Steelmaking: current state and development directions

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Abstract. The analysis of the current state and development directions of steelmaking was performed. The main trends of changes in production, technical and economic indicators of steelmaking in Russian metallurgy are considered. The main directions for the improvement of technological processes are determined.

1. Introduction
Metallurgical engineering in Russia is at the forefront of global steel production, which in 2018 according to the World Steel Association (WSA), increased by 4.6% in comparison to 2017 [1]. At the same time, China, with the production volume of 928.3 million tonnes, remains the leading country in steel production. India occupies the second position and has increased its production by 4.9% to 106.5 million tonnes, overtaking Japan where the production has dropped by 0.3%. The USA holds the fourth position – 86.7 million tonnes, the increase by 6.2%. Russia moved to the sixth position, after South Korea, with an output of 71.8 million tonnes which is 4% of global production.

2. Current state of steelmaking
The converter process is the main method of steel production (table 1) in the world. Converters produce more than 60% of the world steel production, which is due to their high productivity, sufficiently high lining resistance, relative simplicity of the design and equipment operation, and technological flexibility in the composition of cast iron. At the same time, the change in the scrap metal market has led to a decrease in the cost of converter steel production as compared to electric steel.

Currently, in the Russian metallurgy 8 oxygen-converter shops with 23 converters are operating, 10 of them are with volume of 300-350 tonnes, 13 – 160 tonnes. The steel production by the oxygen-converter method slightly decreased in 2018 and amounted to 64.1%, and the production of electric steel increased to 33.7%. With the withdrawal of capacities at the Vyksa Steel Works, smelting of open-hearth steel decreased by the end of the year to 2.2%. The volume of continuous casting has increased. Extra-furnace steel processing has been actively introduced – the volume of steel processed in ladle-furnace assemblies has increased, as well as the volume of evacuated steel [3].

Table 1. Steel production in the regions of the world, mln tonnes [2].

| Region, country                      | 2017    | 2018    |
|-------------------------------------|---------|---------|
| World production (according to the data of 66 countries) | 1729.8  | 1808.6  |
| Including Europe (with the CIS)     | 311.7   | 311.8   |
| EU (28 countries)                   | 168.5   | 168.1   |
Change in the structure of metal processing in the industry allowed the cost of metal charge to be generally reduced by 0.8 kg/t for steel production. In the composition of the metal charge, the cast iron consumption was reduced by 10.8 kg/t, the consumption of steel scrap was slightly increased. The remaining components of the metal charge did not change significantly. The converter shops maintain a steady tendency for reduction of cast iron consumption. The largest reduction was achieved in the converter shops of Magnitogorsk Iron and Steel Works (-10.3 kg/t), Cherepovets Steel Mill of PAO Severstal (-20.1 kg/t) and Chelyabinsk Metallurgical Plant (-21.5 kg/t). In the whole industry the reduction in cast iron consumption for converter steel production amounted to 7.8 kg/t (table 2).

As a result, the specific energy intensity of converter steel has been reduced compared to 2017 in all converter shops of the industry. EVRAZ ZSMK and Cherepovets Steel Mill of PAO Severstal still have the minimum specific energy intensity of converter steel. The high energy intensity of converter steel at EVRAZ NTMK is associated with the technology features of steel smelting by the duplex process in order to obtain vanadium slag. According to the results of 2018, the energy intensity of converter steel in the industry is 614.6 kg cf/t, which is 9.4 kg cf/t lower than in 2017.

### Table 2. Change in specific consumption of cast iron in the converter steel production, kg/t [2].

| Company                                | 2017   | 2018   | Change  |
|----------------------------------------|--------|--------|---------|
| In total in the industry, kg/t:        | 924.1  | 916.3  | -7.8    |
| EVRAZ ZSMK                             | 836.8  | 835.8  | -1.2    |
| Magnitogorsk Iron and Steel Works      | 891.8  | 881.5  | -10.3   |
| Cherepovets Steel Mill of PAO Severstal| 893.8  | 873.2  | -20.6   |
| NLMK                                   | 933.1  | 935.1  | +2.0    |
| Chelyabinsk Metallurgical Plant        | 1030.4 | 1008.9 | -21.5   |
| EVRAZ NTMK                             | 1079.5 | 1078.7 | -0.8    |

The peculiarity of the converters operation with top oxygen blowing is a relatively small fraction (20 – 45%) of smelting high-quality and alloyed steels, which is due to the low efficiency of converter bath agitation; uneven chemical composition and metal temperature; excessive oxidation of metal and slag during the smelting of low-carbon steels; some problems in controlling the bath behavior, especially during foaming and emissions generation; limited options in terms of improving the heat balance of smelting.

