TRANSITION TO INNOVATIVE METALLURGICAL TECHNOLOGIES – PRIORITY DIRECTION OF DECARBONIZATION

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Abstract

The article systematically analyzes the transition to innovative metallurgical technologies in the context of the priority direction of decarbonization. It is determined that at present the main direction of decarbonization can be considered the rapid development of electrometallurgy. Within the framework of this direction, oxygen blowing of liquid metal, extra-furnace treatment, the use of powerful transformers, automatic melting control, processing with synthetic slags, melting in induction furnaces, preliminary heating of the charge, and the widespread use of injection metallurgical processes are recognized as innovative technologies.

Reducing energy consumption in the production of electric steel has been put forward as the main task of metallurgical technologies. Two main directions of decarbonization in the steelmaking complex have been identified: intensification of smelting based on increasing the capacity of the furnace transformer and the introduction of modern "oxygen" technologies and a modular system in smelting.

Keywords: innovative technologies, decarbonization, priority areas, electrometallurgy, extra-furnace processing, injection processes

I. Introduction

It is known that the production of ferrous metallurgy is an industry with a large harmful impact on the environment and large-scale carbon dioxide emissions. Global climate change requires increased innovation activity in the metallurgical industry. The transition to innovative technologies can be considered as a priority direction of the decarbonization process in metallurgy. The main vector of this direction is electrometallurgy or the production of electric steel.

Current trends show that more than 80 percent growth in the use of the electric method in general steel production in recent decades is due to the introduction of innovations. Therefore, researchers propose to evaluate the criterion for accelerating innovative technologies in steel production as a derivative function of innovation growth (million tons/year), (million tons/year2) [1].

Researchers and specialists constantly analyze the role of innovative technologies in increasing the competitiveness of metallurgical products. It has been shown that innovative metallurgical technologies will play a decisive role in improving the quality of metal products in the coming decades and will ensure the protection of the leading positions of countries in the world market [2]. For example, in [3] the issue of removing hydrogen from the surface of liquid metal using a circulating vacuum as an innovative metallurgical technology is considered. It is shown that the removal of hydrogen from the metal surface in a circulating vacuum chamber is a long process and occurs at a very slow rate.

Analytical calculations have shown that removing hydrogen from the surface of liquid metal in the chamber of a circulation vacuum cleaner is not enough to obtain a low residual amount of hydrogen in the metal, and for this it is necessary to carry out additional technological measures.

II. The role of innovative metallurgical technologies in decarbonization of the environment.

In [4], promising innovative directions for the development of steelmaking were studied. It was shown that the share of electric steel in global steel production is more than 30%, in the USA this figure is approaching 40%. The main reasons are indicated as process flexibility, less dependence on the composition of primary raw materials, the possibility of producing alloy steels of various compositions and purposes, the use of large amounts of scrap metal, the possibility of automating processes and environmental aspects, and the rapid growth of electric steel production.

Based on the analysis of the current situation in metallurgical production, it has been determined that modern electric arc furnaces (EAF) have essentially become a smelting unit, significantly freed from the "dirty" metallurgical processing of steel.

Therefore, the priority development of electric steelmaking can be considered as the main direction of technical progress in metallurgical production. It is noted that the total energy consumption of EAF steel production is 1.5-1.8 times less than that of oxygen converters.

The study [5] presented the inevitable direction of development of electric smelting in the metallurgy of Russia, especially in the Ural region. It was shown that the technical and economic indicators of electric arc steelmaking furnaces (electrode consumption, melting time, energy consumption, etc.) have significantly improved in recent decades.

Out-of-furnace steel treatment processes are indicated as a major contribution to the achievements of electrometallurgy. Thus, out-of-furnace treatment allowed not only to abandon long cycles of melt reduction and oxidation and, therefore, to increase furnace productivity, but also to save energy and materials. Mainly, this allowed to significantly improve the quality of steel, to obtain steel with fundamentally new properties.

