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Tendencies to the Improvement of the Cupola Process

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Abstract

Despite the fact of the big development of the technology of melting cast iron in electrical furnaces an essential part of it is still obtained in cupolas. In the paper actual tendencies of the improvement of the cupola process with special consideration of the structure principles of cupolas and their automatic control are presented. The rules of coke cupola processes for cold atmospheric and with oxygen enriched blast, with divided blast as well as for hot wind are presented. The technology of running long-campaign cupolas and the advantages of cokeless cupolas were presented as well. Among new solutions the FAR-system, the cupola with a partial recycling of gases and with using the plasma burners were described. There also were indicated possibilities of using pulsating gas flows as well as ecological problems and principles of complex controlling the cupola processes. The in this paper presented tendencies to improve the cupola process shall aid the foundrymen to make right choice by investment or modernization activities. The diversity of technical, economic and environmental conditions as well as of conditions related to the supply does not allow indicating one best solution.

Key words: Innovative Foundry Technologies and Materials, Cast Iron, Cupola

1. Introduction

By choosing the furnace for melting cast iron there is a need to carry out a technical and economical analysis, taking into account a significant number of factors. The most important of them are: obtaining liquid cast iron of required quality, cost account, availability of energy sources, environment protection etc.

It follows from the comparisons of the cupola process with the electrometallurgical processes [1÷4], that in spite of the more and more increased yield of the electrical furnaces in the cast iron engineering the importance of the cupolas for the melting of the basic amount of cast iron still continues to be unquestionable. In foundries, there still are installed the cupolas – together with the electrical furnaces. At the same time new and known methods of improving the technological and economical aspects of the furnaces' run, e.g. using the hot wind or the wind enriched with oxygen, the divided blast system, using the additional gaseous fuel or even total elimination of coke from cupolas etc, are used.

In the big foundries of USA [4,5] and Japan [6], producing mainly castings for automotive industry and centrifugally cast tubes, in which the demand for liquid metal amounts 45-90 t/h and even more, the fundamental equipment for melting cast iron is liningless hot blast cupola of melting rate till 120 t/h, running in duplex systems with the induction furnaces. By metal demand situated in the scope 5-25 t/h, cupolas and electrical furnaces are used. A distinct tendency to replace cupolas with electrical furnaces appears only when the demand of the foundry for liquid metal is less then 5 t/h. In polish conditions will be the above limits much smaller.

The development tendencies of modern foundries as well as the technical - economic analysis indicate more and more on the necessity of changing opinions upon the usefulness of cupolas and electrical furnaces for melting cast iron; the aim exists to use in possible greatest degree their advantages and elimination their drawbecks through connecting them in the form of systems. That is why by choosing furnaces for new or modernized melting plants often question is asked: "what a furnaces system?" instead of the question: "cupola or electrical furnace?".

The analytical material presented in this paper shall help to the foundrymen, who have decided to melt cast iron in cupolas, for their structural and operational improvement.

2. Cold blast coke cupolas

Cupola is a shaft furnace in which the portions of metallic charge alternatively with the portion of fuel (most often of coke) and fluxing agent drop in the shaft down to the melting and combustion zones, and hot gases rise up to the charging level, thus in countercurrent in respect to the charges, and preheat, melt and superheat the metal. The cupola gases with a high real combustion temperature (1650÷2000 ^{o}C) are generated in the combustion zone extending at a definite height over the tuyere's level, in effect of the exothermic reactions in the blast being insufflated through the tuyeres. The liquid cast iron together with liquid slag is collected in the cupola crucible (or in the cupola receiver), and tapped from it periodically or continuously (by using the syphon spout).

The physical-chemical phenomena occurring during the cupola run can be reduced to three basic groups: processes of fuel combustion and gazification, processes of heat exchange and related to them changes in metal temperature and in metal aggregation state as well as the metallurgical processes trlated to the changes in chemical composition of the metal. Assuming that the stationary conditions have been fixed in the we can isolate particular zones characterized by the run of the definite physical-chemical and thermal processes along the cupol's height. They have been discussed in detail in monographs [1,2]. The elements of these processes will be called beneath, if necessary, by the analysis of particular structural and technological cupola solutions.

Basic technological quantities of the whole cupola process are: blast volume P_z (in m^3/min) or P (in m^3/(m^2·min), coke : metal ratio K or coke's carbon : metal ratio $K·C_k$ (in kg/100 kg of the metallic charge; Ck is carbon content of the coke), blast temperature td (in ^{o}C) and oxygen content of the blast (in %) (inlet quantities) as well as melting rate W_z (in kg/h), superheating temperature of cast iron tz (in ^{o}C) and chemical composition of the cast iron being tapped (outlet quantities).

Blast volume (P) and coke: metal ratio (K) are quantities influencing essentially on the melting rate as well as on the iron temperature (Fig. 1). It should be noted that on the curves: t_z = f (P) a maximum is demonstrated, corresponding to the optimum value of P (= P_{opt}); this value is contained in the interval 100÷120 m^3/(m^2·min) and it increases with increasing the coke: metal ratio.

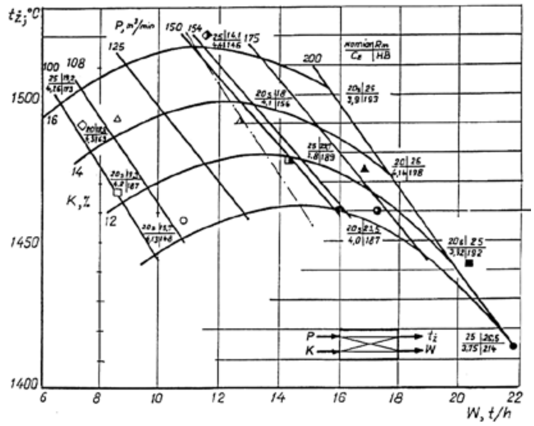

Fig. 1. Net diagram (statistical characteristic) of the interrerelation between the outlet (W_z and t_z) and inlet (P_z and K) quantities of a coke cupola. In the figure also the points showing the influence of charge composition on the properties of the cast iron being obtained are shown. [7]

The interrelation between the main outlet and inlet parameters will often be presented in a form of net diagrams (Fig. 1). Such diagrams, called the static characterics of the furnace, made for definite cupolas, allow a quick choice of the most favourable P and K values with the aim to obtain the required tz and W_z ones.

