- cooling – high 4 – 6 m – stabilization of the structure of fired clinker and its cooling by air to temperature of 700-800 ℃ (Koštial & Benčo 2012, Varga 1999).

Processing of raw magnesite in the shaft furnace consists of four basic operations technological:

- drying,
- calcination or decarbonization,
- sintering,
- cooling.

A major problem of the current shaft furnaces at magnesite thermal treatment is temperatures inhomogeneity in cross section of the furnace. Course of maximum temperature in radius of shaft furnace is shown in Figure 1.

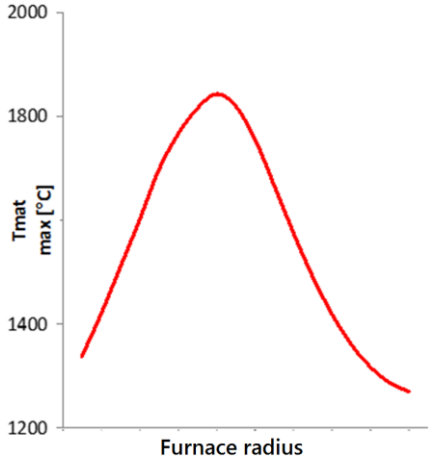

Figure 1. Course of maximum temperature in radius of shaft furnace.

The maximum of the course of temperature in radius of workspace of the furnace is close to the working lining and the minimum is in the centre of shaft furnace (thermal field inhomogeneity in the cross section of the furnace).

The furnace with power of 2.5 t/h for calcination of magnesite is shown in Figure 2.

Figure 2. Shaft furnace for magnesite firing - a general view and detail of the furnace.

Shaft furnace consists of a steel shell of thickness 20 - 30 mm that surrounds the refractory lining. At the bottom of the furnace is placed Gruber grade. Heat generation is provided by 6 burners which are shifted by 60 °. At a distance of 1000 mm below the bottom burners are three sampling openings forming angles of 120 ℃. The furnace has a telescopic hopper on its top through which the charging is provided. Between the bell and the furnace shell is the area without lining, from which flue gases are exhausted. The furnace is closed by top furnace. The flue gases are exhausted from the furnace space to the cyclone separators by pull fan or to the JET filter by own pull fan.

2 CHARGING OF CALCINED ANTHRACITE

The solution regarding a reduction in the size of the difference between T_{max} and T_{min} is carried out by supplying of an appropriate technological fuel to the axis of the shaft furnace. It is necessary to provide sufficient supply of combustion air and burning in height suitable for the settlement of the temperature profile in the sintering furnace space.

2.1 *Theoretical basis*

It is clear that the uniformity of the sintering quality of the charged material depends on the uniformity of temperature in the cross section of the sintering zone. Combustion of natural gas to the all volume of shaft furnace is complicated process due to weaker intersection of technological fuel of the burden as well as worst conditions for the good contact or due to mixing of combustion natural gas and oxygen contained in the primary or secondary air. Increasing the minimum value of the temperature in the middle of shaft furnace is possible to carry out by additional supplying and combustion of suitable technological fuel in the axis of the shaft furnace workspace. The fuel and the creation of such conditions used for burning in the shaft furnace sintering section are an important condition for the success of this solution.

2.2 *Technical solution*

Calcined anthracite of the appropriate grain size composition is considered as an appropriate additional fuel to ensure an increase in T_{min} in the shaft furnace axis in the sintering zone area.

Description of the used calcined anthracite is given in Table 2.

Table 2. Change of supplied heat

Content of C	min. 93,5 %
Ash content	max. 5,0 %
H_2O content	max. 0,5 %
sulfur content	max. 0,8 %
Combustible volatile content	max. 0,7 %
Grain	12-30 mm

Charging was implemented by method shown in Figure 3, 4.