Thus, the conducted research allows us to consider the following processes as innovative in electrometallurgy: 1. Oxygen blowing. 2. Out-of-furnace processing. 3. Water-cooled panels. 4. High-power transformers. 5. Extended-arc welding. 6. Automated monitoring and control. 7. Foam plastic processing. 8. Use of water-cooled arcs. 9. Use of a new type of burner. 10. Tapping metal from the furnace bottom. 11. Ladle furnace processing. 12. Tapping liquid metal without residues ("swamp" melting). 13. Primary heating of the plate. 14. Injection methods or rubbing and blowing with gases.

In the context of the listed innovative technologies, methods for increasing the productivity of modern electric arc steelmaking furnaces were studied in [6]. It was shown that electric arc furnaces currently play an important role in steel production as the main metallurgical unit. EAFs, out-of-furnace processing units and continuous casting machines together make it possible to obtain high-quality steels with significantly lower energy costs and minimal impact on the environment.

It is shown that reducing the metal overheating temperature in the furnace is an effective method for increasing the EAF productivity. The necessity of such measures as high-temperature heating of furnace masonry, preliminary heating of materials added during the melting process, and the widespread use of heat-protective materials in the masonry of furnaces and fireboxes as methods for ensuring this process is substantiated.

The use of efficient energy-saving technologies in the steelmaking complex is considered in [7]. The analysis of technical and economic indicators of an electric steelmaking plant is carried out using an electric arc furnace as an example. Reducing energy costs in the production of electric steel is put forward as the main task of metallurgical technologies in our country.

The following are recommended as the main operations when implementing efficient energy-saving technologies:

1. EAF should be considered only for slag melting and obtaining liquid metal. All cleaning operations should be carried out using extra-furnace methods.

2. Steel smelting should be carried out using the advantages of liquid or "swamp" technology.

3. Only single-pass electric welding technology should be used in EAF. This technology involves increasing the capacity of the furnace transformer to 95 MVA and introducing a "furnace-ladle" device.

4. Minimization of heat losses in the furnace and firebox, preliminary heating of scrap metal, regular feeding of loading baskets into the furnace should be ensured.

5. To intensify the melting process, a modular system should be used. Here we consider such tricks as using fuel-oxygen burners, switching to oxygen injection and carbon blowing, and operating the furnace on long arcs.

6. It is necessary to ensure that the oven is constantly operating in foamed bags. This technology allows you to screen the electric arc operating in long arcs, protect the masonry and water-cooled panels of the furnace. Due to the injection of carbon, the technological advantage creates conditions for foaming of the resin during the reaction with oxygen.

It should be noted that in recent years much attention has been paid to the use of injection technologies in metallurgical production. Thus, in [8] it is shown that injection technologies are currently considered as a promising direction, widely used in metallurgy. This technology is used for processing alloys with materials similar to powders and for reducing heat-technical units.

The above studies showed that most metallurgical processes occur predominantly at the phase separation boundary, and the rate of these processes is determined by the total area of the contact surface. Intensification of the mixing of metal, resin and gases accelerates the course of physicochemical reactions in metallurgical furnaces.

This technology opens up wide possibilities for dephosphorization, desulphurization, deoxidation and alloying of steel, acceleration of slag formation, and carbonization of metal. Higher efficiency of this method is noted when feeding powder materials into the alloy in a gas flow.

The paper [8] also describes the characteristics of injection equipment for the implementation of injection technologies. The main process parameters determining the efficiency of injection technology are considered. As a result of experimental, calculation-analytical and design work, the main parameters of the powder gas flow in the injection metallurgical system were the carrier gas velocity, the mass density of the gas-dust mixture, the critical speed of pneumatic transport, the type of chamber blower (aerator and pneumatic-mechanical). It was determined that as a result of the use of this technology, a significant increase in the durability of the circulation vacuum cleaner pipes is observed.

