RETURN OF THE GASES OF THE MELTING PROCESS POSSIBILITY OF IMPROVING THE PERFORMANCE INDICATORS OF THE TECHNOLOGICAL PROCESS IN THE CUPOLA FURNACE

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Abstract

The research on the possibilities for the recovery of the process gas (CO) in the hearth of the cupola furnace for the production of cast iron in the "Foundry E & E" in Gjakova on Kosovo, aims to recover the heat, which would be used for preheating the air of which is blown THROUGH blowers for burning coke. Modifications to the technological scheme of the process, in this case, would include recovery of thermal energy, additional preheating of the gas, and dosing of preheated and CO-enriched air into the hearth of the coke-burning furnace. According to the data from our study program, the air recovery and heating system with a closed chimney is one of the most suitable commercial and technological solutions for improving the performance indicators of the technological process, heat preservation, and environmental protection. The research of the possibilities of return, thermal energy recovery, and air preheating for the combustion of coke in the cupola furnace in the "Foundry E&E" smelter is part of the research project "Research of the return gas (CO) through blowers in the scrap melting area in " Foundry E&E" supported by MEST of Kosovo. On the basis of the data from the chemical analysis of the charge components, the granulometric composition of the coke, and the thermal recording of the melting process, the thermal potentials of the physical and chemical heat of the process gases and the heat created by the combustion of the fuel have been identified, as well as The CO/CO2 ratio has been determined. While, according to the quantitative and qualitative methods of the charge and process products, we have determined the temperature according to the areas in the furnace and that of the exhaust gases, and based on the measurements we have proposed that the air return, recovery and preheating system for burning yogurt in cupola furnace is one of the most favorable commercial and economic options for application in the cupola furnace in the "Foundry E& E" in Gjakova on Kosovo. The system of energy recovery, preheating, and air enrichment in the oven with a closed chimney is security not only for the improvement of key performance indicators but at the same time it would enable energy saving, process control, product quality management, reduce production costs, and minimization of gas emissions in the atmosphere. Energy recovery and recirculation systems for all cupola furnaces in principle are more or less similar to each other, but systems with a closed chimney, have advantages; the return of dust to the process, the maximum recovery of the physical and chemical heat of the process gases, as well as the near-zero minimization of CO2 in the atmosphere.

Keywords: cupola furnace, gas recovery (CO), performance, controls, environment, etc.

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1. Introduction

The low level of utilization of production capacities, high level of heat losses, losses of colored metal, as well as environmental pollution at Foundry E&E in Gjakova in Kosovo, has encouraged us to research the technical-technological possibilities for the recovery of thermal energy, its utilization for preheating air for coke combustion in the furnace, as well as the recovery of process gas or its utilization for the enrichment and heating of the air blown through the tuyeres in the cupola furnace at this foundry.The cupola furnace, installed in the Foundry E&E in terms of its constructive and principle context, is similar to a small high furnace and is used for the production and processing of cast iron. The management of the E&E foundry has started making modifications to the technological scheme, where an important part of it will be two induction furnaces. After the modifications and the incorporation of the heating, recovery, and gas regeneration system into the furnace, the current cupola furnace can become part of the new scheme. In addition to the production of cast iron, it also contains elements such as austenitic iron, nickel, manganese, and in specific cases (for stabilizing the austenitic structure at room temperature), it also contains traces of copper and chromium. These elements could also be utilized in duplex processes with oxygen blow converters or electric furnaces [1, In Foundry E&E cupola furnace has a practical diameter of 60 cm and an effective height of 3.6 mm [1-4].The furnace is vertically constructed as a cylindrical structure with four legs. It has four tuyeres for air supply into the furnace where coke is burned, a charging port for loading the materials, and a connecting pipe for the conveyance of gases and fumes, giving it the appearance of a large chimney. It is lined with refractory bricks and insulated with heat-insulating materials, which serve to protect the furnace structure from thermal stresses, reduce heat losses, and enable efficient and economical melting. The charge for the cupola furnace in the Foundry E&E consists of scrap (old iron, steel, and other ferroalloys), cast iron residues from the casting process, coke, CaCO3, and ambient air. The melting process in the cupola furnace is achieved through the utilization of thermal energy released from the combustion of coke as well as the energy from exothermic reactions that occur during direct and indirect reactions. The thermal profile of the furnace consists of five zones, where the interaction of the charge components follows the counter-flow principle of solid materials, melting, and process gases. Such pyrometallurgical methods offer opportunities for high efficiency [2]. To improve the efficiency of the technological process and cast iron production, particularly in reducing emissions of greenhouse gases, dust, etc., at this stage of research, we have proposed modifications to the cupola furnace that would rely on the principle of preheating the air for coke combustion in a closed-type furnace without a chimney.