In the interval P > P_{opt} the increase of the melting rate but the decrease of the iron temperature tz with increasing of P is observed, at the same time the melting losses increase, especially distinctly by small K value (Fig. 2).

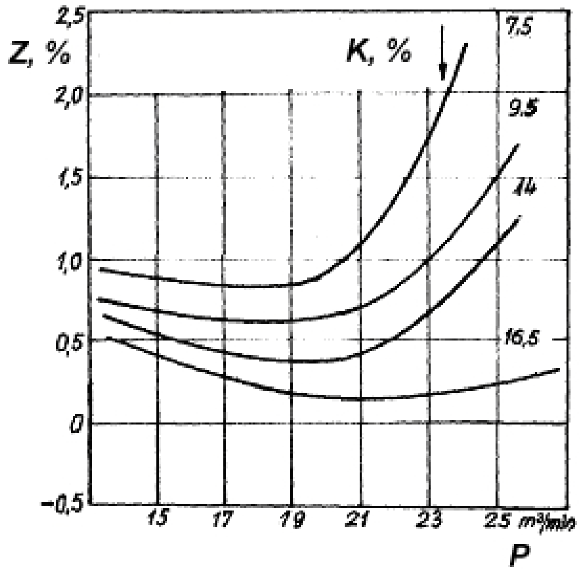

Fig. 2. Influence of blast volume (P) and coke: metal, ratio on the overall melting losses (Z) in an acid 500 mm cupola, by using HCC coke of dimensions 80÷100 mm [2]

3. Cupolas operating by the with oxygen enriched blast

Increasing the oxygen content in the blast contributes, first of all, to the increasing of the volume of cupola gases and thus to the rising of the real temperature of coke combustion and to the rising of the iron superheating temperature. In addition to this the oxygen enrichment of blast offers following possibilities for the cupola process:

- increasing of melting rate and facilitation of its control;
- quick (during about 10 minutes) regulation of the cupola operation (in regard to the iron temperature) disturbed in effect of the longer blast cutting off;
- possibilities of obtaining hot metal from the first tappings;
- possibility of reduction of the coke consumption (by 25% and more) in the case of melting ordinary cast iron of moderately increased superheating temperature what is related to additional advantages (farther increase of melting rate and of thermal cupola efficiency, decreasing of the sulphur content in cast iron and of the emission of harmful cupola gases);
- using of coke of worse quality;
- reducing melting losses;
- easier deduster operation in effect of smaller volume of emitted gases.

Figure 3 presents the net diagrams of the cupola with atmospheric blast and with the blast containing 24 % of oxygen. The enrichment shifts the net to the right and up, to the higher iron temperatures

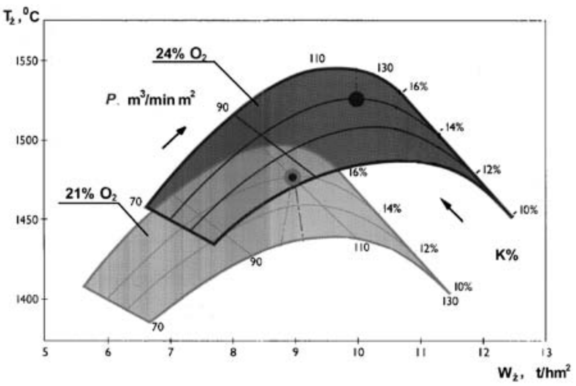

Fig. 3. Influence of the blast enriching by 3 % O_2 and of coke: metal ration K on the cast iron temperature t_z and melting rate W_z [2,9]

The oxygen can be introduced into the cupola either in the mixture with the blast or directly into the tuyeres, through the lances, sometimes with the supersonic velocity (in the case of rather greater cupolas) [8,9]; as an example may serve the technology OXIJET, widespread in Europe and also used in Poland [17]. The oxygen is delivered to the foundries in liquid state by specialized firms and the suitable installations are realized by them on favorable leasing conditions.

An analysis of the operation of cupolas with the blast enriched with oxygen which has been carried out some years ago in polish foundries [40] has proved, that by using such technology measurable effects have been achieved in relation to the cast iron superheating temperature as well as to the melting rates of the analysed cupolas, by favorable economic effects.

As a very interesting solution in this scope the by the firm OSAKA GAS Co. Ltd developed generator of the with oxygen enriched air, by using a membrane with a considerable permeability of oxygen [5], can be regarded. The membrane is very thin (< 0,1 μm) and therefore it is strenthened by porous ceramic plate; the membrane is penetrated by 3 times greater volume of oxygen then the volume of nitrogen, thanks to what the device generates a mixture $O_2 + N_2$ containing about 28 % O_2, which is then mixed with the atmospheric air giving in result the blast containing 24÷26 % O_2.

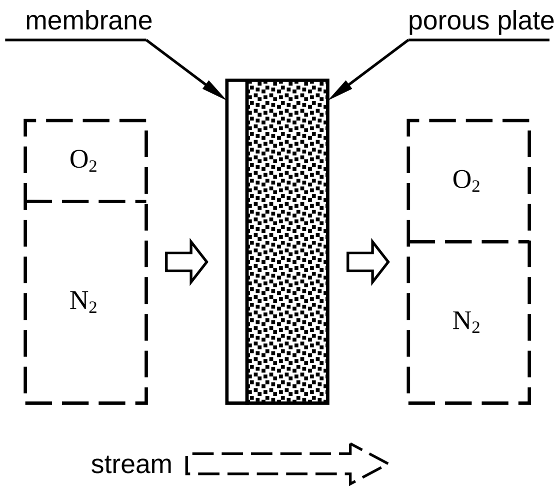

Fig. 4. Generator of the with oxygen enriched blast [5] – principle of the process

4. Divided blast cupolas (cupolas with two rows of tuyeres)

Divided blast cupolas have a rather long history. The idea of the actually developed solution is the positioning of the secondary row of tuyeres at such a level in relation to the level of primary row of tuyeres, which guarantees no combustion of coke in the secondary blast and ensurs the combustion only the CO coming from the reduction zone [1,2]. Thus, the temperature of cupola gases increases, as well as the intensity of the exchange in the preheating zone, the location of melting zone rises, what, in result, increases the superheating temperature of liquid cast iron. (fig. 5).

