ARPN Journal of Engineering and Applied Sciences

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DEVELOPMENT AND APPLICATION OF GAS CUPOLAS IN FOUNDRY PRODUCTION

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ABSTRACT

The physical-chemical study of the melting process both in cupolas and in electric furnaces has been carried out by the author. A methodology has been developed and a thermodynamic analysis of phase interaction during cast iron melting has been conducted which allowed making a comparative quantitative assessment of the influence of different factors on the processes of phase interaction. The authors have developed a method for determining the activities of the components in iron-carbon melts, being far from the diluted carbon content solutions, based not only on the consideration of the temperature dependences, but also on the concentration dependences of the interaction parameters. Technical and economic aspects of technical re-equipment of melting compartments in foundries have been analyzed.

Keywords: gas cupola, cast iron melting, electric furnace, induction furnace, crucible furnace, oxidation-reduction reactions, thermodynamic analysis, component activity, iron-carbon melts, phase interaction, mass exchange, mass transfer.

INTRODUCTION

Substitution of coke for liquid and then gas fuel in cupolas goes back to the end of the XIX century. There were Petrashevsky furnaces in Baku and then Savin furnace in 1985, also in Russia. As for foreign countries, we can name Marx, Simon and Wenner cupola [1]. After that, starting from 1961 gas cupolas in Russia [2] have been developed by the author together with A.A. Cherny and further history of the creation and licensing is connected with patents of Russian scholars [3-17].

BRIEF OVERVIEW OF THE TECHNOLOGY

Classification of furnaces for cast iron melting is given in Figure-1.

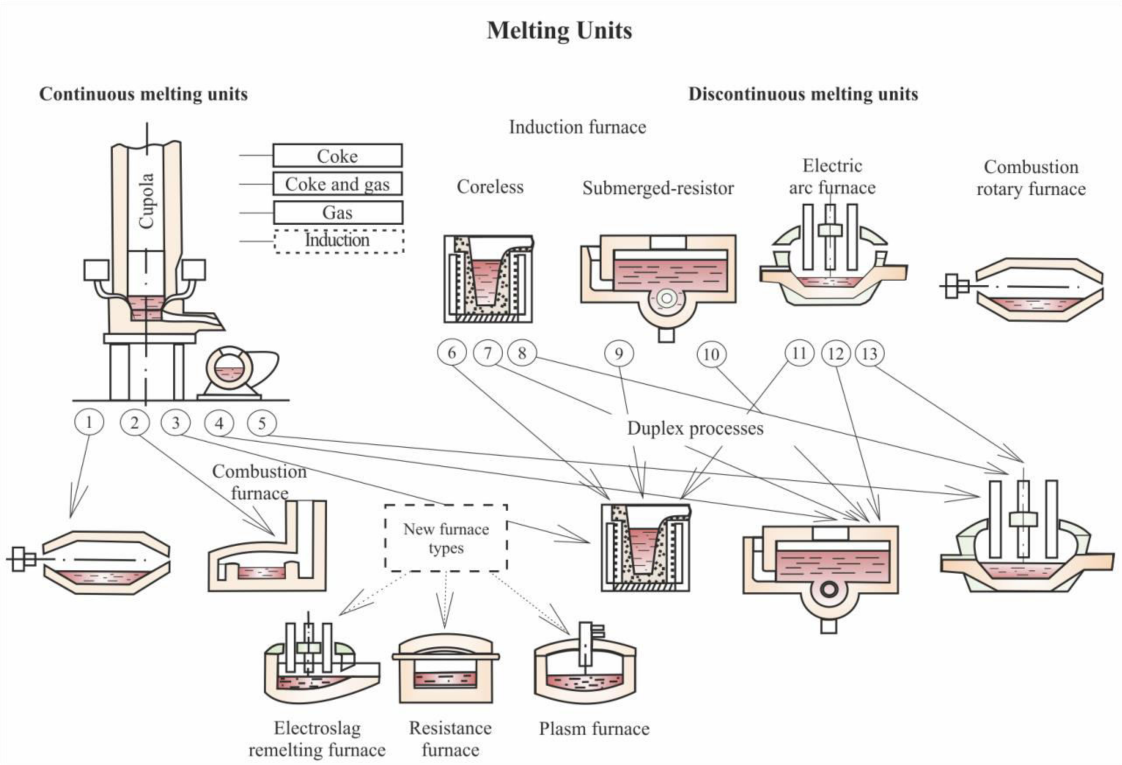

Figure-1. Classification of melting processes and equipment for cast iron melting.

