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Perspectives of Industrial Application of Liquid-Phase Iron Reduction Processes

A.K. Tarakanov, V.P. Ivashchenko, Yu.S. Paniotov, S.V. Bobrovitskiy

National Metallurgical Academy of Ukraine

Liquid-phase iron reduction processes are the real alternative to the blast furnace technology. Since any liquid-phase iron reduction process is, as a matter of fact, energetic-metallurgical, its optimal for particular conditions technological regime and its design solution are appreciably determined by a ratio of prices for different energy sources, first of all–for coal and electric power. The most effective realization of the liquid-phase iron reduction processes is possible now at the integrated metallurgical works in place of small inefficient blast furnaces with the use of entire blast furnace infrastructure.

Keywords: IRONMAKING, LIQUID-PHASE IRON REDUCTION PROCESS, EFFICIENCY, OPTIMIZATION, INDUSTRIAL REALIZATION

Introduction

The fact that the blast furnace process as the main technology for obtaining primary metal from ore will sooner or later give way to cokeless processes was described long time ago by not only metallurgy popularizers, but also professional scientists. However, until now there is still no real alternative to the blast furnace.

Used to a limited extent (5-7% of world production of iron) the processes of (Midrex, HYL, SL/RN, etc.), as well as processes of predominantly solidphase reduction (Corex, Finex, etc.) occupy a certain place in the world iron industry. They produce metallized iron product or cast iron for subsequent processing into steel mainly on mini-works, but they will never be the mass technology for economic reasons. Total energy and financial expenses of steel production according to such schemes is higher than the traditional technology (blast furnace + basic oxygen furnace).

Blast furnace is one of the most economical units due to countercurrent movement of the furnace charge materials and gases. But, nevertheless, this economy is not as high as one may think. By incomplete combustion of fuel in the combustion zones only about 30% of the calorific capacity of coke, and 5% of the calorific capacity of natural gas are used. Despite the almost complete heat exchange, in the blast furnace due to its characteristics as a countercurrent heat exchanger waste gas temperature is high enough (up to 300°C and higher), and the use of heat of blast furnace gas because of its high dust content is impossible.

Reduction potential of the gases in the blast furnace is implemented by approximately 40%. Purified blast furnace gas is used at iron and steel companies as a fuel, but this gas is very dangerous, because it contains about 20% of the CO. The calorific capacity of blast furnace gas is about 10 times lower than natural gas, because of what during its burning a lot of smoke fumes per unit of heat are received and the utilization of heat cannot be high.

Blast furnace process - is unique in its complexity. There is no other technology with such set of heterogeneous processes, interconnected to each other. Therefore, optimization of the blast furnace process is extremely complicated.

Blast-furnace operation requires an expensive and scarce coke, the price of which increases even faster than the price of natural gas. Blast furnace process requires quality iron ore raw materials, production of which gives the lion's share of pollutant emissions in the ore mining and smelting sector.

In comparison with the problems of blast furnace liquid-phase iron reduction processes are very attractive, at least because they do not require coke and iron ore and can operate with any power station coal and any iron-containing materials, but they are fatally unlucky. Theoretically based more than 100 years ago [1], they have long found no effective implementation because of the two main obstacles: heavy slag foaming and the complexity of heat supply to the slag bath. For the first time the reality and effectiveness of the liquid-phase iron reduction processes were practically proved in 1985 at an industrial and in fact experimental installation at the Novolipetsk Steel. The authors of this technology, later called the Romelt process, were the members of the National University of Science and Technology «MISIS»[2]. Nowadays except the Romelt process, such processes as HIsmelt, DIOS, Ausiron [3-5] are ready for commercial development. However, none of the liquid-phase iron reduction processes has yet received industrial use.

Difficulties of the initial industrial development of the liquid-phase iron reduction processes are connected with the fact that by their very nature they are energy and metallurgical processes. Produced in liquid-phase iron reduction aggregates cast iron may indeed be much cheaper than pig iron, but only with efficient use of waste gases energy, mainly for electricity generation, what is unconventional and requires additional investments. Besides, these new processes are implemented as 100% alternative to highly developed blast-furnace process, what also alarms and holds back the investors.

Results and Discussion

The most effective and ready for commercial use are single stage liquid-phase iron reduction aggregates. Their organization resolves itself as follows. Iron-bearing materials are supplied to the slag bath by gravity or blown by gas. They dissolve in slag. Iron oxide are reduced from slag with the help of coal carbon, which is also supplied by gravity or blown into the bath. In order to intensify heat and mass transfer slag bath bubbling with oxidizing gas, which is injected under the surface of the slag, is carried out. Gas containing CO and H_2 evolves from melted slag. Gas is burnt out top blowing. The heat of afterburning mostly provides thermal requirements of the processes occurring in the slag bath. A key element of effective process organization is active heat transfer between the zone of post-combustion and slag bath.

