Š. VILAMOVÁ, P. BESTA, R. KOZEL, M. PIECHA, M. VANĚK, A. SAMOLEJOVÁ, K. JANOVSKÁ, M. ČECH

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INCREASING THE EFFICIENCY OF PRODUCTION OF IRON BY MEANS OF REDUCTION OF HARMFUL ELEMENTS

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Sintering process is a summary of physical, thermal, and physical-chemical processes taking place simultaneously in a given time interval, but in particular order within a time sequence. The input raw materials of the sintering process include a number of negative elements, which can later affect the course of the blast furnace process. The key point is to monitor the amount of these raw materials and purposefully try to reduce their amount. The article deals with the content analysis of selected harmful substances entering the sintering process in order to reduce their amount that later continues into the blast furnace process.

Key words: blast furnace, iron, sintering, costs, efficiency

INTRODUCTION

The sintering process produces the key intermediate product which enters the blast furnace process afterwards. The quality of the produced sinter can significantly affect the efficiency of the blast furnace process [1]. The sintering process can be described as a continuous process, which can use fine grain materials to produce lump sinter suitable for the production of pig iron in blast furnace [2].

In principle, the production of sinter is a process of heating of pre-prepared and suitably selected sintering charge to such a temperature that ensures the mutual consolidation of the individual components of the charge - grains to form sintered porous mass - sinter [3]. The produced sinter can then be assessed in terms of its physical and chemical properties. The key properties include the content of negative elements. It is especially the content of sulphur, lead, cadmium, zinc, and a group of alkaline carbonates [4]. Undesirable elements that are present in iron ore materials and that enter the sinter production process, however, do not behave the same way. The methods of their potential elimination through the sintering process are vastly different as well.

Š. Vilamová, Faculty of Mining and Geology, VŠB–Technical University of Ostrava, Czech Republic
P. Besta, Faculty of Metallurgy and Materials Engineering, VŠB–Technical University of Ostrava, Czech Republic
R. Kozel, Faculty of Mining and Geology, VŠB–Technical University of Ostrava, Czech Republic
M. Piecha, Ministry of Industry and Trade Czech Republic
M. Vaněk, Faculty of Mining and Geology, VŠB–Technical University of Ostrava, Czech Republic
A. Samolejová, Faculty of Metallurgy and Materials Engineering, VŠB–Technical University of Ostrava, Czech Republic
K. Janovská, Business School Ostrava plc., Czech Republic
M. Čech, Faculty of Metallurgy and Materials Engineering, VŠB–Technical University of Ostrava, Czech Republic

The main objective of the article is to analyze the amount of Zn and K_2O entering the sintering process and subsequently transferring into the final sinter. At the same time, it will analyze the main factors influencing the reduction of these negative elements through the sintering process. The data used in this process are the results of a measurement of the monitored sintering plant, which was performed throughout the period of one year.

INPUT RAW MATERIALS AND THE COURSE OF THE SINTERING PROCESS

The charge materials used for the sintering process include natural fine or very fine ores, ore concentrates, various recyclable metallurgical products, especially steel slag, sludge containing iron, and mill scale [5, 6]. In addition to these components, there are also other materials added to achieve the desired composition of slag in the blast furnace, including fluxes, such as limestone, dolomitic limestone, and lime.

Coke with the grain size of 0 mm to 3 mm [7, 8] (coke dust), anthracite and exceptionally different types of bituminous coals with low ash and volatile combustibles content are used as fuel. A specific feature of the sintering process is the fact that at each moment, the fuel burns only in a narrow part of the layer. According to the share of burnt carbon, the combustion zone gradually moves downwards. At any point, there is final sinter above this combustion zone, which is blown through by air cooling the sinter, which preheats it, and the heat is used in the fuel combustion zone. The combustion products pass their heat to the cold raw mixture, which is below the combustion zone, and heat it. The mixture is heated up relatively quickly in the contact point with

Table 1 **The content of harmful substances in input raw materials for sintering**