In [9] the issue of reducing energy costs in the process of steel smelting in a large-tonnage electric arc furnace is considered. It is shown that at present the concept of steel production development is based on innovative technologies of energy-resource-saving and environmentally friendly production of electric steel.

Thus, modern metallurgical technologies include: utilization of heat from furnace gases; use of high-power electric transformers and alternative energy sources in the furnace; application of "oxygen" technologies to intensify smelting; foaming of pulp and combustion of process gases; synchronization of electrical energy and chemical energy of exothermic reactions

Studying the best practices of ferrous metallurgy enterprises allows us to identify two main areas of modernization of the steelmaking complex:

1. Intensification of the smelting process and application of modern "oxygen" technologies based on increasing the nominal power of the furnace transformer.

2. Application of a modular system (DANARC, Italy, DANIELI) in smelting processes.

The DANARC modular system combines maximum utilization of thermal energy, formation of foamed pulp and decarbonization of the liquid bath in one unit. The DANARC modular system has the following advantages over traditional equipment:

- blown coal dust is completely burned in the oxygen cylinder;
- efficient transfer of thermal energy is ensured in the bath;
- stationary placement of the module in the furnace frame is possible;
- ease of operation and minimal maintenance requirements.

It has been determined that the following results can be expected from the use of the DANARC modular melting system: increase in unit productivity - 17.3%; decrease in specific electricity consumption - 7.3%; reduction in defrosting time - 16.1%; decrease in specific electrode consumption - 39.4%; decrease in specific natural gas consumption - 14.8%.

The ways of increasing the productivity of electric arc furnaces are studied in [10]. It is shown that in the last 15-20 years the tendency of continuous increase in production of electrical steel in the world is clearly evident, and at present it makes up 40% of the total volume of steel production. The share of electrical steel in the USA is 45%, in Italy 60%, in Spain 72%, in Azerbaijan 80%.

The advanced development of electric steel production is associated with the direct application of advanced technical and technological developments and allows for a significant improvement in the technical and economic indicators of electric smelting. Increasing the productivity of electric arc furnaces is considered a complex task for metallurgists and power engineers and involves reducing the three main periods of smelting: preparatory, power and technological.

It has been established that further increase in EAF productivity can be ensured by better preparation of slag material for melting (slag scattering density 1.4-1.8 t/m2) and preliminary slag heating (400-500°C). These measures allow saving electricity by 70-75 kW.s/t, reducing melting time by 10-12%.

It is shown that after melting the slag, it is necessary to create and maintain a foamy pulp by blowing coke and oxygen to reduce radiation to the walls and roof of the furnace, as well as to ensure a "closed" arc combustion mode.

Increase in EAF productivity can also be achieved by conducting the melting process cycle in a single-pass mode, reducing the reduction cycle and conducting a number of cleaning processes with extra-furnace treatment.

Therefore, an important direction for increasing EAF productivity is increasing the capacity of the furnace transformer to 800-900 kVA/t. At this time, it is considered appropriate to increase the secondary voltage to 900-960 V.

In [11] it is shown that at present both rolled products and continuously cast blanks are widely used in the production of metal products. It is shown that the use of continuously cast blanks is more economically convenient, since in this case there is no need for additional rolling operations. In addition, the use of continuously cast blanks allows for a significant reduction in scrap metal, an increase in the output of healthy products, an increase in the productivity of rolling units and an improvement in working conditions.

In our country, the development of efficient technologies for the production of pipes and sheets from continuous casting is a pressing task for metallurgical enterprises. At the same time, the use of continuous casting machines allows reducing the cost of pipes by 10% and increasing the productivity of the pipe rolling unit by 15%.

A review of literary sources on the topic under study was conducted and the features of the change in the shape of the metal during radial sliding spreading of the works of Chekmarev A.P., Vatkin Yu.L., Potapov Yu.N., Polukhin P.Yu., Smirnov V.S., Fomichev Yu.A., Teterin P.K., Sveikin V.V., Kolikov A.P., Nikulin A.N. were determined and the works of other well-known scientists were analyzed.