Since the intensity of the process is determined by the amount of heat absorbed per unit of time by the slag bath, the possible burning of pulverized coal fuel in bubbling blast supplied to the slag can significantly increase the efficiency and productivity of liquid-phase iron reduction aggregates. This technology is twice more effective, because it further increases power of bubbling blast without increasing its mass flow. Fuel combustion in the depth of slag bath requires special burners.

During such processes as Romelt and Ausiron, where all the coal is supplied to the surface of the slag, most of its mass remains in the surface layer of the slag bath. Only small particles of coal are involved in the bubbling of slag to the main volume of slag bath [6]. At the same time maintaining of high temperature in the reaction zone by combustion of coal in oxygen bubbling blast in the depths of the slag bath is impossible, although it is declared by the authors Romelt process [2]. Pieces of non-wetted coal can be pushed out from the slag into the popping-up air bubbles, but for 1-3 sec of its floating coal can be burned only in a very small degree.

According to the practice of implementing liquid-phase iron reduction process, the intensity of iron reduction from slag by carbon supplied to the slag is very high. The rate of reduction depends on the concentration of FeO in the slag, as well as on its temperature. The main source of heat in liquid-phase iron reduction aggregates of Romelt type is the burning of coal and gas that are released from the slag in the combustion zone. For assimilation of this heat slag requires a very active and intensive mixing of slag splashes in the combustion zone by means of bubbling.

During the HIsmelt process lump coal is not supplied into the slag bath. Pulverized coal fuel is blown together with iron ore raw materials into cast iron, providing its active carbonization [5]. Reduction of iron here goes by means of cast iron carbon not in microscopic volumes on the surface of coal pieces, but in a controlled reaction zone, formed by blowing. Because of this, the intensity of ruduction is increased, and the process becomes stable and more manageable, although it is achieved at the expense of complexity of not only preparation of coal and iron ore charge, but also the design of the aggregate and service conditions.

So far almost all reasonable options for liquid-phase reduction process are not only offered, but also tested in large-scale semi-industrial plants. Analysis of test results of various processes, published in literature, our own analytical calculations based on balances and mathematical models, as well as quantitative restrictions identified for each process can prove

