Converter steelmaking process: state, dominant trends, forecasts

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Abstract. The analysis of the current state and prospects of development of converter industry in the world is performed. Technological features of steel smelting in Russia and the main directions of process improvement are considered.

1. Introduction
At present, world steel production is 1628 million tonnes, which is an order of magnitude higher than the production of aluminum, magnesium and the production of plastics [1]. At the same time, according to the data of the World Steel Association in 2016 there was a certain increase in the output of steel compared to 2015. It is characteristic that the last 50 years the steel smelting has grown mainly in developing countries [2], the main contribution to this process has been made by the PRC, which accounted for 49.6% of world production in 2016. Accordingly, the steelmaking in such countries and regions as Japan, NAFTA, EU, the CIS decreased by about half with relatively small changes in absolute figures.

2. Results and discussions
Thanks to the contribution of China, the share of smelting of converter steel has increased in the world, which reached 74.3% in 2016; the share of electric steel was 25.3%, the open-hearth furnace steel – 0.4% (table 1).

As can be seen from table 1, steelmaking in 28 EU countries amounted to 162 million tonnes, with a share of converter steel of 60.3%. The ratio of the smelting processes in the EU varies from country to country, which is explained by the historically developed range of production, i.e. requirements of consumers of rolled metal, and the trajectory of development of ferrous metallurgy. For example, in Germany converter steelmaking industry prevails with a share of 70.1% out of 42.1 million tonnes due to the focus on the production of sheet products for the automotive industry.

The share of converter steel in Russia is 66.9% with a total production of 70.8 million tonnes.

World experience of many years in the operation of oxygen converters has shown the merits of the latter: high productivity, sufficiently high lining stability, relative simplicity of construction and operation of equipment, technological flexibility in the composition of processed cast irons. At the same time, there is a number of significant drawbacks, which include the low efficiency of mixing the converter bath; the unevenness of the chemical composition and temperature of the metal; excessive oxidation of metal and slag during smelting of low-carbon steels; some problems in controlling the behavior of the bath, especially when foaming and generating emissions; limited opportunities in terms of improving the heat balance of melting.
Table 1. Structure of world steel production in 2016 [1].

| Country                        | Steel production, mln. tonnes | Converter steel, % | Electrical steel, % | Open hearth steel, % |
|--------------------------------|-------------------------------|--------------------|---------------------|----------------------|
| Austria                        | 7.4                           | 91.0              | 9.0                 | -                    |
| Belgium                        | 7.7                           | 69.3              | 30.7                | -                    |
| Czech Republic                 | 5.3                           | 94.4              | 5.6                 | -                    |
| Finland                        | 4.1                           | 67.1              | 32.9                | -                    |
| France                         | 14.4                          | 66.1              | 33.9                | -                    |
| Germany                        | 42.1                          | 70.1              | 29.9                | -                    |
| Italy                          | 23.4                          | 24.3              | 75.7                | -                    |
| Netherlands                    | 6.9                           | 98.7              | 1.3                 | -                    |
| Poland                         | 9.0                           | 56.8              | 43.2                | -                    |
| Slovakia                       | 4.8                           | 93.7              | 6.3                 | -                    |
| Spain                          | 13.6                          | 33.9              | 66.1                | -                    |
| Sweden                         | 4.6                           | 67.3              | 32.7                | -                    |
| United Kingdom                 | 7.6                           | 80.6              | 19.4                | -                    |
| EU (28 countries)              | **162.0**                     | **60.3**          | **39.7**            | -                    |
| Turkey                         | 33.2                          | 34.1              | 65.9                | -                    |
| Other                          | 4.5                           | 44.1              | 55.9                | -                    |
| Other European countries       | **37.7**                      | **35.3**          | **64.7**            | -                    |
| Russia                         | 70.8                          | 66.9              | 30.8                | 2.4                  |
| Ukraine                        | 24.2                          | 71.7              | 6.8                 | 21.4                 |
| Other CIS countries            | 7.3                           | 56.9              | 43.1                | -                    |
| CIS                            | **102.4**                     | **67.3**          | **26.0**            | **6.7**              |
| Canada                         | 12.6                          | 55.4              | 44.6                | -                    |
| Mexico                         | 18.8                          | 26.2              | 73.8                | -                    |
| USA                            | 78.5                          | 33.0              | 67.0                | -                    |
| NAFTA                         | **109.9**                     | **34.4**          | **65.6**            | -                    |
| Argentina                      | 4.1                           | 56.7              | 43.3                | -                    |
| Brazil                         | 31.3                          | 77.3              | 21.1                | -                    |
| Other                          | 3.8                           | 7.3               | 92.7                | -                    |
| Central and South America      | **40.9**                      | **67.5**          | **31.3**            | -                    |
| Egypt                          | **5.0**                       | **11.4**          | **88.6**            | -                    |
| South Africa                   | 6.1                           | 62.2              | 37.8                | -                    |
| Other African countries        | 1.9                           | 33.8              | 65.9                | -                    |
| Africa                         | **13.1**                      | **38.5**          | **61.4**            | -                    |
| Iran                           | 17.9                          | 12.2              | 87.8                | -                    |
| Saudi Arabia                   | 5.5                           | -                 | 100.0               | -                    |
| Other Middle Eastern countries | 8.1                           | -                 | 100.0               | -                    |
| Near East                      | **31.5**                      | **6.9**           | **93.1**            | -                    |
| PRC                            | **808.4**                     | **94.8**          | **5.2**             | -                    |
| India                          | 95.6                          | 42.7              | 57.3                | -                    |
| Japan                          | 104.8                         | 77.8              | 22.2                | -                    |
| South Korea                    | 68.6                          | 69.3              | 30.7                | -                    |
| Taiwan                         | 21.8                          | 64.2              | 35.8                | -                    |
| Other Asian countries          | 25.9                          | 6.9               | 93.1                | -                    |
| Asia                           | **1 125.0**                   | **84.6**          | **15.4**            | -                    |
| Total                          | **1 628.3**                   | **74.3**          | **25.3**            | **0.4**              |