The main result of technological advances is certainly the use of electric furnaces. However, exploitation costs are extremely high and in this sense cupolas slightly outperform electric furnaces. That is why cupolas are still being used both in Russia and in foreign countries. Moreover, they are becoming increasingly popular in China and India.

The most advanced process is the following: the original melt is prepared in cupolas and then cast iron is brought up to the required level of quality in an electric furnace (Figure-1). Therefore, at the Penza Compressor Factory, where the first gas furnace with a capacity of 710 t/h was produced and is still operating, electric induction furnaces are installed next to it.

DEVELOPMENT AND EXPERIENCE

Throughout the long history of the development and installation of gas cupolas, which has been done by the author for about 55 years since 1961, four types of gas cupolas have been developed and introduced (Figure-2).

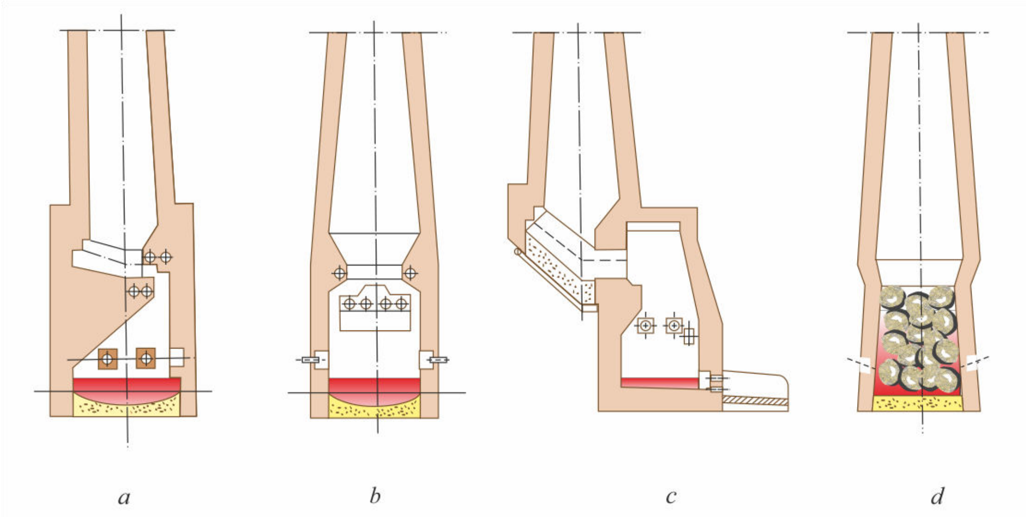

Figure-2. Gas cupolas: with ledges (a), with a plate (b), with an external camera (c),with a heterogeneous bed (d).

A physical-chemical study of the melting process both in cupolas and in electric furnaces has been carried out by the author.

The main scientific provisions that served for the author as a basis for the development of the advanced technological melting processes in gas cupolas and electric furnaces are the following:

a) Quantitative assessment of the probability of oxidation-reduction reactions leading to the formation of the content and the properties of cast iron for different phases and components in melting machines should be carried out through the analysis of the Gibbs energy change differential due to the change in different factors (ΔG°, activities, partial pressure, etc.) and the influence of melting conditions specific to different phases, components and melting machines in general.

b) Determination of components' activities in iron-carbon melts that are far from solutions diluted with respect to carbon content, i.e., in cast iron, with the help of interaction parameters should be carried out not with their fixed values at a certain temperature but, instead, taking into consideration the functional dependence of the value of these parameters on the level of melt's saturation with carbon.

c) Oxidation-reduction reactions of phase interaction in melting furnaces with an electrochemical mechanism in the conditions of irregularity of a temperature pattern are accompanied by the development for each reaction of six electromotive forces per two electrochemical couples located in an electrically conductive environment with different temperatures. Part of electromotive forces of these couples has a reverse direction, i.e., corresponds to a reverse reaction. The development of electrochemical couples in oxidation-reduction reactions, described by two non-overlapping dependencies $\varphi = f(T)$, increases the probability of oxidation of elements with a less positive φ in diverging dependencies $\varphi = f(T)$ and decreases the probability in convergent dependencies. When the interacting phases contain carbon, the development of electromotive force due to the irregularity of the temperature pattern contributes to the development of reduction processes with carbon oxidation at the anodic stage.

d) Mass transfer in melting furnaces can be described by the introduced notion of the visible mass transfer coefficient which represents the density of the flux of mass relative to one percent of the element's concentration which allows applying a single mathematical model for the calculation of mass transfer and melting process optimization with the help of a computer.