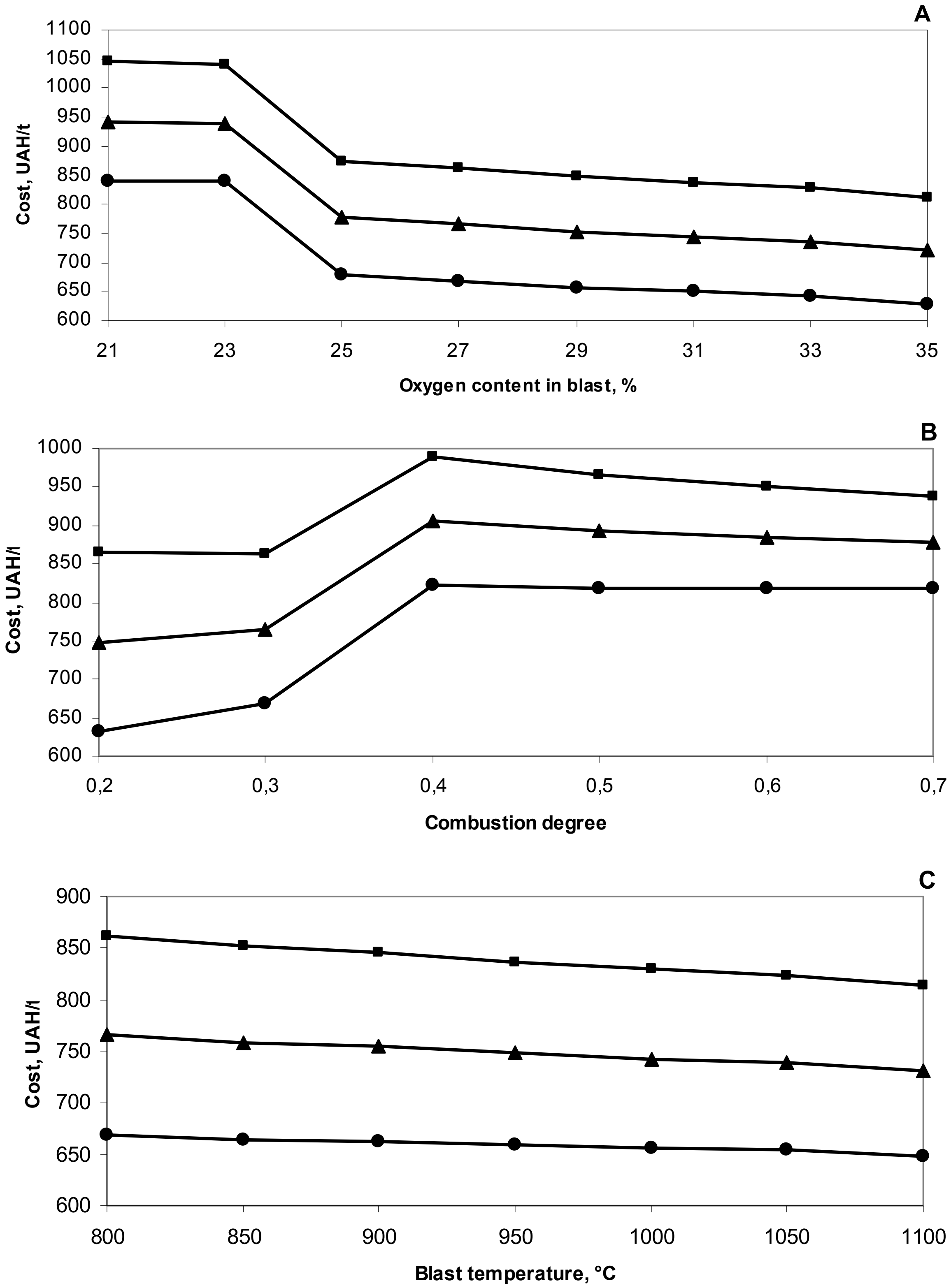

Figure 1. The impact on the cast iron cost of oxygen content in the blast (A), the degree of gas combustion in the working space of the liquid-phase iron reduction aggregate (B) and the blast temperature (C) at different prices of coal: —●— 320 UAH/t —▲— 400 UAH/t —■— 480 UAH/t

for any specific conditions optimal design of liquid-phase iron reduction aggregates and optimal process flow sheet.

Energy intensity for iron smelting can be used as an optimization criterion, but since liquid-phase iron reduction aggregate ensures the production of significant amounts of electricity, the most logical and natural measure for solving the optimization problem is the cost of pig iron with the restrictions on the volume of investment. Optimization problem is solved automatically.

Selection of the optimal mode is based on a mathematical model of the liquid-phase reduction. Developed in NMetAU model is based on material and heat balances of the process. Since the main model is the calculation of the required flow of coal for smelting of one iron unit, a key element of the model is analysis of the thermal performance of liquid-phase iron reduction aggregate. For the universalization of the model there is possibility of using hot blast and supplying coal both to the surface of the slag and the depth of the slag bath in the form of pulverized coal fuel together with an oxidizer. Besides, in order to provide almost complete post-combustion coal in the working space of the liquid-phase iron reduction aggregate supplied to the surface of the slag, if the given degree of afterburning exeeds 70% (which is the maximum possible degree of post-combustion of fuel in one-bath aggregates of the type Romelt and Ausiron), the transition to liquid-phase iron reduction double-bath aggregate modeling is provided. Herewith the first bath is designed for melting and partial reduction of iron materials during full combustion of waste gases and the second bath, where the coal is supplied, - for the final reduction to iron by carbon coal with a partial post-combustion of evolved gases. The possibility of pre-heating and drying of the charge is not provided because such an option, as shown by our study and calculations, is technically too difficult and economically impractical.

The results of solving the problem of choosing the optimal parameters of the liquid-phase reduction of iron depend mainly on the imposed constraints and prices for various energy sources, as shown in **Figure 1, 2.**

Figures show as an example the results of the cast iron cost calculation, which is melted by the technology close to Romelt and Ausiron technologies, with the use of iron ore concentrate, lean coal concentrate, divided into fractions and partially blown into the slag, and hot blast. The variation of individual parameters was carried out here while maintaining a constant base level of the values of other parameters, in particular: the degree of post-combustion of gas in the furnace working space 0.5; the blast temperature 1000°C; the oxygen content in the blast 21%. The range of variation of coal consumption for all calculated options was from 740 to 1100 kg / t of cast iron.