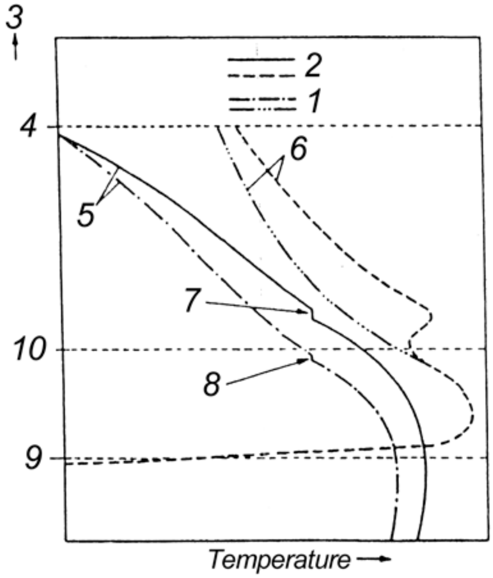

Fig. 5. The course of the changes of the temperature of cupola gases and of the metal in a hot blast cupola with one (1) and two (2) rows of tuyeres [1,2]; 3 – shaft's height, 4 – charging level, 5 – metal temperature, gas temperature, 7, 8 – location of melting zones in the cupola with one (8) and two (7) rows of tuyeres, 9, 10 – primary (9) and secondary (10) rows of tuyeres

5. Hot blast cupolas

Preheating of the cupola blast is one of the technologies being for a longer time used for intensification of cupola processes. This technology aims to higher superheat the liquid cast iron or – when there is no need for high superheating degree in the cupola – to run cupola by correspondingly reduced fuel consumption.

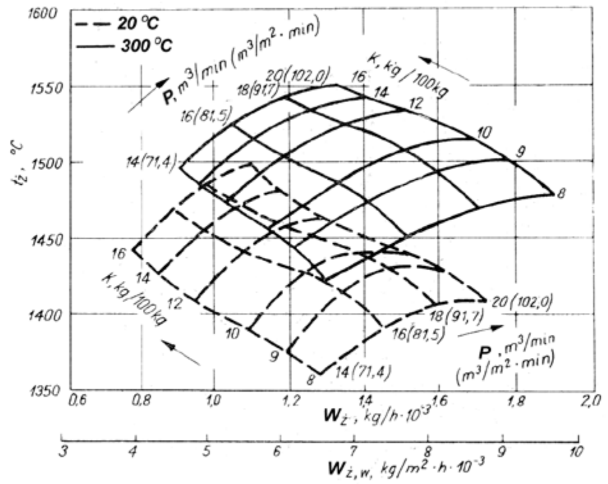

Fig. 6. Influence of the preheating cupola blast to 300 ^{o}C on the melting rate and superheating temperature of the metal [2]

Comparison of running the cupola using cold and hot blast is shown in fig. 6.

There are following additional advantages of using hot blast cupolas:

a) more uniform cupola run, the tuyeres outlets are namely not plugged by slag;
b) improvement of the chemical composition of cast iron, because:

- there is greater recarburation degree of the iron,
- there are smaller melting losses, what is important from technological as well as from economic points of view,
- there is smaller sulphur content in cast iron (because of smaller sulphurisation degree and of reduced coke consumption);

There exists a similarity between the technologies of preheating the blast and enriching it with oxygen when regarding the superheating temperature of the metal and its melting rate. But there also exist here essential differences. The investments costs of the equipment for blast preheating can be amortized in a short time but only in cases of longer cupola daily operations. In the case of running the cupola some hours daily or only some days a week using hot blast is not rentable. Using in such cases the with oxygen enriched blast allows obtaining hot metal just from the first tapping.

The cases are also known where the cupolas are equipped with devices to preheat the blast and to enrich it with oxygen [1,13,14]. The normal operation is the based on hot blast and the blast with superatmospheric oxygen content is reserved only for starting periods of furnace operation, for periods when the need of obtaining metal with higher temperature is demanded etc.

Depending on the method of blast preheating three types of cupolas are distinguished:

- cupolas by which the blast is preheated at the expense of the physical and chemical energy of emitted cupola gases;
- cupolas by which the foreign source of energy is used for preheating the blast;
- cupolas by which for the basic operation of preheaters the heat of cupola gases is used, but for better control of blast temperature also the foreign fuel burners are activated.

In each of the mentioned groups can be, aside from that, the subgroupes distinguished, including the preheaters with different operation principles (radiation, convection or combined – radiation and convection ones) and preheaters differently connected with the cupola himself (being structural elements of cupolas or located separately).

6. Long campaign cupolas

Long campaign cupolas are furnaces which are not emptied after one to two shift daily operation for routine repair the lining [14,16]. These are normally big unities with melting rate equal to 15÷120 t/h. They usually work as hot blast cupolas with blast temperature reaching 700 ^{o}C and more. The preheaters are located separately in relation to the cupolas and operate using foreign sources of energy. But there are also case known where for blast preheating also the energy of cupola gases is used or where the cupolas work as the cold blast furnaces.

The furnaces of this kind are installed as single unities,left "under fire" (i.e. without access of the air, with leaving in the furnace the crucible and filling coke, and in some cases even the normal charge, filling the shaft) for periods of night or weekend breaks.

