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Obtaining sponge iron in a rotary shaft furnace using Inmetco technology with combined sintering and metallisation processes

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Отримання губчастого заліза в обертовій шахтній печі за технологією Inmetco з комбінованими процесами спікання та металізації

Анотація. *З численних процесів без коксової металургії, виробництво губчастого заліза зараз досягло свого найбільшого промислового розвитку. Причиною цього розвитку стала можливість організувати виробництво високоякісного металу за такою схемою: технологія переробки дрібнодисперсних відходів доменного та сталеплавильного виробництва в рудно-вугільні композитні котуни, їх кальцинація та металізація на кільцевій камері ПВП; використання цієї технології в процесах INMETCO, FastMet та DRYIron. У цій статті обґрунтовано умови отримання губчастого заліза в ПВП-печі (роторній подовій печі). Метою цієї роботи є експериментальне дослідження процесу отримання губчастого заліза шляхом поєднання спікання та металізації рудно-вугільних композитних котунів у роторній подовій печі. Методи дослідження: хімічний аналіз отриманих котунів, визначення загального та металевого заліза, залишкового вуглецю, шлакоутворюючих компонентів. Матеріальний та тепловий баланс процесу металізації, розрахунок питомої витрати енергії та визначення втрат тепла по зонах печі.*
Ключові слова: *дрібнодисперсні відходи, рудно-вугільні композити, піч ПВП, губчасте залізо.*

Abstract. *Of the numerous processes without coke metallurgy, sponge iron production has now reached its greatest industrial development. The reason for this development was the possibility to organise the production of high-quality metal according to the following scheme: technology for processing finely dispersed waste from blast furnace and steelmaking production into ore-coal composite pellets, their calcination and metallisation on a PVP ring chamber calciner; use of this technology in the INMETCO, FastMet, and DRYIron processes. This article substantiates the conditions for obtaining sponge iron in a PVP furnace (rotary hearth furnace). The aim of this work is to experimentally study the process of obtaining sponge iron by combining sintering and metallisation of ore-coal composite pellets in a rotary hearth furnace. Research methods: chemical analysis of the obtained pellets, determination of total and metallic iron, residual carbon, slag-forming components. Material and heat balance of the metallisation process, calculation of specific energy consumption and determination of heat losses by furnace zones.*
Keywords: *finely dispersed waste, ore-coal composites, PVP furnace, sponge iron.*

1. Introduction

The blast furnace (BF) continues to be the main reactor for the production of iron due to its high productivity and thermal efficiency. However, it requires a minimum amount of coke and a high-quality iron ore charge. The presence of coking coal, coke plant, sintering plant is mandatory, which is a major problem in terms of cost and environmental pollution [1,2]. The total CO2 emission from the blast furnace is about 2 tons of CO2/ton of hot metal. Another important aspect is the use of fines generated during the mining/enrichment of iron ore and coal. All these factors have led to the development of alternative routes for the production of iron. Rotary hearth furnace (RHF) processes are one such category of alternative routes for the production of iron that has recently attracted significant attention [3-6].

Presently, most of the iron is produced through blastfurnace route, which requires metallurgical coke. Thedepletion of coking coal reserves and growing environ-mental concerns have motivated researchers to search forcoke-free iron ore reduction processes leading to alterna-tive routes of iron making. One class of methods is directedat the production of iron nuggets/sponge using iron orefines and non-coking coal fines in the form of pellets. Thesponge/nuggets are then smelted separately. The otherclass of methods directly produces molten iron. Severalvariants of RHF technologies aimed at sponge/nuggetsproduction have evolved such as Inmetco, Fastmet,Fastmelt, and ITmk3. It is claimed that these processesreduce CO2emission, although specific data on cases arelacking.RHF process is a coal-based direct reduction processthat uses iron ore fines and non-coking coal fines toproduce premium-quality sponge iron or iron nuggets

The globalisation of the world economy has had a major impact on the ferrous metallurgy industry and continues to influence this sector. This industry is undergoing significant structural transformation. During the 1990s and 2000s, these changes were characterised by the development of new concepts in steel production (e.g. mini-electric steelworks, new concepts for electric arc furnaces, new casting technologies and direct reduction or recovery smelting technologies).

For the first time on an industrial scale, INMETCO introduced a new continuous metallisation process [2] for RHF iron ore pellets. The basics of the RHF rotary hearth furnace process are well known: raw pellets are obtained from a charge consisting of iron-bearing pellets and carbon in appropriate proportions for their metallisation [2-5].

