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SYSTEM IMPROVEMENT OF VANADIUM HOT METAL PROCESS AT EVRAZ NTMK

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Evraz NTMK, hot metal, vanadium, titanomagnetites, staflux, oxygen, pulverized coal (PC)

ABSTRACT

Evraz NTMK boosted the rate of its blast furnace process and cut down the coke rate critically over the last decade. This progress was based on the improved design of NTMK blast furnaces themselves, as well as improved process conditions, V staflux practice introduced in the process, higher oxygen in the blast air and use of PCI. The blast furnaces after some upgrades gave a chance to improve certain process parameters of the blast furnace process that uses titanomagnetites. In particular, lower Si in the hot metal at the same temperature level of the hot metal as before was made possible thanks to the pressure of gases boosted inside the furnace. For improvement of burden conditions, it is related to developments of the practice for production and application of V staflux, which took raw materials out of the burden, reduced the number of components and fixed the problem of FeV waste disposal. The staflux implemented in the smelting process improved the venting quality of melting stock column and reduced specific gas output, which created a precondition for intensification and power saving activities without having to worry about any failures in the operation of the blast furnaces to be run smooth. Which is why higher oxygen in the blast air (at least 30%) plus PCI were the next logical steps taken to improve the ironmaking practice.

The higher rate of the smelting process made it possible to shut down the other blast furnaces, which were obsolete and deteriorated, without any critical output loss. At the moment, the blast furnaces of Evraz NTMK show the best performance and cost-efficiency not only in Russia, but also throughout the world.

Using titanomagnetites in the V hot metal process has a few specific features. The final target of titanomagnetite process is to recover vanadium together with iron reduction. If done right, the blast furnace process is to fully transfers vanadium to the hot metal at the minimum loss of vanadium compared to other products of the smelting process.

Vanadium is a hard-reducing element and the key condition for its maximum transition to the hot metal is the higher process temperature. The accepted truth [1] is that the key complications of titanomagnetite process are related to high-melting-point Ti compounds (carbonitrides) generated as an individual phase between the slag layer and hot metal layer, whereas higher heating rate contributes to titanium dioxide recovery and titanium carbide generation in the hearth [2]. This is the principal inconsistency of this process and it makes the relationship of temperature level and vanadium recovery much more complicated. The process conditions are set in the trade-off manner and is determined by vanadium recovery on one side, and the titanium recovery rate on the other side so that to keep an opportunity to run the blast furnace at its normal performance. As the ironmaking process runs with surplus carbon the blast furnace should be operated at the high rate and as cold as possible to prevent over-reduction of titanium. All the values that help the furnace to run smooth at high rate are critical in this case.

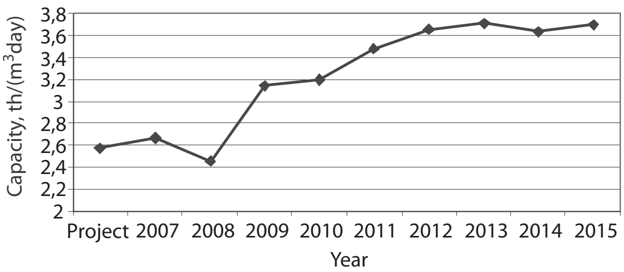

Fig. 1. Specific performance variation for the blast furnaces (per working volume), average for the Iron Shop

Evraz is the only company in Russia that can process titanomagnetite ore from burden materials into final products, since Evraz is one of the most critical vertical group of companies in steelmaking and mining business [3, 4]. Evraz runs a few companies that produce vanadium ore materials and use them in their processes:

– Evraz KGOK (Kachkanarskiy Mining and Processing Complex) mines the ore, processes it into concentrated ore and then into sintered materials like sinter and pellets;

– Evraz NTMK (Nizhniy Tagil Metallurgical Plant») operates the blast furnaces that processes sintered materials of Evraz KGOK into V hot metal, and a converter steel shop that produces its steel with the duplex process (i.e. the fist process step makes DeV hot metal plus V slag, the second step uses DeV hot metal to make steel);

– Evraz Vanadiy Tula uses V-slag (i.e. the final product of NTMK) to produce pure vanadium pentoxide (V_2O_5) and various V-alloys..