Particular attention is paid to the advantages of the radial-sliding spreading method over other deformation methods. The intensity of compaction of the structure over the entire crosssection of the blanks, the possibilities and advantages of various schemes of the stress-strain state of the blanks are noted.

The conducted theoretical and practical studies allowed us to come to the following main conclusions in the analyzed work. The features of profiling the rear end of the workpiece in the form of a truncated cone and changing the shape of the cone of the workpiece during rolling on three-roll compression and piercing machines, based on the joint implementation of rolling processes on a compression machine, were determined.

Based on the products obtained during production tests and modeling using the Deform-3D program, it was established that smaller values of compression depth are observed when compressing a truncated cone blank 70 mm long.

During the physical and mathematical modeling of the process of profiling the end of the workpiece, it was found that as the profiling speed increases, the metal delaminates on the surface. Rational calibration and deformation modes have been developed, ensuring compression-free molding at the rear end of a truncated cone of a 70 mm long workpiece.

The process of profiling the tip of a workpiece with a cooled outer layer was simulated. It was found that cooling the outer layer at the end of the workpiece before profiling allows for a significant reduction in the depth of compression. In this regard, a cooling unit should be provided for in the working design for the reconstruction of the input section of a three-roll press machine.

In [12] it is shown that the fuel and energy complex of our country places serious demands on the products of the pipe industry. However, despite numerous theoretical and technological works, the problem of increasing the efficiency of seamless pipe production remains relevant.

The capabilities of pipe factories do not allow producing oil-quality pipes with a guaranteed level of properties that meet the technical requirements of developed countries. 95% of seamless pipes abroad are produced by continuous casting.

During the research work, the basic requirements for metal quality were scientifically substantiated and the following technological processes for the production of high-quality continuous casting blanks were developed:

- technology for the production of highly reliable oil and gas pipeline pipes operating at pressures up to 50 MPa;
- technology for the production of highly corrosion-resistant oil and gas pipeline pipes operated at low temperatures down to minus 60°C;
- technology for smelting carbon and low-alloy steels, furnace and out-of-furnace processing, continuous casting of square and round section pipe blanks.

III. Application of injection technology in metallurgy for decarbonization

Recently, interest in injection technologies has increased significantly, which are considered one of the most common technologies and one of the promising areas in metallurgy. These technologies are used for processing alloys with powder materials, as well as for gunning heating equipment units.

Shotcreting is a method of applying concrete mixture to a surface layer by layer under compressed air pressure [13].

It is known that most metallurgical processes occur at the phase boundary. The speed of these processes is determined by the total area of the contact surface. Intensification of the mixing of metal, resin and gases significantly accelerates the course of physical and chemical reactions [13].

A greater effect is achieved by accelerating alloy flows and simultaneously increasing the specific surface area of the reacting phases. These processes occur when using injection technologies. The high efficiency of this method is demonstrated when injecting powder materials into a metal alloy from a gas-bearing flow.

This method is used for dephosphorization, desulfurization, deoxygenation, acceleration of rust formation during steel alloying, and also for metal carbonization. In addition, injection of refractory materials can be used for twisting the mesh surfaces of metallurgical units [14].

Successful application of injection technologies depends on the use of injection equipment that provides a greater number of processes. In the 70-80s of the last century, work on the use of rapid carbonization of metal was carried out at various metallurgical plants.

At that time, pneumatic blowers manufactured in these establishments were used. The necessary scientific, technical and design research, operations and calculations were not carried out during the creation of these objects. Mainly for this reason, this promising method of metal processing has not yet found wide application [15].

In addition, work on improving injection technologies, especially on the design of powder blowing devices, has been developed abroad for many years.

The work carried out has led to the successful development of innovative metallurgical technologies in Japan, Germany, Austria, America and other countries. This promising direction has made it possible to intensify metallurgical processes, improve the quality of metal, and increase the service life of smelting units in these countries.