Melting cast iron in long campaign cupolas is characterized by considerable savings in comparison to the cupolas whuch are emptied after each melt. These savingscome from:

- refractory materials and labor costs related to the lining repairs,
- coke and flux agents,
- surface demand, simplified charging system,
- simplified system of dedusting the emitted gases,
- simplified system of delivering blast and, eventually, oxygen to the cupola.

It also was stated that the run of cupola is more stable, what is expressed by smaller dispersion of chemical composition of cast iron.

Savings on coke (because of the lack of consumption of the crucible coke) can reach 1 t daily and 20 t weekly [15].

The operation of melting plant with a long campaign cupola is very flexible. It allows to control the melting rate in the range ± 25 %.

The analysis of the operation of 9 long campaign furnaces, working with hot and cold blast, in some cases enriched with oxygen, has proved that their investment costs have been amortizated during 0,5 to 1,5 years [15].

A classical example of such a furnace is the long campaign cupola produced by the firm KÜTTNER (earlier GHW - Gesellschaft für Hüttenwerksanlagen), shown in fig. 7. It is equipped with a special cover for closing the shaft in the beginning and ending periods of cupola operation, as well as during leaving the furnace "under fire", when the gases, because of the reduced degree of filling the shaft with the charge flow into the atmosphere with omitting the dedusting equipment.

An original element of the furnace is the pressure receiver; cast iron and slag flow in it continuously; in the syphon follows the separation of the slag from the metal (principle of difference of their densities) The syphon is closed wit a cover and that is why there is the same pressure over the metal here as in the cupola shaft. The syphon can operate without repairs a week or more.

Results of the reduced coke consumption (decreased cupola gases and dust) are in case of long campaign especially great because of their big melting rate.

In Poland there have been installed a long campaign cupola operating in Iron Foundry ŚREM. Designed by the Company PRODLEW-Cracow [36] it has the diametre (in tuyers' zone) 1200 mm and melting rate about 15 t/h. It operates in weekly campaigns, with using hot blast (blast temperature till 400 oC), enriched with oxygen blown in through the tuyeres. It also is equipped with the dedusting installation, designed and realized by the firm KÜTTNER.

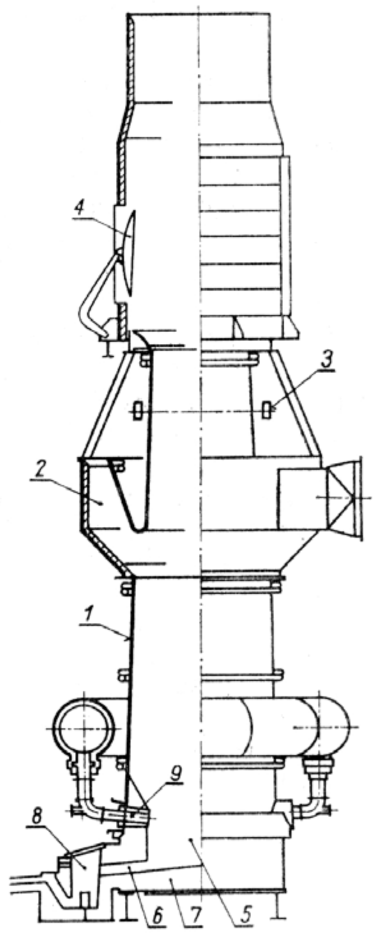

Fig. 7. Long campaign liningless cupola of the firm GHW there (actually Küttner – Germany [14]; 1 water cooled mantle, 2 – draw ring of exhaust gases, 3 – isotopic signalling device of the charge level, 4 – cover, 5 – crucible, 5 tapping channel, bottm, 8 – pressure syphon, 9 - tuyeres

7. Cokeless cupolas (gas cupolas)

Cokeless cupolas present an essential progress in the scope of development of the melting technology with using gas fuel. In such furnaces, in the lower part of the shaft, gas burners with great combustion efficiency (fig. 8) are installed. Over the burners 4a grill 3 made of water cooled steel tubes covered with carbonaceous refractory material is situated; on this grill a layer 2 of ceramic spheres (125 mm in diameter) containing carbon is arranged and plays the role of heat exchanger for the metal droplets running down to the crucible. On this layer rests the metallic charge being preheated and melted (with a correspondent amount of fluxing agent). The height of the column of metallic charge corresponds to the amount of charge being equivalent to the hourly melting rate of the furnace.

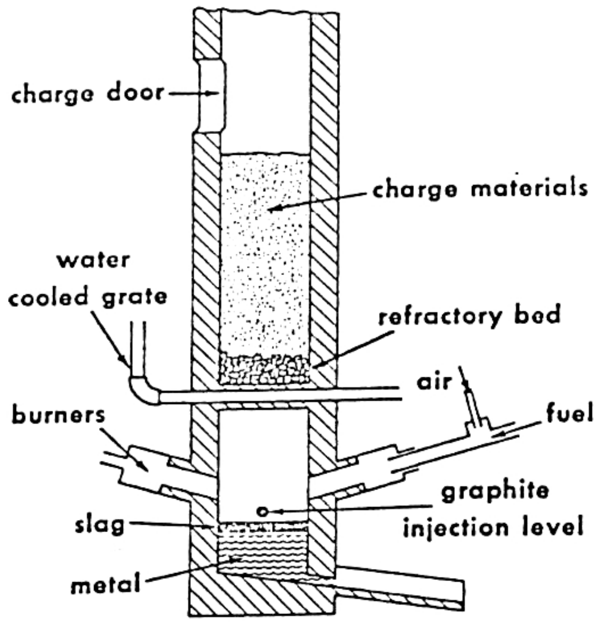

Fig. 8. Scheme of a cokeless cupola [17]

The melting rate of the furnace depends exclusively on the melting rate of the pieces of metallic charge and this is determined, mainly, by the real blast volume delivered to the burners, referred to the 1 m^2 of the section of the cupola shaft at the grill level.

The recarburation of liquid iron 6 takes place at costs of the graphitic dust insufflated with the help of an injector 5, located between the slag tapping opening 7 and burners (over the level of the slag 7); some amount passes also from materials of spheres and grill.