*aassessment
In order to eliminate the shortcomings of the upper oxygen blowing in the late 60’ s of the last century, a new converter processes with a bottom supply of fuel-oxygen blowing spread. However, the forecasts of significant advantages of bottom oxygen-fuel blowing were not justified. At the same time, a number of positive results (the possibility of intensification of blowing, increased prime yield savings in ferroalloys, etc.) served as an incentive for the development of combined converter processes.

In the 80’ s of the last century, a converter process was developed with an upper blowing of oxygen and a bottom blowing of inert gas. According to this technology, up to 80% of the world’s converters worked [2]. Bottom blowing intensified the bath mixing, increased the yield of iron and manganese, facilitated the control of slag formation and the process of dephosphorization. However, the appearance of the process of bath slagging to improve the stability of the converters lining led to the fact that the producers began to sacrifice bottom blowing in favor of the lining slagging process. Nevertheless, integral components of modern technology are: the combination of the upper oxygen blowing with bottom blowing of inert gases; use of special designs of blowing devices; cutoff of slag to reduce its entry from the converter into the ladle during discharge; automation of the process to ensure sustainable results; an emission prevention system to increase yield, improve process control and ensure the personnel safety; use of special models to predict various scenarios of the converter shop from the viewpoint of minimizing the costs of resources and time for the production and execution of technological operations [3].

The development of modern converter production aims at achieving traditional goals: improvement of products quality, reduction of production costs, increase in the productivity and improvement of environmental protection. In the world, the use of steel scrap is steadily increasing, reaching 590 million tonnes in 2016. But the ratio of the mass of liquid iron to the mass of the smelted steel increases and reached 74%. At the same time, in the crisis year 2009 it was 82%. With regard to converter steel production, it is expedient to provide process flexibility for the use of a metal charge in a wide ratio of different melting coolers and with a reduced proportion of cast iron. Replacing cast iron scrap, as it is known, dramatically reduces the energy intensity of steel and labour costs for its production.

In accordance with the developed provisions in the work of converter plants in Russia in 2017 for the first time in the last few years the tendency was observed to reduce the consumption of cast iron (table 2) [4]. The greatest decrease was achieved at EVRAZ NTMK (-10.4 kg/t).

Figure 1 shows the results of calculating the energy intensity of converter steel [4]. Despite the reduction in the consumption of pig iron, the energy intensity of the converter steel at EVRAZ ZSMK increased by 10 kg f.e./t as a result of the increase in the energy intensity of pig iron.

On the whole, the energy intensity of 1 tonne of converter steel according to the results of work in the first quarter of 2017 was 626.7 f.e./t, which is 7.1 f.e./t lower than the in same period in 2016 (figure 1).

Table 2. Change in the specific consumption of pig iron in the production of converter steel, kg / t.

| Company       | 1st quarter of 2016 | 1st quarter of 2017 | Change  |
|---------------|---------------------|---------------------|---------|
| As a whole on branch | 924.6               | 923.1               | -1.5    |
| EVRAZ ZSMK    | 831.9               | 829.4               | -2.5    |
| MMK           | 894.8               | 886.1               | -8.7    |
| CherMK        | 906.5               | 899.7               | -6.8    |
| NLMK          | 942.2               | 938.9               | -3.3    |
| ChelMK        | 969.7               | 1003.9              | +34.2   |
| EVRAZ NTMK    | 1085.8              | 1075.4              | -10.4   |
The recent increase in the requirements for the quality of products in the metal market predetermines the corresponding requirements for the quality of steel scrap on the content of non-ferrous metal impurities, as well as physical properties. However, the amount of recycled scrap is reduced due to the improvement of the technology of continuous casting of steel, and in the amortization scrap due to repeated remelting the content of individual elements, contributing to the decrease in the performance properties of metal products, is increased. At the same time, the effectiveness of technologies for preparing steel scrap for converter smelting in domestic metallurgy does not always solve these problems.