A distinctive feature of the process is the loading of a thin layer of pellets onto the furnace floor, which are heated by radiation from a high-temperature torch burning directly above the layer. This ensures that the pellets are heated and almost completely restored within 6-8 minutes. The rotary furnace can be divided into three zones. In the first zone, the pellets are heated to 980-1000°C for 1.5-2.0 minutes by burning the volatiles released from the coal. In the second zone, at 1150°C, a noticeable reduction reaction takes place. The furnace atmosphere in this zone is oxidising with respect to iron, but the carbon monoxide released from the pellets protects the reduced iron from oxidation. In the third zone, at 1250-1320°C, the reduction is completed. The atmosphere in this zone corresponds to the equilibrium for the Fe-FeO system. At high temperatures, the reduced iron particles sinter, which leads to volumetric shrinkage of the pellets and their compaction.

The heat for reduction in the second and third zones is released during the combustion of CO. In addition, natural gas or fuel oil. The implementation of the counterflow principle of heating gas and pellets ensures full fuel utilisation. The degree of metallisation of sponge iron is over 90%. A change in the residual carbon content in the metallised product from 1.5% to 10% is an integral characteristic of this process.

Loading the metallised product with a temperature of at least 860°C into the smelting unit will significantly reduce the consumption of electricity, electrodes and refractories. The research results below can be used as initial data for designing a section for the production of metallised raw materials as part of a mini-plant [7-15].

2. Experiments in a tube furnace.

The research was conducted in two stages. The main elements of the technology were tested in the first stage in a laboratory tube furnace, and in the second stage in a semi-industrial furnace.

The following materials were used for testing in the tube furnace:

Name	Fe_{tot}	SiO_2	CaO	Al_2O_3	MgO	S
Magnetite concentrate	64,1	3,2	1,9	0,8	1,1	0,01
Bentonite	3,1	64,5	1,0	17,2	3,2	<0,1
Ash	13,5	35,7	20,1	10,2	3,3	-

Name	C	S	V	A	H_2O
Petroleum coke	94,8	2,4	4,8	0,4	11,0
Coal	48,6	0,3	37,2	14,2	5,5

The granulometric composition of raw materials and fuel was as follows:

% fraction, mm	+1,0	+0,5	0,1	0,071	-0,071
Magnetite concentrate	0	0,2	0,2	4,6	95
Petroleum coke	0	12,2	65,9	13,6	8,3
Coal with volatile content	0,2	9,3	30,2	22,8	37,5

three batches were studied, from which raw pellets were obtained and then reduced in a tube furnace.

Composition of raw pellets, %

Batch 1: 73% concentrate, 26% coal, 1% bentonite

Charge 2: 85% concentrate, 14% coal, 1% bentonite Charge 3: 80% concentrate, 9.5% coal, 9.5% petroleum coke, 1% bentonite

After high-temperature reduction, metallised pellets with the following compos

ition were obtained:

Burning		Composition of metallised pellets, %								
t^0C	τ, min	Charge	C	S	Fe_{tot}	Fe_{met}	Al_2O_3	CaO	MgO	SiO_2
1225	15,0	1	3,3	0,1	81,1	95,6	1,7	3,5	1,6	8,5
1280	10,0	1	0,98	0,1	83,0	94,0	1,7	3,6	1,6	8,4
1225	15,0	2	2,0	0,4	84,5	90,2	1,2	2,1	1,3	5,6
1225	10,0	3	1,9	0,4	83,3	96,2	1,3	2,6	1,4	6,8

The experiments showed that it's basically possible to get metallised pellets from a mix of iron ore concentrate and carbonaceous materials of different compositions, including iron-containing waste.

3. Experiments to determine the technical and economic indicators of the Inmetco process were carried out using a semi-industrial plant.

The following materials were used for these experiments: iron ore concentrate: Fetot – 68,8%; S – 0,04%; fractions – 0,071 mm - 95%; coal: C -51,3%; S – 0,83%; ash – 9,0%; volatile matter – 39,7%; in coal ash: SiO_2 -62,5%; A12O3 - 28.6%; CaO - 4.4%; MgO - 00.33%; fractions - 0.050 mm - 21.8%; +0.050 mm - 78.2%; bentonite: FeOb - 3.1%; SiO2 - 064.5%; Al2O3 - 017.2%. Raw pellets: moisture content - 10.3%; carbon content - 19.3%; pellet size - 8 - 10 mm, compressive strength - 1.4 kg/p.

The experiment lasted 9 hours, of which 4 hours were identified as having the best performance. The results of the experiment are shown in Table 1, and the material balance is shown in Table 2.

Table 2 Indicators of the metallisation process on a semi-industrial installation

Indicator name	Average for 9 hours of work	Best 4 hours of work.
Effective bed area, m2	5,723	5,723
Carbon content in raw pellets, %	19,3	19,3
Loading rate, t/hour	5,0	5,0
Temperature, °C		
Zone 1	1225	1225
Zone 2	1335	1335
Layer height, m	0,0172	0,0172
Specific productivity, t/m2hour	0,422	0,422
Chemical composition of the product, %		
Sample No. 4	92,8	93,4
Degree of metallisation, %	5,8	5,6
Residual carbon content, %		
Sample No. 5	87,8	89,1
Degree of metallisation, %	4,4	4,5
Residual carbon content, %	4,27	4,26

Table 3 Material balance of the metallisation process at a semi-industrial facility.