The most important advantage of the cokeless cupolas is, however, their almost total harmlessness for the environment: the overall emission of gases is lesser and they are deprived practically from CO and SO_2; dust emission is no greater than 50mg/m^3; CO_2 emission is about three times less than in the case of a coke cupola; also small is the amount of the generated slag [15]. Regarding the fact that the sulphur content in a gas cupola is very small the gas cupolas are well suitable for melting cast iron being next undergone treatments of nodularizing and vermicularizing.

Actually, because of the problems with the superheating the metal and its recarburation the cokeless cupolas operate most often in duplex processes with the induction furnaces.

8. New solutions in the domain of cupolas

Looking for the new possibilities of sparing managing the energy by melting cast iron has led to some interesting propositions holding in different grades promises for industrial implementation.

One of such solutions is a Brasilian cupola type FAR [2,19] in which into the central shaft only metallic charge is introduced, while the coke together with fluxing agent are introduced directly into lower part of the central shaft through six chutes symmetrically arranged round it.

The coke chutes are connected with the shaft in the way which guarantees the flow of gases only through the shaft. The CO containing gases, just before entry into the shaft, are burnt in secondary blast. The total elimination of CO from the gases flowing through the shaft, and thus elimination of losses of their chemical energy allows to dramatical reduction of the coke: metal ratio, namely to the level 6÷7 kg/100 kg of metal. Thanks to this following advantages from running such furnace are expected: high thermal efficiency η_c = 50÷70 %, small emission of gases, about 85 m3/t, lesser sulphurization degree of the metal.

Similar reduction of gas emission can be achieved in the cupola with closed [2] or partial [39] gas circulation.

In both propositions mentioned above the addition of oxygen to the blast and in the first case also the plasma burner for increasing the metal temperature are used. There are also installations of plasma burners proposed for normal cupolas – experiences have shown that by this way the preheating blast temperature in a range 500÷1300 ^oC can be obtained, what offers possibilities of superheat metal to any practically demanded temperature.

Delivering the gaseous factors through the perpendicularly arranged tuyeres does not ensure the even combustion of coke layers, especially in big furnaces. For equalization the flows the proposition is presented to form the shaft like this of blast furnace, with an oblique arrangement of tuyeres and increased velocity of the blast being introduced (over 50 m/s) and with eventual addition of oxygen or compressed air through the lances with very great inlet velocities, till the supersonic ones.

Another way of equalization the flows and intensification the combustion and heat exchange processes in the cupola shaft is using the extorsions of pulsations of the blast, oxygen or their mixtures with the coal dust. Introduction of such pulsations enables measurably increase the metal temperature and melting rate of the cupola [22].

9. Ecological problems of the cupola process

9.1. General remarks

The gases emitted from cupolas are polluted with dust and harmful gaseous components generated during the physical and chemical processes, specific for such furnaces. The worldwide tendencies to sharpen regulations concerning the emission of harmful gases and dust into the atmosphere are demonstrated.

The amount of emitted gases in respect to the production value of melting plant increases when we consider the cupolas in the order: hot blast cupola without cooling its mantle (in average 550 m^3/t), the lined long campaign cupola (560 m^3/t), the liningless long campaign cupola (675 m^3/t), the cold blast cupola not cooled externally (770 m^3/t). Enriching the blast with oxygen causes reduction of generated gases also in result of the reduction coke: metal ratio.

The value of CO emission in the unburnt waste gases being emitted from coke cupolas is as high as 50-100 m3/t.

The average amount of gases leaving the cokeless cupolas amounts 660 m^3/t; as opposed to the coke cupolas these gases contain only CO_2 and water steam.

The ecologic problems include more and more often the emission of CO_2 (this is related to the so called "greenhouse effect").

The value of sulphur emission from cupola is mainly a function of the coke: metal ratio and of coke quality. The sulphur contained in coke divides in different proportions between cast iron, slag and gases. Most often its content in emitted gases increases proportionally with the increase of the coke: metal ratio. It appears here in form of SO_2. To a decrease of sulphur emission lead all the technologies and treatments which enable reduction of the coke consumption in cupola. One of advantages of the cokeless cupola follows from this, because in such furnase sulphurless fuel, i. e. the natural gas, is used.

The emission values of NO_x were not searched till now, because all the measures show the appearence of these oxydes in quantities very far from limiting values.

The solid wastes of the cupola process are dust and slag. The dust is continuously discharged in the stream of wastet gases and the slag – in the liquid form from the cupola crucible (periodically or continuously) or from the syphon spout (continuously).

The values of dust emission from the cupolas are contained in a wide range; they amount most often 8÷10 kg/t of cast iron (for comparison: average values of dust emission from British cupolas amount for: coke cupolas – 8,5 kg/t, for arc furnaces – 5kg/t, for induction furnaces – 0,75 kg/t, for rotary oxygen-gas furnaces – 1 kg/t). A great part of the dust are particles of coke being generated in result of abrasion of charging coke moving down in the cupola shaft; that is why the dust emission changes proportionally to the coke : metal ratio; another advantage of cokeless cupola becomes here visible.

In the chemical composition of dust appear also harmful components, but in limited amounts; e.g. the oxides ZnO and PbO appear only in case of using undesirable scrap. The polluting of metal with them, however, increases lately because of utilizing in cupola the automotive scrap, especially the galvanized sheets of car bodies. The vapors of zinc generated in such cases during melting oxidize in cupola atmosphere to ZnO in the form of white, flourlike dust which must be separated from the gases being emitted into the atmosphere. Also the silicates and oxydes of alkali metals, originating from coke ash and soluble in water, can be harmful.

It follows from the above considerations that the energetic efficiency of cupolas as well as the degree of the environment pollution by them increase as the coke: metal ratio increase. Correspondingly to this the expenditures for purifying the emitted gases shall increase. More and more great importance have the technologies which increase the energetic efficiency of cupolas and reduce the coke consumption in them, and mainly:

- preheating the blast to higher temperature,
- enriching the blast with oxygen,
- using gaseous fuel in cupola.