With the current ratio of prices of coal and electricity the reducing of the degree of gas post-combustion in the aggregate workspace from 0.4 to the admissible minimum, as well as increasing of oxygen concentration in the hot blast from 23 to 25% in this example significantly lower potential cost of cast iron in relation with possible power generation during this transition from steam to gas-steam cycle.

At a lower price for the generated electricity, what is inevitable if it is sold to electro-distributing companies rather than consume it for own needs, thereby reducing the consumption of purchased electricity, increasing the concentration of oxygen in the blast has little effect on the cost price of cast iron.

The liquid-phase iron reduction technology is universal. It can be used for preferential production of high quality and cheap cast iron, as well as for primary power station coal gasification and production of hot reducing gases, in particular, suitable for gas-steam cycle of power generation with efficiency almost twice higher than for conventional thermal power plants. Choosing the appropriate composition of the charge for liquid-phase iron reduction aggregate, it is possible to obtain, except for cast iron, slag clinker for production of super-cement - alkaline binder. This versatility makes the liquid-phase iron reduction technology especially effective in short-term fluctuations in metal prices on world markets and in times of economic crisis.

One of the most important conditions for improving the efficiency of liquid-phase iron reduction is the use in this process hot blast and due to this transition to low-oxygen or even oxygen-free technology. The air heated to 1200°C gives the same combustion temperature as cold oxygen. But the blast is heated up to 1000°C only in HIsmelt aggregate according to a very complex process flow. The industrial design of the aggregate capacity of 800 tons of cast iron per year is built in Australia. Difficulties in industrial development of the HIsmelt aggregate are highly related to the provision of heating the blast by means of waste gases. All other technologies of liquid-phase iron reduction aggregate, including Romelt technology, based on which a mini-factory in Myanmar (formerly Burma) is being built, are mainly oxygenous processes.

The most realistic initial industrial

development of liquid-phase iron reduction process in Ukraine could be implemented within the blast furnace of an integrated steel plant in place of decommissioned inefficient blast furnace, in order to make maximum use of its infrastructure and to heat the blast for liquid-phase iron reduction aggregate by blast furnace gas existing air heater. Structurally the aggregate can be implemented using mainly standard equipment in the blast-furnace and conventional power plants. The main