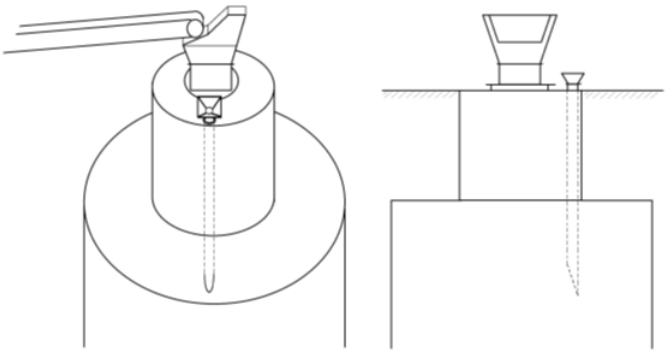

Figure 3. Schematic depiction of the method of additional fuel dosing.

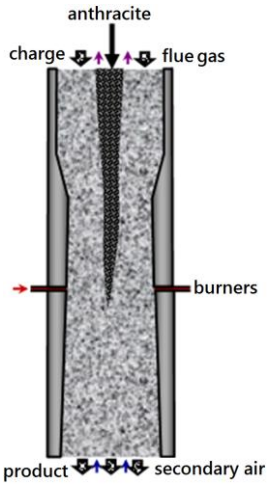

Figure 4. Shaft furnace charging scheme.

An important prerequisite for obtaining the required T_{min} in central of shaft furnace was to ensure supply of a fixed quantity of calcined anthracite. Movement of anthracite was verified on physical 2D model (see Figure 7). Required diameter of a charging pipe was calculated based on the rate of charge movement in the upper part of furnace and on the calcined anthracite density.

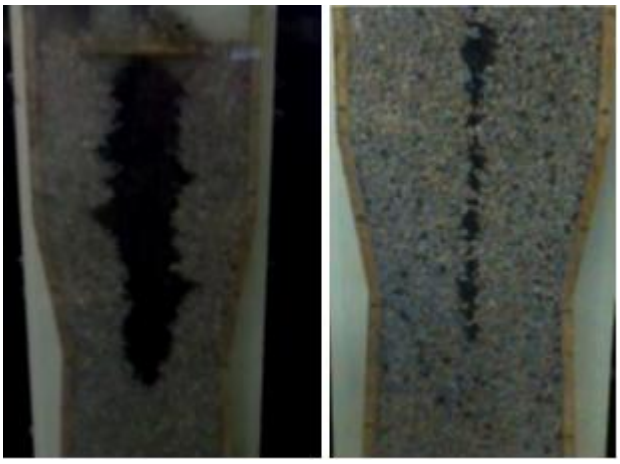

Figure 5. Physical 2D model of shaft furnace.

Calculations were provided considering refund of 20 % amount of natural gas by anthracite. Supplied heat change over use of natural gas by anthracite combustion in presented in Table 3.

Table 3. Supplied heat change

Volume of natural gas	360	m^3/h
Calorific value of natural gas	34	MJ/m^3
Supplied heat by natural gas	12,24	GJ/h
Volume of anthracite	83,3	kg/h
Calorific value of anthracite	26	MJ/kg
Supplied heat by anthracite combustion	2,17	GJ/h
Supplied heat increase	**17,7**	**%**
Amount of burned air by anthracite combustion	739,8	m^3/h

2.3 *Mathematical simulation*

Selected alternatives of anthracite charging using mathematical model (Koštial 2013) based on elementary balances method were validated by simulation. Results of simulations are presented on the Figure 6 - 8.

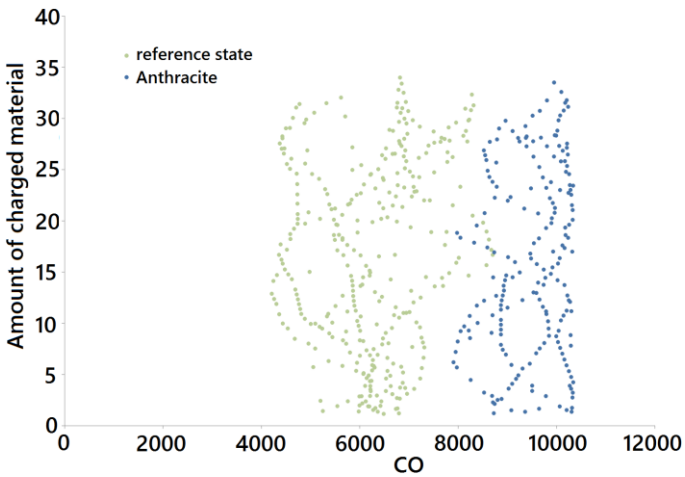

Figure 6. CO ratio change over the charged material.