RESULTS

The academic novelty of the obtained results is in the theoretical generalization of one of the main foundry processes - cast iron melting - which has been carried out by means of a systematic analysis. A methodology has been developed and a thermodynamic analysis of phase interaction during cast iron melting has been performed that allowed giving a comparative quantitative assessment of how different factors influence the phase interaction.

The methodology of thermodynamic calculations is fully provided with numeric parameters and computer software.

The authors have developed a method for determining the activities of the components in iron-carbon melts, being far from the diluted carbon content solutions, based not only on the consideration of the temperature dependences, but also on the concentration ones of the interaction parameters. The thermodynamic calculation method has been completed, using numerical parameters and computer programs.

The influence of temperature pattern irregularity on thermodynamics and the mechanism of phase interaction processes have been determined. An electrochemical interaction mechanism employed under conditions of an irregular temperature pattern has been developed; the role of carbon in phase interaction has been demonstrated that allows preventing a harmful influence of a mixed valence ion charge exchange. The influence of an electric field on the phase interaction has been experimentally proven; an electrochemical mechanism of a crucible reaction has been experimentally proven by a potentiodynamic method.

Theoretical generalization of mass exchange kinetics during cast iron melting has been given. Separate fragments of mass exchange have been proven to be described by a set of diffusion-convection equations, motion equations (Navier-Stokes) and continuity equations that are solved together with driving force equations. A comprehensive description of mass transfer during melting has been made with the help of the introduced notion of a visible mass transfer coefficient. Working mathematical models that allow obtaining computer solutions to melting optimization problems with consideration of certain mass transfer conditions have been developed.

The analysis of technical-economic aspects of technical re-equipment of melting compartments in foundry has been performed.

Practical relevance

The practical relevance of the research consists in the development of methods of thermodynamic and kinetic calculations fully provided with numeric parameters and software and that allow solving the problems of cast iron melting optimization and improvement.

New designs of gas cupolas and cast iron melting technology for them have been developed; recommendations have also been developed on implementing of electroslag technology during cast iron melting and production of synthetic iron from iron and steel cuttings, iron-ore pellets and pyrites cinder.

Based on the analysis of an electrochemical mechanism of the phase interaction, the following has been developed: the way of influencing phase interaction by an electric field, reduction of element loss during melting and a method of protecting induction furnace lining from wearing during crucible reaction which allows increasing the life cycle of a furnace lining. The technology of cast iron melting in induction crucible furnaces with the increased specific capacity has been developed.

Based on the conducted research, as well as on numerous semi-industrial and industrial experiments, functional constructions of cupolas with ledges in a shaft, with a plate in a shaft and with external camera overheating, where cast iron is melted for the first time on an industrial scale for complex heavy duty casting for compressors have been developed. A disadvantage of these gas cupolas in this sense is big volume and complicated maintenance. A new gas cupola with a fire-resistant bed made of composite fireproof materials and coke or another carbonaceous material, developed on the basis of melting thermodynamics mechanism and kinetics in different conditions, is more advanced in this regard. The electrochemical research and analysis of process kinetics have shown that carbonaceous material is a necessary metallurgic component in cast iron melting.

The systematic analysis of refractories' applicability in the function of beds carried out on the basis of specific and general quality indicators with a certain system of limitations will allow determining that in acid processes it is efficient to use high-alumina and fireclay refractory in the function of refractories. As for carbonaceous materials, it is recommended using broken electrodes.

In order to optimize a bed, a planned experiment has been carried out including the three above mentioned components. Regression equation has been set and the content of a bed has been optimized with the help of Harrington's desirability function. Computer optimization of a bed has been carried out as well. As a result, the recommended composition of beds for cupolas with different capacities has been drafted.

The experiments have demonstrated that in a gas cupola with a fire-resistant bed composed of seven refractories and a carbon material the sufficient temperature of cast iron (1,420-1,450°C) is obtained with a bed charge height within the range of 600-1,500 mm. The calculation of heat exchange in a bed charge of a gas cupola based on similar calculations for coke and a gas cupola and experimental data will allow determining the optimum heights of beds for cupolas of different capacities.