9.2. Utilization of cupola wastes

The by-products of cupola processes are cupola gases with the dust contained in them and the slag. The possibilities of taking advantage from physical and chemical energies of cupola gases were discussed above. Two problems appear related to the presence of dust in the cupola waste gases: dedusting of gases and removing the dust out of the foundries.

The modern dedusting facilities can be divided in two groups: dry and wet ones [1, 2, 41]. The first group includes the cyklons (for primary, coarse dedusting efficiency = 80 ÷ 90 %) and filter chambers (for final dedusting – efficiency = 98 ÷ 99,8 %). The filtration bags are made from special materials resistant to the gas temperature reaching 300^{o}C, e.g. glass, nylon, polyester etc. In some cases the electrostatic filter are used.

Among the wet dedusters we distinguish: the tower washer (scrubbers – dedusting efficiency 50÷80 %), dedusters with Venturi tube (efficiency 97÷98 %) and desintegrators (centrifugal dedusters – efficiency about 98 %).

The main shortcoming of all the wet dedusters ist a considerable amount of polluted water with a big amount of silt generated by their operation. This silt is transformed, for logistic aims, in dehydrated cakes. The water demand is here also significant. That is why the dry methods of dedusting are more popular.

The costs of deposition of dust and silt become greater and greater. This conclusion concerns all the wastes generated in foundries. In this connection different technologies allowing blowing dusts into the cupola are developed.

These dusts can be divided in following groups [2]:

a) carbonaceous dust, economically rentable as recarburizers or fuell,
b) coarse grain cupola dust from the initial dedusting process,
c) fine-grain cupola dust from the final dedusting,
d) dust from fettling shop,
e) fine-grain residue from coke storage yard,
f) after-reclamation dust of furan sand.

Different mixtures of the above kinds of dust can be prepared and blown into the cupola through the tuyeres; so can be the advantage can be made from the in mixtures contained fuel or metallic elements; the non-metallic components can be transformed in the granular slag, for which there are easily the receivers to be found.

In fig. 9 is shown, as example, an exhaust device operating on the principle of subatmosphericc pressure, generated through the Venturi tube built in it. The use of such dispositif reveals following advantages:

- introduces the dust by a reduced energy consumption,
- distributes automatically the dust in case of disturbances in singular tuyeres,
- reduces the wear of the parts contacting with the dust (in comparison witch blowing in).

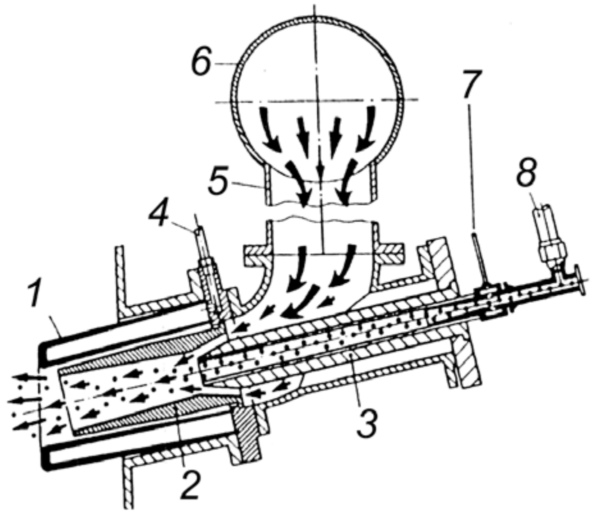

Fig. 9. The injection-suction device for introducing the fuel and after-reclamation dust through the tuyeres into the cupola [21]; 1 – copper tuyere, 2,3 – the injection inserts (części 1 i 2), 4 – inlet of the cooling water, 5 - the hot blast duct, 6 - the blast ring, 7 – aiding injector, 8 – dust delivering (on suction principle)

10. Computer-aided control of the cupola process

The computer technique includes actually, as regards its scope and possibilities, almost every part of whole, combined cupola process. There can be distinguished following controlling blocks, using of which has been evident in improving and optimization of the partial processes in the technical and economical regards [2]:

block 1 – materials managing,
block 2 – the course of cupola process,
block 3 – the furnace control,
block 4 – Data collecting and transforming.

Block 1. Material managing

The materials managing includes:

- supplying the necessary materials and their storage connected with registrationto of their quantity and quality characterisics,
- determining the composition of the metallic charge being optimal in respect on technology and economy, as well as the coke : metal ratio and fluxing agent : coke ratio,
- controlling the course of weighing charging materials with the current correction of this operation, controlling the charging operations, registration and collecting data on realized corrections.

In all the above scopes becomes the computer technique more and more normal operational tool in planning and realizing the cupola process. The first and last of mentioned tasks are routine actions with using computer and do not need any commentary. The fourth task is a simple problem from the scope of automatic control, with using indicator of the charge level as the factor which activates the drive of the charging bucket.

Most advantages are lately derived from aiding the cupola processes, which shall be optimal from the technological and economical points of views, as well as the operations of preparations the charges with minimizing the weighing errors and with their correction with help of the automatic regulator [23÷25]. The determining of the economically optimal charge is the more important, the more components of the charge are there at disposal. These tasks are realized using techniques of the classic linear programming, e.g. OPTIMA, CHARGE and LIFU (France), LEAST COST CHARGE (USA), OPTIMISATION DES CHARGES Belgia). Also Polish programs have been developed [23, 24].

The problem being discussed includes, in wider depiction, the correction of chemical composition in cupola receivers, e.g. in the induction furnaces: examples of corresponding computer programs are: the French program BAIN and AGH program [24].

Block 2. The course of cupola process

The stable and effective cupola operation as well as the desired very good quality of the melted cast iron, by maximal elimination of the hand labor can only be ensured in conditions of utilization the modern methods of controlling and monitoring all the cupola partial processes. It becomes more and more evident by actually existing possibilities of using the computer technique.