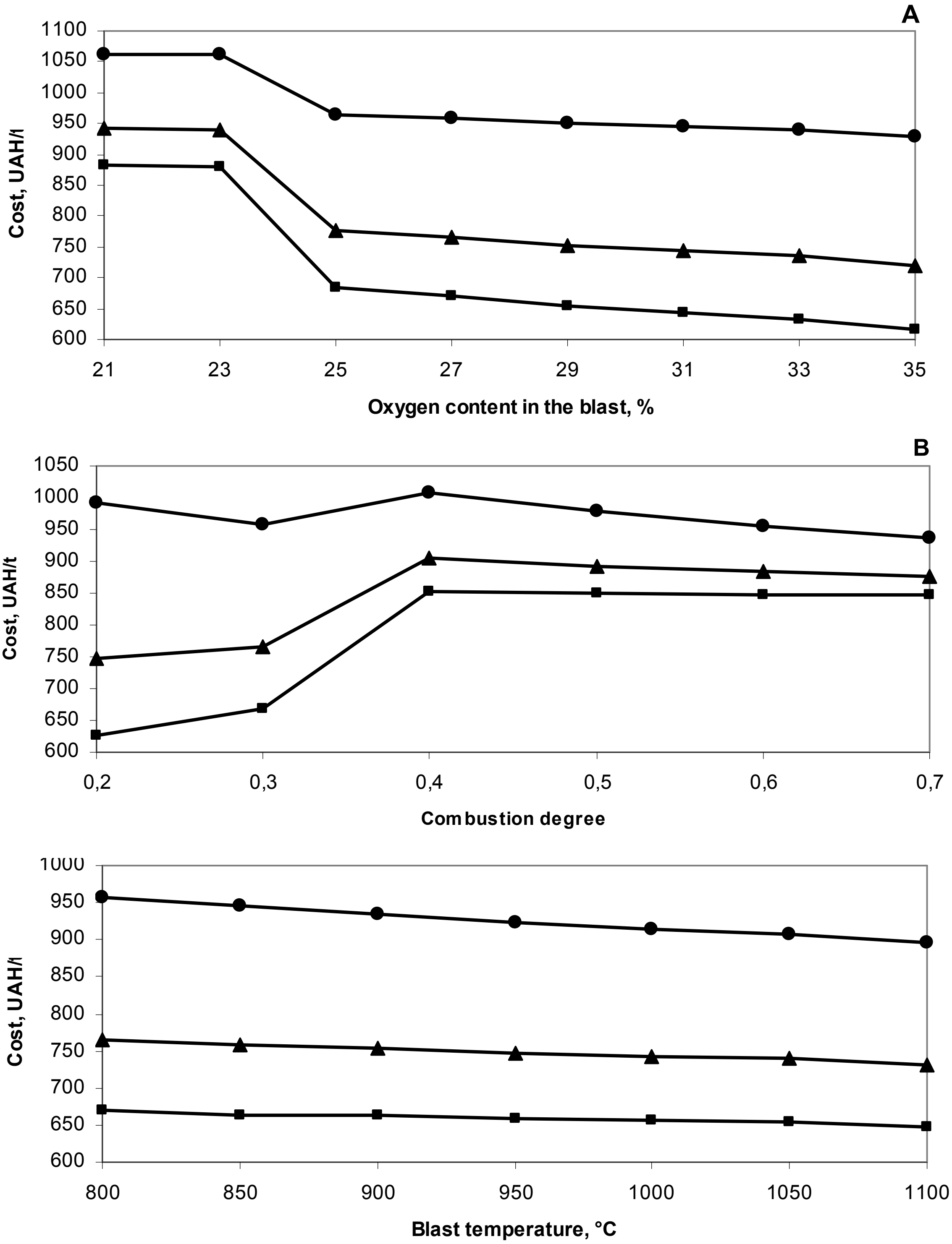

Figure 2. The impact on the cast iron cost of oxygen content in the blast (A), the degree of gas combustion (B) and the blast temperature (C) at various price of the produced electricity: 240 UAH/MWh 400 UAH/MWh 560 UAH/MWh

problem is lack of investors willing to invest without an immediate guaranteed return into creation of original technology that could be the beginning of revolutionary changes in iron industry [7].

Conclusions

The analysis shows that the liquid-phase iron reduction processes, which during large-scale tests proved their advantages compared to blast furnace ironmaking technology, but they are not yet accepted by investors and even some scientists as a real alternative to the blast furnaces. For the initial industrial development of new efficient liquid-phase iron reduction technologies it is rational to implement it in the current blast-furnace plant in place of decommissioned inefficient blast furnaces with the use of their infrastructure and provision of blast heating by means of blast-furnace gas.

References

1. Chernov D.K. *O pryamom poluchenii litogo zheleza i stali v domennoi pechi*, Sb. “D.K. Chernov i nauka o metallah”, Moscow, GosNTI po chernoi i tsvetnoi metallurgii, 1950, pp. 307–327. *

2. *Protsess Romelt*, pod red. V.A. Romenetsa, Moscow, MISIS, Izdatelskii dom “Ruda i metally”, 2005, 400 p. *

3. Romenets V.A. *Novye perspektivy proizvodstva metalla: sostoyanie i perspektivy*, Metallurg, 2001, № 11, pp. 30–38. *

4. Kurunov I.F., Savchuk N.A. *Sostoyanie i perspektivy bezkoksovoi metallurgii zheleza*, Moscow, Chermetinformatsiya, 2002, 198 p. *

5. Bates P., Coard A. *HIsmelt, the future in ironmaking technology*, Proceedings of the 4-th European Coke and Ironmaking Congress. June 19-22, 2000, Paris, France, Vol. 2, pp. 597–602.

6. *Povedenie uglya v shlakovoi vanne pechi Romelt*, A.V. Balasanov, A.B. Usachev, V.Ye. Leherzak i dr., Izv. vuzov. Chernaya metallurgiya, 1999, № 7, pp. 12–17. *

7. Tarakanov A.K., Ivashchenko V.P. *Tendentsii i perspektivy razvitiya proizvodstva chuguna v Ukraine,* Stal, 2002, № 8, pp. 13–16. *

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Перспективы промышленного использования процессов жидкофазного восстановления железа (ПЖВ)

Тараканов А.К., Иващенко В.П., Паниотов Ю.С., Бобровицкий С.В.

Процессы жидкофазного восстановления железа (ПЖВ) являются реальной альтернативой доменной технологии. Поскольку любой процесс жидкофазного восстановления является по своей сути процессом энерго-металлургическим, его оптимальный для конкретных условий технологический режим и его конструктивное решение в значительной мере зависят от соотношения цен на разные энергоносители, прежде всего,– на уголь и электроэнергию. Наиболее эффективная в настоящее время реализация ПЖВ возможна на интегрированных металлургических предприятиях на месте малых выводимых из эксплуатации неэффективных доменных печей с использованием всей их инфраструктуры.