The technology of the cast iron electroslag treatment according to the structurally improved single-phase circuit and in furnaces, which combine gas melting with electroslag processing of cast iron, has been developed. It has been determined that an element loss and reduction of slag in the metal can be regulated when using fluxes of different composition. The process of metal and slag reaction is significantly influenced by the temperature of slag and metal. In carbon fluxes, reduction processes start at a lower temperature and as the processing time increases, the intensity of processes increases significantly, too. Synthetic cast iron has been obtained in an electroslag furnace from cast iron and steel cuttings. At the same time experiments have shown that cast iron melting from cuttings takes place with general metal

VOL. 11, NO. 23, DECEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

burning, which is achieved due to reduction processes when carbon is introduced into the flux contents.

Research on cast iron smelting from non-metallic crude ore has shown that it is possible to produce iron by oxidation-reduction reaction with an electroslag method and using accessible reducing agents. Similar data has been obtained when silicon carbide and natural gas with ferrosilicon deoxidation were used as reducing agents. Electroslag cast iron smelting from pyrites cinder has been performed.

The study of cast iron melting in induction crucible furnaces with increased specific capacity allowed determining the main peculiarities of the melting technology and the implementation of electrochemical protection from a crucible reaction. The study of properties of cast iron smelted using different methods has shown that cast iron from a gas cupola, especially from the one with a fire-resistant bed, has a higher flowing power than the cast iron from an induction furnace. The highest level of the flowing power is characteristic of cast iron after electroslag processing. Cast iron melted in gas cupolas and electroslag furnaces has more favorable shrinkable characteristics: slightly less linear shrinkage, a relatively bigger shrink hole and considerably less porosity.

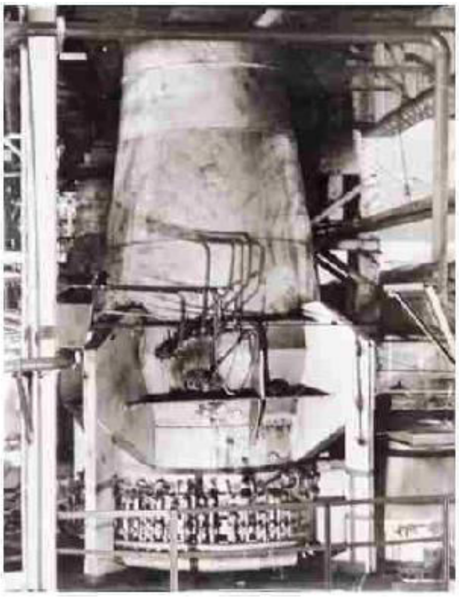

Figure-3. The first gas cupola with ledges in a shaft, capacity 7 t/h. Author Grachev V.A., Cherny A.A. et al. Author's certificates: AC№949295; 209656; 251776; 293487; 167613; 256930; 250368; 293489; 873739; 187251; 238105; 941823; 243151; 257700. Installed at Penza Compressor Factory and at other factories in the country.

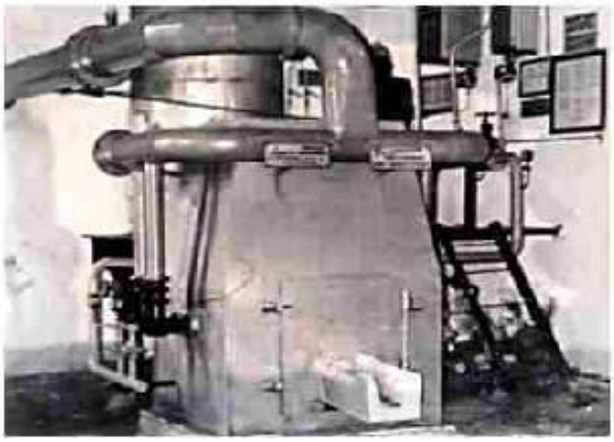

Figure-4. Gas cupola with external camera.

The greatest achievement in Russia is the installation of gas cupolas at AMO ZIL plant.