The full automation of the cupola process stays further a difficult problem in what considers practical realization, because some principal aspects of this problem did not yet been solved till the end. The point is to determine the most important inlet and outlet quantities of the process (which change in time) and then determine the relations between them, i.e. to develop the mathematical model of the cupola process, describing possibly exactly the physical and chemical phenomena occurring in cupola as well as their results.

By developing the mathematical model of the cupola process the authors base on the theoretical physical-chemical and thermodynamic principles of the partial processes running in particular elements of furnace shaft or on the experimental data enabling determination of the regression equations for the interrelations between the particular outlet and inlet quantities of the cupola process, treated as a whole. In the last case the model usually boils down to the net diagram of the furnace.

To the most important achievements in this scope can be recognized three mathematical models, taking into account mechanical, thermal and chemical aspects of the process: the in 70-th years of past century in Germany developed model [26], with success used in next research works [27] and similar simulation model developed in Technical University in Łódź in the years 1987÷1997 [34] as well as the being developed since 1989 year by considerable group of the researchers from universities and the industry, coordinated by AFS [28]. The costs of the later model after 10 years of its realizing amounted about 1,8 mln USD. It corresponds to the costs of the operation of all American cupolas during 4,5 hours. The importance of the model emphasizes the fact that 40 % of overall costs was covered by the Energy Department of the USA Federal Government. The aim was reasonable reduction of energy consumption in the cupola processes. Result of this project are computer programs, intended for practical use in different industry conditions. Despite of enormous expenditure of labor and costs the developed programs are still corrected [31] what proves about the complexity of the processes running in cupolas. The analysis of the above models [32] leads to the conclusion that despite of greater simplicity of the German and Polish models the results obtained by their use are nearer to the real results of cupola processes than in the case of American model. It probably follows from assuming here some thesis being not compatible with the theory of cupola process which has been fixed till now.

Block 3. The furnace control

The computer aided control and inspection concerns actually whole process of producing liquid cast iron, and especially [2,33]:

- iron grades, its chemical composition and corresponding charging program (composition of charging portions, number of portions per melt, charging sequence etc.); data, concerning real metal composition and stored in the memory of controlling system, which are called out systematically, serve to determine deviations in relation to the assumed data and to do necessary changes in the charging program;
- consumption of crucible and filling coke;
- key inlet parameter (blast volume, its temperature and oxygen content, coke: metal ratio) and outet ones (melting rate, iron temperature);
- hours of starting and ending the melt;
- material balance; comparison of the assumed melting rate with real one; determination of the recarburation, sulphurization and melting losses values; correction of the material balance;
- thermal balance (in hourly distances), based on data taken from the material balance;
- gas and water managing.

Important and effective tool of the computer system of controlling the process is visualization of its run; the information are presented in this case in form of synoptic (digest) pictures as well as of system points pictures [24, 34, 37]. In such a way are expressed actual process situations with the most important number data, concerning the flow of materials as well as gas and water managing. On the visualization pictures are also presented emphasized facts, e.g. alarms and technological warnings, failures of equipment etc. All these data are registered automatically. The reports are basis for determination the production costs.

The inspection and control of the process, carried out by this way, allow increase the confidence at obtaining the metal of desired quality by minimal expenditure of time and energy, thus by minimal hazard for environment.

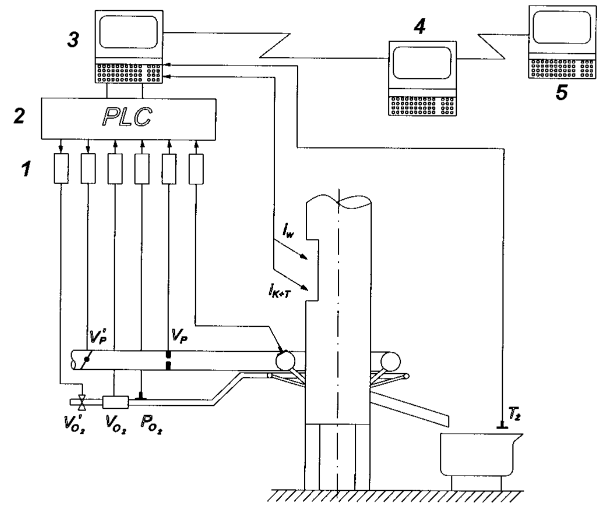

Fig. 10. An example of the computer controlling configuration with the visualization for a cupola operating superatmospheric oxygen content in the blast. Continuously measured and controlled quantities: blast (V_P) and oxygen (Vo_2) flow rates as well as blast pressure (p); periodically measured quantities: cast iron temperature (t_z) and weight of the metallic charge at the definite charging moment i. Equipment: 1 – converter, 2 – controller, 3 – operator station, 4 – dispatcher station, 5 – managing station

Block 4. Data storage and transformation

It already was mentioned above about essential significance of the storage of the data which are introduced into the computer memory from particular stands of the cupola installation. These data, after their arranging, are put in archives and remain to disposal for the managers of the melting plant. They serve then as excellent basis for determining or correcting the relationships between different process parameter. These activities can include determining relationships between the metallurgical parameter and properties of iron castings, very useful in systems of ensuring quality.

Interesting possibilities of using computer techniques by controlling the cupola processes give a version of expert system, without the learning process, with using the so called "fuzzy logic" [34÷36]; the in this way constructed nonlinear controllers allow assimilate the action of the system to the action of an experienced operator. The notion "fuzzy logic" means , generally, inaccurate expressions of the type "too hot", "almost full" etc., which, as reflection of the experience of an experienced foundryman are introduced into the system, which transforms them to the precise ("sharp") notions and thus aids in taking exactly formulated decisions and solutions.

11. Summary

The in this paper presented tendencies to improve the cupola process shall aid the foundrymen to make right choice by investment or modernization activities.

The diversity of technical, economic and environmental conditions as well as of conditions related to the supply does not allow indicating one best solution.