In the 80’s of the last century the introduction of a process with top oxygen blowing and inert gas bottom blowing ensured intensification of bath agitation, control of slag formation and dephosphorization process, increased the yield of iron and manganese. However, the application of a slag skull to increase the durability of the converters lining led the manufacturers to abandon the bottom blowing in favor of the process of slagging of lining.

The integral components of modern technology of converter steel production are: the use of special designs of blowing devices; cut-off of slag to reduce its ingress from the converter into the ladle during production; process automation to ensure sustainable results; emission control system to increase yield, improve process control and ensure staff safety; the use of special models to predict various scenarios of the converter shop from the position of minimizing the cost of resources and time for the production and execution of technological operations [3, 4].
In electric furnace steelmaking at enterprises with a full metallurgical cycle, the share of cast iron in the charge remained almost unchanged – from 15 to 41%. In mini-mills the share of cast iron in the metal charge remains within the range from 0.07 to 1.4%, with the exception of Izhtal PAO and Vyksa Steel Works, where the share of cast iron was 12.3 and 11.1%, respectively. At individual enterprises of this group, there is a tendency to abandon completely the use of cast iron in the charge (table 3).

**Table 3. Specific consumption of cast iron in the production of steel in electric arc furnaces, kg/t [2].**

| Group | Company                                           | Cast iron consumption, kg/t | The share of cast iron in the charge, % |
|------|---------------------------------------------------|-----------------------------|----------------------------------------|
| 1    | Magnitogorsk Iron and Steel Works                 | 188.0                       | 16.5                                   |
|      | EVRAZ ZSMK                                        | 279.8                       | 25.1                                   |
|      | Ural Steel                                        | 471.3                       | 39.1                                   |
|      | Cherepovets Steel Mill of PAO Severstal           | 408.0                       | 38.5                                   |
|      | Chelyabinsk Metallurgical Plant                   | 250.3                       | 22.3                                   |
|      | Nadezhdinski Metallurgical Plant                  | 397.1                       | 34.4                                   |
| 2    | Volgograd Metallurgical Plant Krasny Oktyabr      | 27.4                        | 2.4                                    |
|      | Metallurgical Plant “Electrostal”                 | 19.2                        | 1.7                                    |
|      | Izhtal PAO                                        | 201.7                       | 17.7                                   |
|      | Zlatoust Steel Mill                               | 0.9                        | 0.08                                   |
|      | Seversky Pipe Plant                               | 1.5                        | 0.13                                   |
|      | Taganrog Metallurgical Plant                      | 0.3                        | 0.02                                   |
|      | Volzhsky Pipe Plant                               | 0.0                        | 0.0                                    |
|      | Vyksa Steel Works                                 | 124.8                       | 11.2                                   |
|      | NLMK-Kaluga                                       | 6.0                         | 0.55                                   |
|      | Pervouralsk New Pipe Plant                        | 0.9                        | 0.08                                   |
|      | Abinsk Electrometallurgical Plant                 | 4.3                         | 0.38                                   |
|      | Ashinsky Metallurgical Plant                      | 0.0                         | 0.0                                    |

In the whole industry the share of cast iron in the charge is 10.7%, which corresponds to the level of 2017. In specific terms the consumption of cast iron for electric smelting decreased by 0.6 kg/t and amounted to 122.4 kg/t. The specific energy consumption of electric steel, in addition to the consumption of cast iron and metallized pellets, is greatly influenced by the consumption of electricity for smelting. At Chelyabinsk Metallurgical Plant an increase in electricity consumption by 239 kW·h/t with an unchanged proportion of cast iron in the composition of the metal charge increased the energy intensity of electric steel by 91 kg cf/t. At OEMK, due to the increase in the share of metallized pellets in the charge by 3% and energy consumption by 12.6 kW·h/t, the energy intensity of steel increased by 18.2 kg cf/t. At Volzhsky TK, a decrease in energy intensity of steel by 41 kg cf/t is associated with a decrease in consumption of energy by 105.7 kW·h/t and metallized pellets by 11.4 kg/t. Data on the specific energy consumption in the production of electric steel is given in table 4.