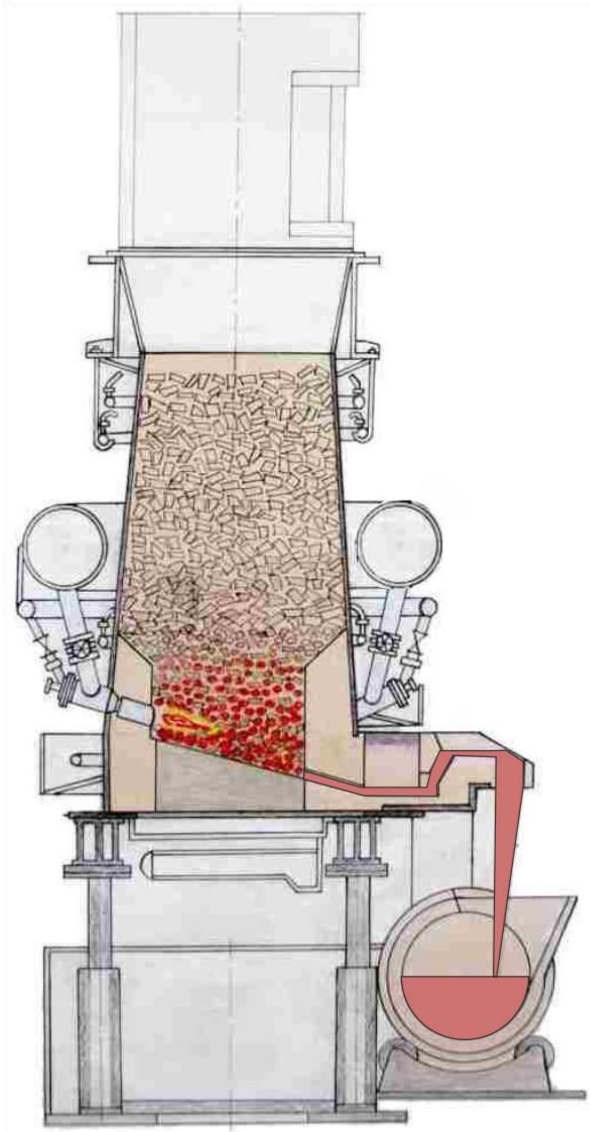

Figure-5. Gas cupola, capacity 20 t/h, installed at AMO ZIL.

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Technical characteristics: natural gas flowrate - 1,800-2,100 m^2/h air flowrate with gas flaring and A=1.0 - 18,000-21,000 m^2/h, temperature of liquid iron - 1,480-1,530°C, composition of a fire-resistant bed: fireclay refractory breakage (dimensions of sides at least 65 mm) - 33%, high-aluminia refractory breakage (dimensions of sides at least 120 mm) - 33%, graphite electrode breakage (pieces 100-300 mm) - 34%. Height of a fire-resistant bed – 1,200 mm, weight of a fire-resistant bed - 5.6 t, number of burning apparatus - gas burner type GVK 150 - 12 items.

Numerous analyses of gas content in cast iron from a gas cupola have shown that gas content in this cast iron is in average 1.44 times lower than in cast iron from a coke cupola. The total amount of metal inclusions in cast iron from a gas cupola with a fire-resistant bed is less than from that of a coke cupola.

It has been determined that electroslag processing of cast iron allows reducing the gas content by 20-35% and the amount of non-metallic inclusions - by 25-55%. Metallographic assessment of cast iron non-metallic impurity has shown that cast iron from a gas cupola and from an induction furnace has an index, which is 3 times lower than the cast iron from a coke cupola. Cast iron after electroslag processing has the lowest impurity index (1.78).

A comparison of mechanical properties of cast iron melted in coke and gas cupolas has demonstrated gas cupolas produce cast iron being 15-20% more durable comparing with the cast iron from a coke cupola with equal carbon equivalents. The microstructure of gas molten cast iron has higher perlite dispersiveness and a smaller amount of graphite inclusions with their homogeneous distribution along the joint cross-section. The macrostructure contains eutectic grains, which are 20-30% smaller. These structural peculiarities are connected with melting conditions and provide more enhanced mechanical properties.

CONCLUSIONS

The exploitation experience of gas cupolas at PO Penzkompressormash Plant, the Gomel Machinery and Repair Plant, the Volgograd VSPKZ Production Plant, the Cheboksary Hardware Plant and others has proven to be highly efficient: the release of harmful substances into the atmosphere has reduced significantly, cast iron quality is increasing, and fuel cost has been cut. High quality of gas molten cast iron has been proven by many years of gas cupolas functioning under industrial conditions. The installation under license of gas cupolas in the Italian company "Accuierie e Ferrierie Pugliese" has demonstrated that gas cupolas can produce cast iron with a temperature up to 1,510°C and sulfur content 0.015%. The implementation of high quality refractories guarantees reliable performance of cupolas.