References

[1] C. Podrzucki, J. Szopa: Furnaces and metallurgical devices used in foundry practice, ŚLĄSK, Katowice (1983) ((in Polish)..
[2] F. Neumann: Cast iron – Melting, metallurgy, treatment of liquid metal, Expert-Verlag, 2. wyd. Düsseldorf (1999) (in German).
[3] A. Jopkiewicz.: Energetical and organizational apects of melting cast iron. Proceedings of the Conference on "Modern technologies in foundry engineering, Uniejów (1971), 125¸146 (in Polish)..
[4] A. Jopkiewicz.: Forecast of developing the technology of melting cast iron. Proceedings of II Conference on "Deeveloping tendencies in technology of machines". Zielona Góra, Section „Foundry engineering and welding, 159¸17 (in Polish).
[5] T. Ishino: Przegląd Odlewnictwa v. 40 (1990), No. 5, 69÷175 (in Polish).
[6] C. Podrzucki, C. Kalata: Metalurgy and foundry engineering of cast iron. ŚLĄSK, 2. ed., Katowice (1976) (in Polish).
[7] J. Szreniawski A. Jopkiewicz: Research opf the melting process of cast iron in duplex system: cupola- induction channel furnace. Design problems of metallurgy and machine industry. (1974), No. 5, 136¸144 (in Polish).
[8] Ph. Beaudoin et a.: [in:] International Conference on Cupolas. Strasbourg (2000), 1/15÷15/15 (in French).
[9] A. Jopkiewicz.: With oxxygen enriched blast as a controlling quantity for cupola process.Proceedings of the III Polish Foundry Congres. Warszawa (2001), 153¸159 (in Polish)..
[10] J. Bosch J., R. Hamberger: Giesserei v. 89 (2002), No.1,. 56 (in German).
[11] R. Cairns: Brit. Foundryman, v. 78 (1985), No. 11, 448÷452.
[12] A. Dahlmann: Giesserei, v. 66 (1979), No. 1, 2÷6 (in German).
[13] F. Neumann : Giesserei, v. 77 (1990), No. 5, 142÷148 (in German).
[14] H.G. Rachner.: Przegląd Odlewnictwa, v. 40 (1990), No. 6, 189÷195 (in Polish).
[15] A.S. Griffiths.: Foundry Tr. J., v. 167 (1993), No. 3467, 36÷37..
[16] M. Lemperle: Giesserei, v. 86 (1999), No 6, 123÷128 (in German).
[17] R.T. Taft: The Foundryman, v. 86 (1993), No 7, 241÷244.
[18] Newell D.: Foundry Tr. J. 166 (1992), nr 3446, s. 23.
[19] Rachner H.G.: [W:] VDG Seminar "Schmelzen von Gusseisenwerkstoffen in Induktions- und Kupolöfen".Part III, Hannover (1991) (in German).
[20] P. Brelaud, B. Million-Rousseau: Hommes et Fonderie (1990), No. 210, 21-26 (in French).
[21] W. East: Foundry Manag. and Techn. v. 117 (1989), No 11, 54÷55.
[22] A. Jopkiewicz: Controlling cupola process with usin blast pulsation Sterowanie procesem żeliwiakowym z zastosowaniem pulsacji dmuchu. Zeszyty Naukowe Politechniki Łódzkiej, Dissertations, No. 41, Łódź (1981), 112 pages –Dr. habil. dissertation (in Polish).
[23] C. Podrzucki, E. Ziółkowski: Metallurgy and Foundry Engg v. 17 (1991), No.2, 193÷208.
[24] E. Ziółkowski: Optimization and stabilization of the choosen cupola processesDoctorate dissertation. Faculty of foundry Engineering AGH, Kraków (1995) (in Polish).
[25] I. G. Vanhoutte : La Fonderie Belge (1991), No. 4, 3÷18 (in French).
[26] W. Rühenbeck, R. Günther: Giessereiforschung v. 25 (1973), No 2, 47÷59 (in German).
[27] L. Ruschitzka, W. Lenz: Proceedings of the 56. WFC, Düsseldorf (1989), paper No. 16 (in German).
[28] V. Stanek et a.: Trans. AFS 100 (1992), s. 425÷466, p. I-IV; 101 (1993), s. 825÷852,p. V÷VIII; 103 (1995), s. 803÷816, p. IX÷X.
[29] N. P. Lillybeck: Proceedings of AFS International Cupola Conference. Rosemont. USA, March (1994), 263÷264.
[30] A. Jopkiewicz, K. Warpechowski: „Research on the computer model of the cupola process, International Foundry Conference on „Solidification and crystalization", Bielsko-Biała, Zeszyty Naukowe PAN "Krzepnięcie metali i stopów" (1997), No. 30, 109÷118 (in Polish)
[31] V. Stanek et al.: Proceedings of the 2nd International Cupola Conference Triere (2004), paper No. 4÷2.
[32] C. Podrzucki Przegląd Odlewnictwa v. 47 (1997), No 10, 340÷345 (in Polish).
[33] H.G. Rachner: Giesserei v. 72 (1985), Nonr 25, s. 691÷696 (in German).
[34] A. Jopkiewicz: "Automation of the cupola process". Proceedings of the International conference on producing noular iron castings when using cupolas and electrical furnaces", Kłodzko (1995), 1÷8 (in Polish) Büchel M.: Giesserei 81 (1994), nr 11, s. 329÷331.
[35] M. Büchel: Giesserei v. 81 (1994), No. 11, 329÷331 (in German).
[36] J. Nadhera: Przegląd Odlewnictwa, v. 47 (1997), No. 3, 76÷76 (in Polish).
[37] A. Jopkiewicz: Przegląd Odlewnictwa, v. 44 (1994), No. 6, 200÷204 (in Polish)
[38] R. Bartkowiak et al.: Przegląd odlewnictwa, v. 48 (1998), No. 7÷8, 213÷218.
[39] L. Ruschitzka et al.: Giessereiforschung, v. 46 (1994), No. 2÷3, 40÷50.
[40] C. Podrzucki, M. Asłanowicz: Przegląd Odlewnictwa, v. 49 (1999), No. 12, 487÷491.
[41] L. T. Schmidt: Proceedings of AFS International Cupola Conference. Rosemont, USA (1994), 69÷92.