**Table 4. Specific energy consumption in the production of electric steel, kW·h/t [2].**

| Company                                           | Consumption, kW·h/t | Change |
|---------------------------------------------------|---------------------|--------|
| Russia                                            | 453.5               | -5.4   |
| Magnitogorsk Iron and Steel Works                 | 345.3               | +68.0  |
| Cherepovets Steel Mill of PAO Severstal           | 283.6               | +1.5   |
| Ural Steel                                        | 292.2               | -26.0  |
| EVRAZ ZSMK                                        | 430.8               | -12.6  |
| Chelyabinsk Metallurgical Plant                   | 348.4               | +239.0 |
| Nadezhdinski Metallurgical Plant                  | 314.2               | +13.1  |
| Volgograd Metallurgical Plant Krasny Oktyabr      | 494.5               | +134.5 |

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Electric steel production is rapidly developing due to the fact that the electric furnace is a universal unit in terms of mobility, metal oxidation, furnace atmosphere and the proportion of the liquid charge, which makes it possible to melt any product in it.

The electric furnace, with the development of technologies and equipment, has gradually turned into a universal melting unit equipped with fuel burners and tuyeres for blowing gas and pulverized coal materials, oxygen blasting, bottom agitation devices, devices for preheating the charge, eccentric bottom tapping. The productivity of electric furnaces has more than doubled over the past 20 to 30 years. The power of electric furnace transformers reaches 1000 MVA, the melting time decreased from 120 to 40 minutes, as well as the specific consumption.

3. Results and discussion

The development of extra-furnace steel processing methods has significantly changed the technological process of smelting and casting. The electric furnace has evolved from a steelmaking unit to a charge melting unit. All further operations: refining, alloying and adjustment in composition and temperature before the continuous casting machine are carried out in extra-furnace steel processing units.

Thus, further unification of modern methods of steel production is observed. The converter and the electric furnace are turning into units for the smelting the intermediate product. In the production chain they are followed by the units of extra-furnace steel processing [3, 4]. The steel is treated after being tapped from the unit in various types of vacuum vessels to obtain low concentrations of dissolved gases and non-metallic inclusions in it. Units ‘ladle-furnace’ with vacuum processing are the most versatile; practically all steel processing can be carried out in them, especially if it is possible to flush slag from the ladle. The improvement of the plants is mainly aimed at intensifying the metal agitation in the ladle. It is being carried out by improving the equipment for inert gas injection, the location of the blowing devices, the period and intensity of gas injection; for units of batch and vacuum processing – by improving the design of the chamber and nozzles.

To improve the technological effectiveness of steel casting at the continuous casting machine, it is recommended to reduce the cross section of the workpieces and increase the casting speed, as well as the use of curved machines; the use of intermediate buckets of increased capacity and height; crystallizers with a taper of variable height, with a more perfect swing mode; electromagnetic braking of steel flows in the mold and soft compression of the unhardened ingot in the secondary cooling zone [3].

The recent increase in the requirements for product quality in the metal market determines the corresponding requirements for the quality of steel scrap in terms of the content of non-ferrous metal impurities, as well as physical properties. Moreover, steel scrap preparation technologies used in domestic metallurgy do not always solve these problems. It is necessary to improve the traditional composition and technological regime of the formation of solid metal charge using, in particular, iron-containing products of steelmaking slag processing [5].
The most important component of the metal charge in steelmaking is cast iron. At the same time, external desulphurization of cast iron has become widespread, as well as its desiliconization and dephosphorization. A decrease in the silicon content in cast iron to 0.30 – 0.35% provides not only the possibility for subsequent external dephosphorization and efficient low-slag technology in the unit, but also allows significant saving in the smelting of cast iron to be achieved [3].

In steelmaking, much attention is paid to reduction of costs for refractory materials. Therefore, in the smelting of steel in converters and arc steel furnaces, high-magnesia fluxes are widely used, which makes it possible to increase MgO content in slag, reduce its aggressive effect on the lining and obtain a refractory protective coating on the lining [4].

4. Conclusion

In accordance with the developed provisions, the scientists of the university scientific school together with the specialists from EVRAZ ZSMK have developed the main directions for improving steelmaking processes in modern conditions:

- improvement of steelmaking technologies to reduce the specific consumption of raw materials and materials, as well as improve product quality;
- reduction of the environmental impact from steelmaking and increase in the degree of industrial waste recycling, including slag, gases and associated energy flows;
- maintenance of the steelmaking competitiveness throughout the entire life cycle of the enterprise.

References

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