2. Materials and research methods

The process of cast iron production in the cupola furnace at Foundry E&E in Gjakova begins with the technologically controlled melting of scrap iron. Coke metallurgy is used as the fuel and reducing agent, while the commonly used flux is limestone. However, there are also cases when dolomite, calcium carbide, and fluorite are used as flux materials.

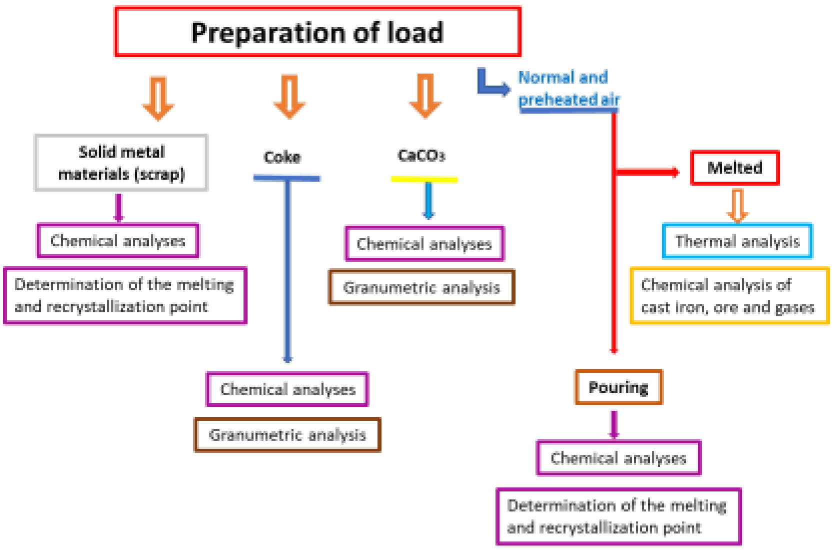

Figure 1: Materials and research methods

3. Experimental evaluations

The experimental part of the study focused on investigating the possibilities of process gas recovery in the cupola furnace, was conducted at Foundry E&E in Gjakova/Kosovo. The foundry has installed a cupola furnace with a diameter of 600 mm and an effective height of 3600 mm. The furnace is equipped with four tuyeres with non-standard opening sizes. The charging of materials is done through a top-opening charging door located at the top of the furnace's effective zone. The furnace has two channels for metal pouring and a separate channel for slag pouring. The gases, dust, and other particles are discharged into the environment without any means of purification or recirculation (Figure 2).

Figure 2. View of the cupola furnace in the Foundry E&E

The cupola furnace melting process is generally preferred due to its high heat utilization coefficient and low fuel consumption compared to other equipment. However, this applies when preheated air and/or oxygen-enriched air are used for combustion. In the case of Foundry E&E in Gjakova, normal ambient air is used for combustion instead of preheated air or oxygen-enriched air, which has resulted in unfavorable performance indicators for the furnace.According to the current approach, the average production capacity of cast iron ranges from 1600 to 2100 kg/h. The thermal energy required for the melting process is generated through direct and indirect reactions.The direct reactions occur at temperatures above 1000°C with the aid of solid carbon (C) derived from coke, resulting in the production of CO as a byproduct. In fact, solid carbon cannot diffuse into solid pieces of scrap iron, but only CO can. Therefore, the direct reaction is the result of two reactions:

$$MeO + CO \rightarrow Me + CO_2 (-\Delta H) \quad (1)$$

$$CO_2 + C \rightarrow 2CO \quad (2)$$

$$MeO + C \rightarrow Me + CO \quad (\pm\Delta H) \quad (3)$$

Direct reduction is only possible at high temperatures and during direct contact between molten FeO-slag and coke [2, 6]. Above the temperature of 1000°C, in the presence of solid carbon, CO2 is not stable and reacts with solid carbon according to the Boudouard reaction (4).

$$CO_2 + C \rightleftarrows 2CO \quad \Delta H^0 - 233790 \text{ kJ} \quad (4)$$

Reaction (4) is fully reversible in the temperature range of 300 to 1000°C, which means that both CO and CO2 can be present in the gas composition [2]. In the case of a cupola furnace with normal air combustion instead of preheated air, reaction (4), which is endothermic, begins to intensify only at temperatures above 800°C (Figure 3). As the temperature increases, the reaction rate continues to increase until reaching 1300°C, after which the rate of reaction gradually slows down The technological process in cupola furnaces generally occurs in five technological zones (fig.4). The combustion and gasification of coke mainly take place in zones V and IV. The burned coke releases the necessary energy for the production process of iron casting. Zone V, the melting zone, was quite limited in our study case, and in the upper part of the melting zone, an oxidizing atmosphere will be maintained, while in the middle, a weakly oxidizing atmosphere will be present, and at the very bottom of the melting zone, the atmosphere is non-oxidizing. Thus, in this case, the iron and slag formed in the upper part of the zone begin to cool due to heat loss through the partially refractory walls and the reaction's progress [4]. If a sufficient level of oxygen is provided to the air (in the case of combustion with non-preheated air), the oxidation of the iron will occur through the reaction (5).

$$FeO + 1/2O_2 = Fe_3O_4 + Q \quad (5)$$

Reaction (5) is not sustainable and proceeds sluggishly according to reaction (6), which is the second endothermic reaction with high heat consumption.

$$Fe_3O_4 = 3FeO - Q \quad (6)$$

The data from the study demonstrate that the technological process in the cupola furnaces of Foundry E&E in Gjakova is consistently developed, as shown in Figure 3.

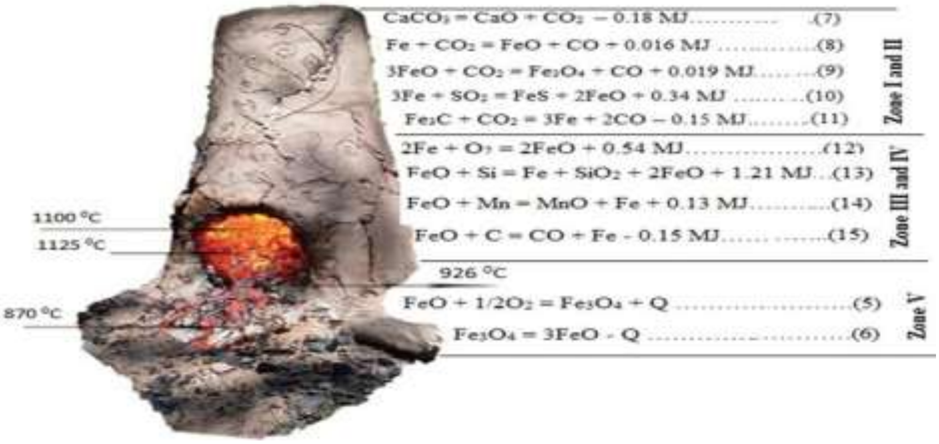

Figure 3: Experimental research in the hearth of the furnace (Zone V and IV), the zone with preprimary slag is observed and heat losses occur through the refractory wall as a result of endothermic reactions.