Figure-6. Cast iron tapping from a gas cupola installed license in an Italian company Accuierie e Ferrierie Pugliese.

Data received from the company in 1984, as well as the experience obtained over many years, have shown that these cupolas can produce a wide range of grey cast iron grades including high-carbon iron (3.8 - 3.9% C). Cupolas operate 16 hours a day and one cupola is able to operate 12-15 campaigns in a row without maintenance and then the lining of the arch is replaced; the shaft lining is replaced after 90 campaigns. Cupola capacity amounted to 8 t/hour (the ordinary capacity being 6 t/hour).

The research conducted in Russia has encouraged similar research abroad and now gas cupolas have been already installed in the UK, Egypt, Germany and Iran. Technical-economic and ecological data has proven that cast iron gas melting has long-lasting benefits.

Economic calculations have shown that as a result of gas melting the production cost per ton of effective cast can be reduced by 12% on average, considering spoilt output losses.

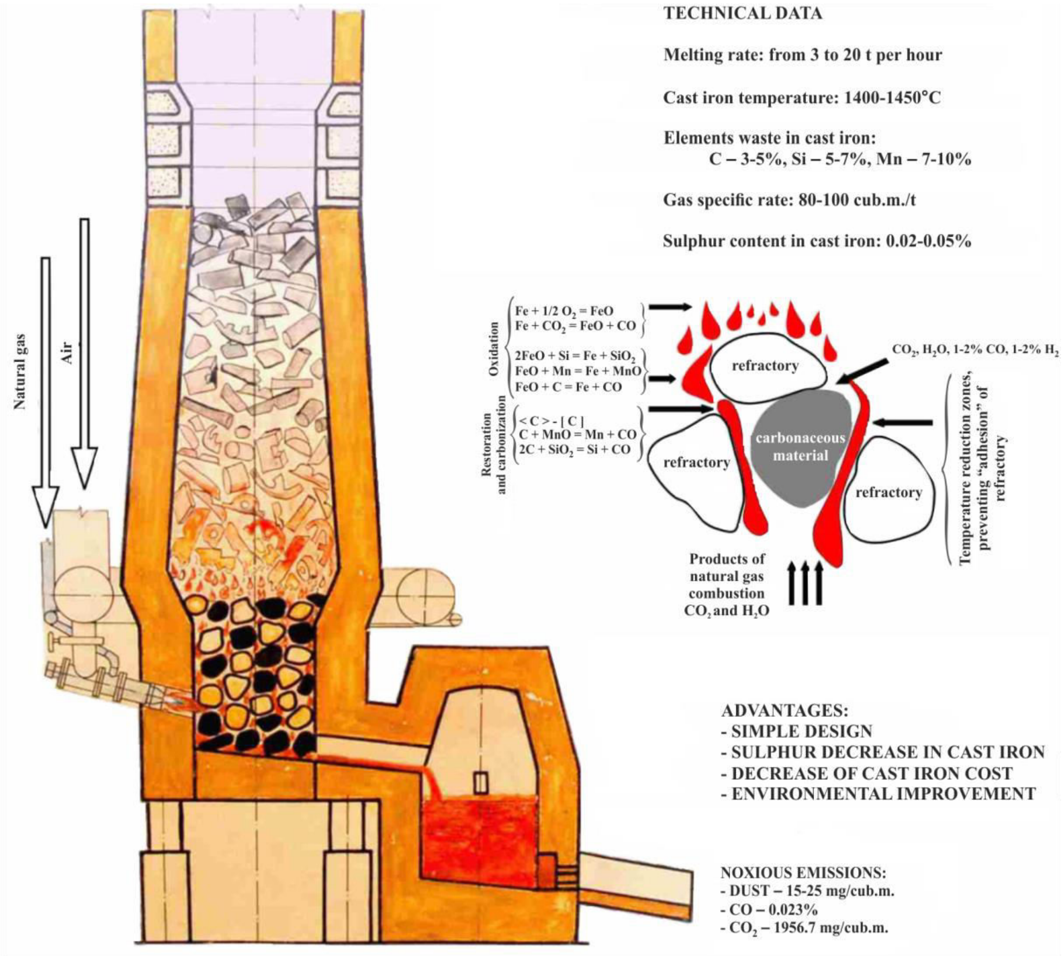

Figure-7. The most efficient type of a gas cupola created by the author is a gas cupola with a fire-resistant bed.

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