Change of CO amount at reference state and during charging of anthracite is presented on the Figure 7. As one can see there is a slight increase of CO in the flue gas which indicates worse use of supplied heat however this does not exclude increase f temperature field homogeneity in the furnace cross section.

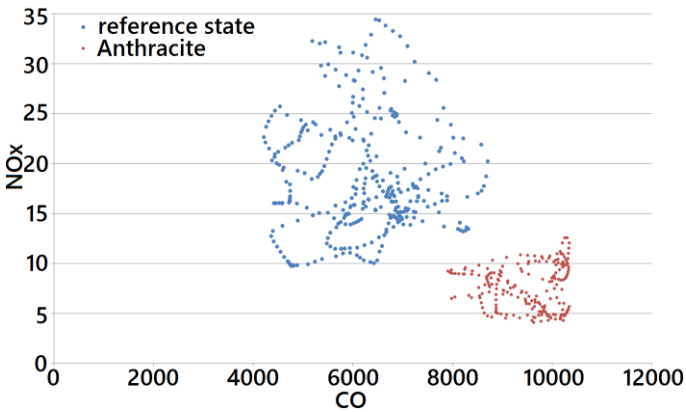

Figure 7. Ratio change of NO_x and CO.

Reduction of NO_x in the flue gas is explained by the extreme decrease of the maximum temperature

in the furnace (which evolves a greater volume of NO_x), and by the unused secondary air decreasing.

Movement of anthracite charging was verified on a physical model at scale 1:10 (Figure 5). The selected variants of anthracite use as a required supplemental fuel have been simulated using mathematical model. The results are shown in the Table 4 and in Figure 8.

Table 4. Mathematical simulation data.

Alternative		**1**	**2**	**3**	**4**	**5**
Product [kg/h]		4750	4750	5000	5000	4750
Batch	**Anthracite [%]**	3	3	3	5	4
	Magnesite [kg/h]	6790	6790	7275	7125	6720
	Anthracite [kg/h]	210	290	225	375	280
Natural [m^3/h]		330	360	360	360	360
Primary air [m^3/h]		3400	3700	3700	3700	3700

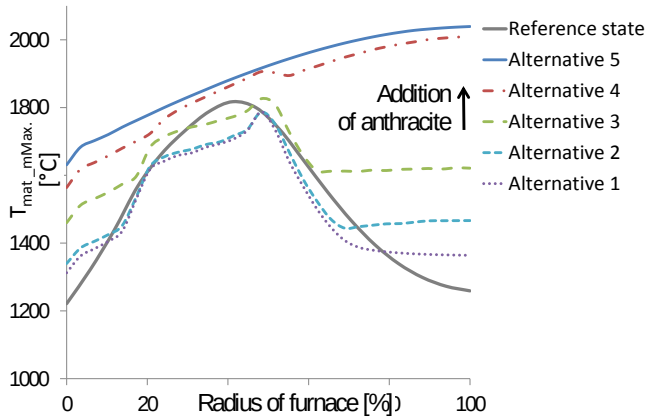

Figure 8. Anthracite combustion influence on temperature homogeneity over shaft furnace cross section.

3 CONCLUSION

This technical solution solves serious problem of temperature inhomogeneity over the furnace cross section resulting in negative impact on quality of produced clinker and need for sintering time extension of produced clinker. Combustion of anthracite in central of shaft furnace enables to use large amount of freely passing secondary air. This will limit the total, yet practically 100 % overage of secondary air in the shaft furnace, thereby avoiding the energy losses in the heating and heat from fuel combustion technology could be used for sintered magnesia production.

4 ACKNOWLEDGEMENTS

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