Sintering input raw materials	Weight	Quantity	Zn		K_2O	
	/ t	/ kg·kg^{-1}	/ %	/ kg·kg^{-1}	/ %	/ kg·kg^{-1}
Return sinter	1 240	0,0008	0,009	7,61·10^{-8}	0,063	5,07·10^{-7}
CaO sinter	258	0,0002	0,082	1,44·10^{-7}	0,061	1,05·10^{-7}
Residual sinter	1 590	0,0010	0,062	6,72·10^{-7}	0,090	9,76·10^{-7}
Slag concentrate	24 985	0,0170	0,039	6,65·10^{-6}	0,070	1,19·10^{-5}
Steel slag	690	0,0004	0,004	1,83·10^{-8}	0,042	1,88·10^{-7}
Ore mixture	8 450	0,0057	0,032	1,84·10^{-6}	0,350	2,01·10^{-5}
Blast furnace sludge	8 960	0,0061	0,480	2,93·10^{-5}	0,191	1,16·10^{-5}
Blast furnace sludge - fine	5 960	0,0040	0,005	2,03·10^{-7}	0,160	6,50·10^{-6}
Sinter – fine	42 300	0,0288	0,009	2,59·10^{-6}	0,080	2,31·10^{-5}
Scale	28 690	0,0195	0,009	1,76·10^{-6}	0,020	3,91·10^{-6}
Fe ore – Záporoží	680 962	0,4648	0,005	2,32·10^{-5}	0,050	2,32·10^{-4}
Jugok concentrate	509 369	0,3477	0,004	1,39·10^{-5}	0,020	6,95·10^{-5}
Cegok concentrate	115 745	0,0790	0,002	1,58·10^{-6}	0,050	3,95·10^{-5}
Dolomite	119 680	0,0816	0,001	8,16·10^{-7}	0	0
Lime	6 982	0,0047	0	0	0	0
Limestone	115 600	0,0789	0,002	1,57·10^{-6}	0	0
Coke	72 400	0,0494	0,002	9,88·10^{-7}	0,142	7,01·10^{-5}
Coal – ground	48	3,21·10^{-5}	0,001	3,27·10^{-10}	0,159	5,21·10^{-8}
Total raw materials	1 743 909					

the combustion zone, it loses freely bound and then also crystalline water [9].

The zone of intense heating of the mixture is the point where the physical and chemical processes of decomposition of carbonates and hydrates take place, and iron is oxidized or reduced. Although the sintering process takes place with excessive amount of air, reducing atmosphere prevails in micro-volumes with burning fuel particles. The charge is melted and passes through liquid and plastic state, thanks to the fuel content. Once the fuel has been used up, the high temperature zone moves downwards and the melt is cooled by the flowing air. The final sinter is actually a result of melt crystallization. Blast furnaces process sinter of suitable grain sizes exceeding 5 mm. Material below this grain fineness is returned back to the charge as return material. All relevant input raw materials then contain different amounts of Zn and K_2O. These negative elements can enter the blast furnace process through the final sinter.

EXPERIMENTAL PART

The content of zinc and K_2O in the input raw materials and output products was monitored during one year within the scope of the sintering process.

These harmful substances were chosen as typical substances for the area of metals and alkaline carbonates, which negatively affect the course of the following blast furnace process. The actual measured values of the contents of these harmful substances are presented in Table 1.

Table 1 shows the total amount of the individual input raw materials and their amount calculated per kilogram of produced sinter. The content of the monitored negative elements is presented in / % and it is determined per kilogram of input raw material. These data were used as the basis to determine the total amount of the individual harmful substances. Table 2 shows the share of the individual input raw materials on the total amount of negative elements entering the sintering process.

Table 2 **Relative share of negative elements in the input raw materials**

Input raw materials	Zn	K_2O
	/ %	/ %
Return sinter	0,09	0,10
CaO sinter	0,17	0,02
Residual sinter	0,79	0,20
Slag concentrate	7,78	2,43
Steel slag	0,02	0,04
Ore mixture	2,16	4,11
Blast furnace sludge	34,36	2,37
Blast furnace sludge fine	0,24	1,33
Sinter – fine	3,04	4,71
Scale	2,06	0,80
Fe ore – Záporoží	27,20	47,36
Jugok concentrate	16,28	14,17
Cegok concentrate	1,85	8,05
Dolomite	0,96	0
Lime	0	0
Limestone	1,85	0
Coke	1,16	14,30
Coal – ground	0	0,01

Based on the measured data, it was found that the largest volume of zinc, which enters into the sintering process, comes from blast furnace sludge (34,36 %) and the used iron ore 27,20 %. The tertiary source is represented by the used Jugok ore concentrate (16,28 %).

In the case of K_2O, the largest volume entering the sintering process is contained in the used iron ore (47,36 %). Other major sources include coke (14,30 %)

and ore concentrate Jugok (14,17 %). The essential element here, however, is the amount of K_2O entering the sintering process through the ore, which accounts for almost half of the total amount.

The same way was used to monitor and evaluate the content of harmful substances in the output products of sintering. Exact data are presented in Table 3. The evaluation does not include the data on the amount of harmful substances contained in the form of outgoing gases and gases emitting into the atmosphere due to the lack of adequate measurement technology. All the obtained information was subsequently converted into kilogram of produced sinter or into kilogram of output product (in the case of monitored negative elements).

The total amount of negative elements and their partial share in the individual components was determined again, just like in case of the input materials. The values of the relative share of the negative elements contained in the output products are shown in Table 4. In case of zinc, most of its quantity is concentrated in the produced sinter (90,24 %). In case of K_2O alkali, the amount contained in the produced sinter is 55,66 % and in case of dust removal, it is 40,27 %. It is necessary to take into account the number of production specifics of the monitored harmful substances, but, above all, it is necessary to apply different tools to minimize them.