At the moment Evraz NTMK uses two blast furnaces after rebuild and upgrade, each having the working volume of 2200m^3. The technology used here has the following specific features: the iron ore in the burden includes sintered Ti material of Evraz KGOK plus V-staflux; the high rate of the blast furnace process due to higher oxygen in the blast air; the coke rate is low due to extensive use of powder coal and natural gas.

The smelting rate was critically ramped up in the ironmaking process of NTMK over the last years. See Figure 1 for the trend of specific performance variation for the blast furnaces in terms of the working volume (volume inside the furnace from tuyere level to the stockline level).

That critical ramp-up of the ironmaking process rate and improvement of the technology is based on the upgraded ironmaking facilities. Two high-performance blast furnaces were launched through 2004 to 2006 i.e. BF6 in 2004 and BF5 in 2006). The furnaces were designed, built and equipped with account taken of the latest advance of the ironmaking process throughout the world [5 – 8].

The upgrade of the blast furnaces included the following key solutions: The furnace stack profile has an alternating slope angle, the design is improved for the top shell rings, and the dimensions are optimized for other parts of the furnace profile. Each blast furnaces has a self-supporting shell. The hearth and bottom refractory is carbon blocks and graphite blocks protected with a ceramic cup. The furnace is equipped with an advanced cooling system. Each furnace has 22 tuyere stocks, two iron tapholes and two cast houses. The furnaces charging operation is full automatic, burden materials are delivered from the high line hoppers to the skips by belt conveyors, double bell charging gear is replaced with a chute type bell-less top. The air blast is pre-heated in Kalugin stoves and blown with brand-new advanced turbine compressors. The gas cleaning systems was critically upgraded as well as the dedusting systems of the highline hoppers and cast houses. The blast furnaces are equipped with an emergency water supply. Computerized control systems are used in the production process.

The upgrades of BF5 and BF6 made them meet up-to-date performance standards, ensured high serviceability, reduced pollutant emissions greatly and improved working conditions. This created preconditions for high performance at low power consumption.

The burden material feeds downwards and the hot blast blows upwards [9]. There are two different ways to control the blast furnace process conditions i.e. it can be controlled with downward force and with upward force, as the furnace is controlled basically by altering parameters of its inputs. The process condition control with the downward force means to observe the charging condition, to timely adjust the charging condition and the burden material composition. The process conditions are controlled with the upward force by changing parameters of the fuel-enriched blast (blast-aided control).

The system improvement of titanomagnetite process involves optimized parameters for blast and charging, and their harmonization to reach maximum performance, minimum possible consumption of total fuel, maximum extraction of vanadium into hot metal and to prevent over-recovery of titanium. The following are the most important actions taken to improve the V hot metal process in the Iron Shop of Evraz NTMK:

1. using upgraded BFs to master the V hot metal process (through 2006 to 2007), which included developing new charging practices with the use of BLT;

2. scheduled Si minimization in the hot metal (from 0.15–0.20% down to 0.05–0.10%) through 2006 to 2007;

3. mastering the smelting process with V staflux in 2009;

4. ramping up oxygen in the hot blast from 24% to 30% (and more) through 2010 to 2011;

5. mastering PCI practice with natural gas through 2012 to 2013.

The upgrade of BF6 in 2004 and BF5 in 2006 required new process conditions for V hot metal production on one hand, and made it possible to improve a few process parameters of titanomagnetite smelting process on the other hand. In particular, with the BLT installed, it gave place to fundamentally new charging conditions capable to provide smooth running of the process and steady composition of the hot metal [10]. It was always critical for titanomagnetite smelting process to provide a stable process. Defining an optimal sequence of skip charging and introducing initial (partial) blending of sinter and pellets helped to improve the process stability [11]. This provided off-grade S in the hot metal reduced by 1.4% of the absolute level and V recovery increased by 1.1% of the absolute level.