Under the current conditions, it seems expedient to improve the traditional composition and technological regime for the formation of a solid metal charge with the use, in particular, of iron-containing products for the processing of dump converter slags, the processing technology of which remains technologically primitive and ecologically imperfect [5].

Despite the modern developments, cast iron remains the most important component of the metal charge when steel is smelted. At present, the converter process is considered as a complex process, including the preparation of cast iron, the actual smelting process and the out-of-furnace refining of steel, including its processing in the intermediate ladle of the continuous casting machine.

Extensive desulphurisation of cast iron, as well as its desiliconization and dephosphorization, was widespread. Reducing the silicon content in cast iron to 0.30-0.35% provides not only the possibility of subsequent secondary dephosphorization and effective low-slag technology in the converter, but also allows significant savings in the smelting of cast iron to be obtained. In general, this is becoming one of the main areas for improving technology in the blast furnace – basic-oxygen converter.

To obtain low concentrations of dissolved gases and nonmetallic inclusions in the converter steel, it is treated after being discharged from the unit in various types of vacuums. In the world, 27% of the steel produced is evacuated, in Japan – up to 50%.

The ladle furnace with evacuation is the most versatile, it is possible to carry out practically all the steel processing, especially if it is possible to load slag from the ladle. The improvement of facilities is mainly aimed at creating conditions conducive to the acceleration and deepening of metal refining. This is primarily an event that contributes to the intensification of metal mixing in the ladle. They are implemented by improving the equipment for inert gas injection, the location of blowing devices, the period and intensity of gas injection; for the units of batch and circulating evacuation – the improvement of the design of the chamber and inlet branch.
To improve the processability of casting of converter steel on continuous casting machine it is recommended to reduce the cross-section of billets with increase in casting speed in order to keep the productivity; it is advisable to use curvilinear machines for all types of blanks; to use intermediate buckets of increased capacity and height; crystallizers with a variable cone, with a more perfect swing mode; electromagnetic slowdown of steel flows in the mold and soft compression of the non-solidified ingot in the secondary cooling zone; thermal action on the workpiece in the end zone of solidification; use of technologies of “hot landing” of blanks in heating devices before rolling [3].

Much attention in the world metallurgy is paid to reduction of refractory materials costs in the production of converter steel. The requirements for the stability of the converters lining have predetermined the following world trend in the use of refractories: from the use of resin-bonded dolomite, then periclazodolomite and periclase, backed periclase impregnated resin in vacuum, to refractories of periclase-carbonaceous composition with antioxidant additives that are widely used at present.

Thanks to the use of periclase carbonaceous refractories, in combination with the “hot” repairs, which is an important component of the converter lining servicing, a record-breaking performance was achieved – 20 thousand (USA), 30 thousand (China), 7 thousand (Russia) smeltlings [3]. A certain role in improving the lining stability is also played by laser systems for measuring the profile and walls of local wear of refractories, which automatically scan and output data on their condition for the operative application of corrective measures.

It is characteristic that in the Russian metallurgy, high-magnesia fluxes are widely used in the smelting of steel in converters; this allows the MgO content to be increased in the slag, its aggressive effect to be reduced on the liner, and a refractory protective coating on the lining to be obtained when the slag is blown [6]. “Hot” repairs also include welding, semi-dry and/or flame gunning with the supply of gunite masses based on backed magnesite or dolomite using horizontal and vertical types.

To improve the efficiency of hot repairs of the converter lining, it is recommended to use special designs of gas-cooled tuyeres that provide for joint (separate) application of slag skull by blowing the final slag with nitrogen jets and flare gunning of lining with cheap gunning mix based on unfired magnesian slag-forming materials [7].

3. Conclusion
In accordance with the developed provisions, the scientists of the university scientific school together with the specialists of EVRAZ ZSMK have developed various options for steelmaking processes in oxygen converters using natural raw materials and man-made waste that ensure resource saving and rational use of the technological environment in the region. The inventions found application in the enterprise, which made it possible to increase the efficiency of converter production and the quality of metal products.

At present, research of the process of steel smelting in oxygen converters is carried out using iron-containing products for processing converter slags in solid metallurgy, and the development of new refractory coatings and materials, methods for hot repairs of the converter lining and devices for their implementation, which reduce the cost of refractories.

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