Indicator name	Average for 9 hours of work	Best 4 hours of work.
Zone 1		
- natural gas, m3/hour	143	139
- combustion air, m3/hour	2438	2352
Zone 2		
- natural gas, m3/hour	137	140
- coal on the burner, kg/hour	457	457
- combustion air, m3/hour	4041	4715
- air for coal transportation, m3/hour	292	292
Raw pellets	4,54	4,54
Material consumption, t/hour		
concentrate	2,994	2,994
coal	0,953	0,953
bentonite	0,018	0,018
water	0,468	0,468
Product output t/huor	2,6	2,6

Table 3 Energy consumption

Indicator name	Average for 9 hours of work		Best 4 hours of work.	
		%	$\frac{G_{кал}}{час}$	%
Natural gas:				
Zone 1	1,17	9,7	1,14	9,5
Zone 2	1,12	9,3	1,14	9,5
Coal				
Burners	3,24	27,0	3,24	27,0
Pellets	6,49	54,0	6,85	54,0
total	12,02	100,0	12,01	100,0

Table 4 Energy expenditure with and without carbon accounting

Metallised product output	0,574 т/т $_{raw\ pellet}$
Specific energy consumption	G кал
Amount of energy from carbon remaining in the product	4,62 $G_{calories}/t_{product}$
Energy consumption minus residual carbon	0,35 $G_{calories}/t_{product}$
Heat losses:	$G_{calories}/t_{product}$
with cooling water during unloading	4,27 $G_{calories}/t_{product}$/0,23
through the furnace walls	0,27
refrigerators	$8,8 \times 10^{-6}$
- with exhaust gases	1,34
-unburned components of exhaust gas	0,45

The advantages of using sponge iron in a blast furnace are reduced coke consumption (about 7% for every 10% of metallic iron in the charge) and increased productivity (about 8% for every 10% of metallic iron in the charge). The blast furnace is less demanding in terms of slag-forming content and degree of metallisation, but strict control of the content of alkalis, zinc and other impurities in the charge is necessary.

When using sponge iron in electric arc furnaces, higher requirements are imposed on it. The degree of metallisation, the amount of slag-forming substances, the sulphur content, density and strength are critical factors that determine the productivity and quality of the metal. Accordingly, good results can be achieved by using iron-containing materials with a low content of slag-forming agents, low-ash and low-sulphur coal and, as a result, sponge iron with a high degree of metallisation.

Table 5 shows the costs for the production of sponge iron using Inmetco technology for conditions in the USA.

Sponge iron produced in a rotary hearth furnace using Inmetco technology is the cheapest. Production costs for a plant with a capacity of 500,000 tonnes per year of sponge iron are approximately 60 USD per tonne.

As a rule, in order to save energy costs, rotary hearth furnaces are built at mini-plants or full-cycle metallurgical plants. The capacity of one furnace is up to 600,000 tonnes of sponge iron per year.

Table 5 Characteristics of raw materials and sponge iron for some processes

Characteristics of materials	Blast furnace Electric arc furnace Blast furnace Electric arc furnace	Blast furnace Electric arc furnace Blast furnace Electric arc furnace
Iron ore concentrate, iron ore by SiO_2 content (%)	<6	<3
Coal ash	<12	<8
Arrivals (Na_2O_3)	<3 kg/m_{Fe}	-
Arrivals of zinc	<2 kg/m_{Fe}	-
Pellet size, mm	16-22	8-14
Degree of metallisation, %	85-82	>90
Residual carbon content, %	4-7	1,5-3,0
Compressive strength, kg/pellet	>250	>200

Thus, the production of sponge iron in a rotary hearth furnace using Inmetco technology is the most efficient way to obtain high-metal pellets from finely ground concentrates and various carbonaceous reducing agents. Sponge iron produced using this technology is a source of primary metal for steelmaking.

Table 6 Costs for sponge iron production using Inmetco technology

Production costs	Units of measurement	Consumption kg/t
Raw materials:		
iron-containing	kg	1335
coal	kg	410
bentonite	kg	5
organic binder	kg	5
Total: raw materials		
Energy costs:		
electricity	kW · hour	65
natural gas	m^3	60
nitrogen	m^3	10
water	t	0,30
Other expenses		
Expenses	USD	
Repairs and spare parts	USD	

Conclusions

Thus, the production of sponge iron in a rotary hearth furnace using Inmetco technology is the most effective way to obtain high-metal pellets from finely ground concentrates and various carbonaceous reducing agents. Sponge iron produced using this technology is a source of primary metal for steelmaking in the smelting of low-carbon steels and alloys. Due to the high residual carbon content in sponge iron, there is no need to add carbon-containing materials in the production of high-carbon steels.

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