In the cupola furnace, initially, the pre-prepared charge is loaded, where at the bottom of the hearth up to a certain height under the tuyeres, a layer of coke is placed, the composition and size of which are given in Table 1 [8]. Its purpose is to withstand the weight of the load placed on it and provide the necessary energy for the melting of the solid components of the charge and ensure carbon fixation. It is sufficient for the development of direct and indirect reactions.

TABLE 1: Chemical composition of metallurgical coke

Composition	Cfix	H_2O (wet) max.)	Ash max.	S max.	P max.	Qd (calorific value), KJ/kg
%, weight	89.90	1-1.5	10.80	0.58	0.037	27600 - 29500

Source: foundry "E&E" Gjakova/Kosova

On top of the coke layer, a layer of flux - CaCO3, is placed, the chemical composition of which is given in Table 2[8]

TABLE 2: Chemical composition of limestone (CaCO3)

Composition	CaO	FeO	SiO_2	MgO	Al_2O_3	H_2O
%, weight	52	1	0.6	1.2	1.5	0.6

The melting process is similar to that of a small high furnace, where materials flow in the opposite direction [2, 7]. Based on the chemical composition of the charge components (tab. 1, 2, and 3) and their weight ratios, the thermal profile of the cupola furnace technological process has been developed (as shown in Figure 4).

TABLE 3:Chemical composition and tensile strength of metal materials – scrap

Type of scrap (%)	C	Si	Equal C	T sol. ^{0}C	T liq. ^{0}C	Tcas. ^{0}C	σ_mMPa

Cast iron 4.5% C, ASTM A48	3,2 –3.6	2.2 2.8	3.78	1997	1261	1304	414 - 1380
Engine block	3.1 –3.4	2.2 –2.7	3.73	1994	1205	1293	275
Steam cylinder/ cast iron	2.8 –3.1	0.9 –1.0	4.15	1997	1157	1327	277
Diesel engine head	3.0 – 3.2	0.9 – 1.2	3.67	1197	1209	1293	274
Block engine head	2.9-3.1	1.4 – 1.6	3.70	1195	1207	12901	314
Car discs	3.0- 3.6	1.8 – 2.8	3.59	1204	1302	1373	-
Scrap of radiators	3.2-3.8	1,9 – 2.3	3,52	1209	1306	1337	288
Reinforcing bars for construction concrete	1.2 -2.13	1.5 – 1.8	2.8	1227	1318	1376	223

Based on the industrial investigations of performance indicators of the cupola furnace in Foundry E&E in Gjakova (where ambient air, not preheated, is used), it is evident that the primary energy input into the furnace is derived from coke combustion. Therefore, the design of a system for oxygen enrichment and preheating of oxygen-enriched air is a crucial factor in determining all other performance indicators of the technological process and production in Foundry E&E in Gjakova. Based on theoretical and experimental studies conducted within the framework of this research project, the most suitable option for increasing production capacity and reducing costs is identified. Improving quality and environmental protection involves implementing a technological scheme based on the air preheating system in closed-chamber cupola furnaces (Fig. 5).

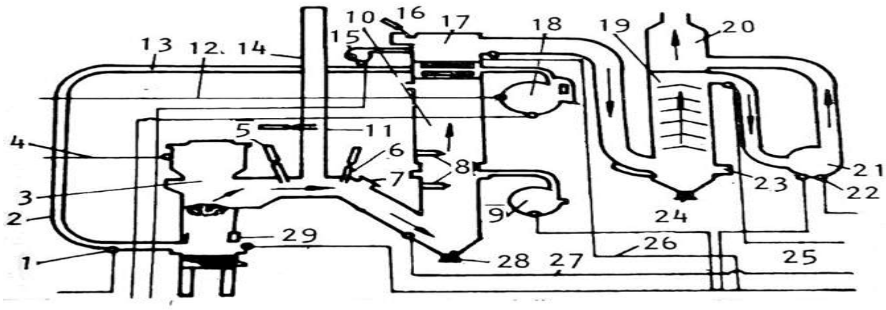

Figure 5: Closed-chamber cupola furnace with air preheating system:

Hot air temperature control point, 2. Hot air supply pipe, 3. Closed-chamber cupola furnace stack, 4. Control point, 5. Gas discharge control point for cupola furnace, 6. Pressure control point, 8. Safety valve, 9. Air fan for cupola furnace gas combustion, 10. Combustion chamber/room, 11. Flue gas damper valve, 12. Automatic air volume regulator, 13. Hot air supply pipe, 14. Reserve supply pipe, 15. Exhaust fan for recuperator heating, 16. Safety valve, 17. Recuperator, 18. Valve, 19. Wet air cleaner, 20. Combustion chamber/room, 21. Stack, 22. Regulator, 23. Vent, 24. Removal/cleaning of ashes, 25. Control point, 26. Control point, 27. Control point, 28. Removal of large particles).

TABLE 4: Chemical composition of slag for charge no. 14/V-23

Composition (%)	Fe	Ni	Cr_2O_3	MnO	CaO	MgO	Al_2O_3	SiO_2	FeO	Oth.
Samp. no.1	0.97	0.02	0.01	3.5	24.80	4.52	6.97	51.76	7.3	0.44
Samp. no.2	0.94	0.02	0.01	3.38	26.70	4.98	6.82	49.50	6.98	0.42
Samp. no.3	0,98	0.03	0,01	3.4	25.95	5.03	6.67	49.76	7.4	0.45

As a solvent, the amount of CaCO3 utilized in relation to the metallic portion of the charge varied in industrial conditions. For the 14/V-23 charge, it ranged from 3% to 6%. Additionally, the coke, with a fixed carbon concentration of 89.0%, was dosed with 10.9% of metallic components for charges numbered 14-5/23. Based on these ratios and the charge composition presented in Table 3, the product of the smelting process in the cupola furnaces at Foundry E&E is a gray iron with a chemical composition as shown in Table 5.

TABLE 5: Cast iron composition at the E&E Foundry

Elemente	**Mean**
C	3.25
Si	1.03
Mn	0.61
P	0.14
S	0.07
Cr	0.54
Ni	<0.015
Cu	0.19
Co	>0.50
Fe	92.93
CE	0

As a result of using normal (non-enriched with oxygen) and non-preheated air, the oxidizing zone V has shown a limited extent, with the lower part experiencing temperatures around 900°C. In the upper part of zone V (the upper part of the flames), the oxygen in the air is almost completely consumed due to the oxidation of the charge components. In the uppermost part, due to oxygen depletion, the oxidation of fixed carbon from coke through CO_2 (reaction 4) has occurred, known as the gasification reaction, which has a high heat consumption.

In cases where the level of oxygen supply to the flames is provided, the oxidation of zinc has occurred according to reaction (5), where the endothermic reaction ($Fe_3O_4 = 3FeO – Q$) has been stimulated due to the weak stability of Fe_3O_4. Losses of heat were observed not only due to these two endothermic reactions but also during the charging process in the charging openings/doors and through the furnace walls.. According to theoretical estimations of the process, the ratio between CO and CO_2 in the gas reduction did not exceed the level of 30% CO and 70% CO_2.

3. Conclusions with recommendations

Based on the current approach, the cupola furnace in the Foundry E&E has been characterized by low production capacity, high metal loss with slag, lower melting temperatures, high refractory wear, high heat losses, and high environmental pollution. These technological indicators, along with the low performance of the production process, have determined poor process quality and control, high production costs, and inconsistency in the production of gases and other iron-carbon connections. To improve the performance indicators of the process, the production of gases and other ferroalloys, cost reduction, and environmental protection, the option of necessary air preheating for coke combustion in the furnace hearth, as well as energy recovery, constructive optimization, and air preheating in cupola furnaces without chimneys, would be the most suitable technological and economic solutions for the case of the Foundry E&E in Gjakova.

Acknowledgements

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