RESULTS AND DISCUSSIONS

Blast furnace sludge and the used ore represent significant identified sources of zinc. These two input raw materials bring 61,56 % of the total amount of zinc into the sintering process. The use of blast furnace sludge is therefore highly problematic. It is essentially a waste material that contains large amounts of iron. At the same time, however, it concentrates high levels of harmful substances. The processing of these wastes by means of sintering is therefore highly questionable.

A cheap source of rich metal-bearing charge brings high levels of harmful substances that impair the technological parameters of not only sintering, but also the blast furnace process.

The dominant source in the case of alkaline carbonates is the used iron ore again. Almost half of the total volume of this compound enters the process through

Table 3 **Amount of harmful substances contained in the output products**

Sintering output products	Weight	Quantity	Zn		K_2O	
	/ t	/ kg·kg^{-1}	/ %	/ kg·kg^{-1}	/ %	/ kg·kg^{-1}
Produced sinter	1 464 883	1	0,007	$7{,}01 \cdot 10^{-5}$	0,051	$5{,}01 \cdot 10^{-4}$
Dust removal	9 850	0,067	0,031	$2{,}08 \cdot 10^{-6}$	5,380	$3{,}61 \cdot 10^{-4}$
Fine sinter	89 250	0,0609	0,009	$5{,}48 \cdot 10^{-6}$	0,062	$3{,}65 \cdot 10^{-5}$
Total products	1 563 983					

Table 4 **Relative share of negative elements in the output raw materials**

Sintering output products	Zn	K_2O
	/ %	/ %
Produced sinter	90,24	55,66
Dust removal	2,69	40,27
Fine sinter	7,07	4,07

iron ore. As far as the output products are concerned, zinc is mainly concentrated in the produced sinter, which contains 90,24 % of its total volume. According to the performed chemical analyses, its content in the produced sinter is 0,007 %, which can be regarded as an average value. A natural effort is to reduce the content of this metal to a minimum.

Zinc has very negative effect in blast furnace, where it has particularly negative impact on the life of the lining. A cycle of this element occurs within the scope of the blast furnace. Zinc is transformed into gaseous form at the bottom of the furnace, and it goes to the upper and cooler parts of the furnace. It is deposited here in the colder parts of the lining and then causes its continuous degradation. It is possible to remove zinc during the sintering process by increasing the volume of fuel. This has been experimentally confirmed within the frame of the conducted research. The amount of fuel was increased during the selected production campaigns. A significant reduction in zinc content in the produced sinter was achieved only with relatively high shares of fuel (30-35 %). Higher amount of fuel creates favourable reduction conditions for the removal of zinc, but it is very inconvenient, for example, for the reduction of sulphur. This would not be so critical, given the fact that most of the sulphur will be removed in the form of slag in case of an effective blast furnace process. The key shortcoming of this solution, however, lies primarily in significantly higher costs given by the required higher amount of fuel. A possible solution would be the addition of NaCl to the sintered mixture. If we keep adequate gas-dynamic conditions, it is possible to remove up to 60 % of zinc using this method. This form will vaporize zinc, but it is necessary to ensure quality exhaust and removal and purification of the flue gases. Leakage of zinc vapour into the atmosphere can naturally have very negative consequences for the environment. In the case of alkaline carbonates, it is particularly necessary to monitor their content in the input raw materials and to use high quality raw material sources. The conducted research has identified a significant amount of these harmful substances allocated in the used (Ukrainian) ore. The removal of alkali from the sintering process is possible through changes in alkalinity of the sintering mixture. Increasing alkalinity goes hand in hand with substantial decrease of alkali content in the produced sinter. This solution is convenient also with regard to the fact that the used ore is rather acidic from the viewpoint of alkalinity. This means higher demands regarding the amount of basic additives. Their further increase, however, will again be reflected in the form of cost of sinter and, subsequently, the cost of the produced metal. Increasing sinter basicity may also be combined with other procedures, such as additives based on chlorides.

CONCLUSIONS

The removal of harmful substances from the blast furnace process is possible, either by minimizing their amounts in the input raw materials, or by using adequate technological means. In case of alkaline metals, everything takes place in the form of removal by means of slag. In case of minimizing the amount of harmful substances entering the blast furnace process, it is especially necessary to optimize the process of sinter production. It is possible to remove harmful substances by increasing the amount of fuel, or by using other additives. Everything is, however, associated with the cost of these measures again. The basic aim of all metallurgical companies should be to monitor the amount of harmful substances in the input raw materials and to choose resources adequate from this perspective. In terms of quality, the use of high quality Brazilian ores seems to be ideal, but it is, of course, very difficult given the current costs of their transportation. The reduction of the content of negative elements in the blast furnace raw materials therefore does not involve only the technological sphere, but also the economical one [10]. In order to make the metallurgical companies competitive, it is necessary to take into account all relevant factors based on the specific conditions.

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