In the mid-90s of the last century, German injection devices were first used at the Serp and Molot plant (Moscow) with the participation of the Metallurgical Institute of the Russian Academy of Sciences.

In 1999-2000, the Institute of Metallurgy of the Ural Branch of the Russian Academy of Sciences completed the international project "Application of Casting Technologies at Metallurgical Enterprises of the Urals". As a result of studying the experience of applying casting technologies at European metallurgical plants, as well as research on the application of various powder materials to the alloy, it was recommended to continue work on equipping metallurgical enterprises with injection devices [16].

In this regard, there was a need to create casting equipment that is no different from foreign analogues in terms of quality, reliability and durability, but also meets the operating conditions of metallurgical enterprises in our country, and at the same time is significantly cheaper than imported ones [16].

For example, in the Russian Federation, experimental, computational-analytical and design work was carried out on the aerodynamics of powder-gas flows in injection-metallurgical systems and the influence of operating and design factors on the intensity of the output of sprayed materials from a pneumatic-mechanical feeder [17].

As a result of the conducted scientific research and experimental design work, the main parameters of powder gas flows in casting metallurgy systems were selected. The carrier gas velocity value is taken as the main parameter of the carrier gas flow mode.

One of the main characteristics of a two-phase flow is the mass density of the mixture, which is defined as the ratio of the mass flow rate of the solvent to the mass flow rate of the gas. At that time, gas-rubber mixtures with a mass flow rate of 2 to 60 kg/kg were used for blowing metal.

The critical speed of pneumatic transport was assessed as the main parameter ensuring the reliability of the blowing structure as a whole. One of the main and determining factors influencing the successful operation of injection equipment is the correct choice of the chamber blowing system.

Currently, two types of equipment are used for injection technologies: aeration and pneumatic-mechanical. Aeration-type chamber blowers are used for deep injection of powder materials and partially for reducing torque. In recent years, pneumatic chamber blowers have become increasingly widespread in the world. They are used for twisting stone surfaces, as well as shallow injection of powder materials into metal alloys.

Such blowers have a design more suitable for the operating conditions of metallurgical production in our country, are simple and reliable in operation, and have a wide range of applications. As a result of research and development work for injection metallurgy, a pneumatic-mechanical type design was chosen as a chamber blower [18].

This type of air blower is equipped with a tray dispenser, which is placed horizontally in the lower part of the working chamber. The dispenser has a separator ball wheel, the speed of which is regulated by an electric motor equipped with a frequency converter.

In 2001, the NIM-01-2 injection device for blowing powdered materials into a liquid alloy in an open-hearth furnace was put into operation at the plant in the Russian Federation. Work on the application and development of metal carbonization technology continues here. In 2002, an injection device for tightening pipes of a circulating vacuum cleaner of the NIM-01-4 type was put into operation. A new design was developed, manufactured and launched into production, cutting off the flow of gunite mass with the ability to adjust the angle of dispersion from 30 to 360 degrees for internal gunning of vacuum cleaner pipes. As a result of the device's introduction, the service life of the circulating vacuum cleaner pipes has increased significantly.

IV. Conclusions

1. The transition to innovative metallurgical technologies was systematically analyzed in the context of the priority direction of decarbonization. It was determined that at present the main direction of decarbonization can be considered the rapid development of electrometallurgy. In this direction, blowing liquid metal with oxygen, using physicochemical methods in extra-furnace (ladle furnace) processing, using powerful transformers in electric furnaces, automated control and management of melting, in the processing of synthetic resins. "Swamp" melting in induction furnaces, preliminary heating of slag, and widespread use of injection metallurgical processes were assessed as innovative technologies.

2. Reducing energy costs in the production of electric steel is put forward as the main task of metallurgical technologies. Two main directions of decarbonization in the steelmaking complex are defined: intensification of metallurgical processes based on increasing the capacity of the furnace-transformer and the introduction of modern

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