With BLT and new turbine compressors, the furnace gas pressure can be boosted and, thus Si in the hot metal is cut and, as a consequence, the processes that produce hard-melting Ti compounds are suppressed, the performance of the furnaces ramps up, the coke rate reduces and recovery of V grows [12, 13]. Indeed, since Si and Ti recovers at an increased volume of gases,

$$SiO_2 + 2C = [Si] + 2CO \text{ and } TiO_2 + 2C = [Ti] + 2CO,$$

the boosted furnace pressure prevents such recovery provided that the temperature is steady, i.e.:

$$[Si] = \frac{A}{p^B} \text{ and } [Ti] = C \cdot [Si],$$

where A, B, C – empirically determined ratios.

Moreover, lower Si helps Ti to dissolve in the hot metal, which diminishes the probability of titanium carbides and titanium carbonitrides precipitating from the metal into an individual phase. At the average, the pressure boosted by ~100 kPa made it possible to cut Si from 0.14% down to 0.07–0.08% in the hot metal, cut the coke rate by 10–15kg/t of hot metal and ramp up the performance of the furnaces by 5–10%.

The technology used before 2009 had the following disadvantages:

– high consumption rate of raw limestone in the burden material (over 60kg/t of HM) to maintain the slag basicity required, which caused additional heat input to decompose it;

– multiple components of the burden (5 persistent components including coke), for instance, manganese oxides were added separately as Mn sinter to prevent titanium carbide generation;

– improper use of wastes with Fe, V, Mn, Ca, which came out in high end-to-end losses of V and Mn.

To fix the above issues and improve end-to-end V recovery, a V-waste recycling practice[1] was developed for the blast furnace process, for which reason a V-staflux production facility was launched. The basicity level of the staflux made it possible to remove the raw limestone from the burden material provided that the sinter-pellets ratio meets the target, and for the Mn lost during long-term warehousing outdoors, Mn was added in the staflux process charge to make up for Mn loss. Further, the V-staflux facility began to recycle V-wastes of the Chemical Plant and of the Steel Shop.

The V-staflux facility was launched at the Sinter Plant of OAO VGOK (Vysokogorskiy Mining Complex). This company is also located in Nizhniy Tagil and runs an open lime stone pit. It does not need to use mainline railways to deliver its product. These things make the staflux production cost low.

Once mastered, the V-staflux smelting process gave the following changes in the cost-performance ratio: the specific performance rose from 2.8 to 3.2 t/m^3 per day, the coke rate dropped from 421 to 403 kg/t of HM (i.e. by 18 kg/t), the Vanadium Recovery Ratio right in the blast furnace process rose by 2.5–3.0% of the absolute value (from 83.5 to 86.3%), and the end-to-end V recovery performance rose by ~3÷5% of the absolute value The consumption rate of Mn sinter imported was also cut by 40%.

Using the V-staflux of VGOK that lost some of its output in the world's economic crisis through 2008 to 2009 **gave that company an opportunity to keep about 500 jobs**, which for certain helped to relieve the social strain in Nizhniy Tagil.

Our company has a golden medal of XVIth International industrial exhibition "METAL-EXPO' 2010" for development and implementation of V hot metal process using V-flux.

Using staflux in the V hot metal process made it possible to remove sinter fines, lime stone and Mn sinter from the burden. It improved the burden's venting quality and the specific gas output (through CO_2 and limestone taken out and coke rate reduced). The specific top gas output was cut by ~50m^3/t of HM. Thus, using the staflux in the V ironmaking process makes it possible to implement activities that step up the performance and save the power without having to worry about the furnace to be run smoothly. That is why the next logical action to step up the process rate was increasing oxygen in the blast (**fig. 2**), which was actually done.

The effect of high-oxygen blast on the performance of the blast furnace process (even if it is just regular hot metal) is still disputable and not clear, as the indirect recovery rate drops and the gas-dynamic load of the process grows, alongside with the increased process rate, reduced specific blast rate and reduced top gas output.

Besides, defining the effect of different blast oxygen concentrations on the furnace performance and on the specific coke rate in the titanomagnetite process is complicated by its influence on the process of titanium carbide generation. High oxygen in the blast raises the theoretical temperature of the fuel combustion rate in the combustion zone and puts more heat in the high temperature zone of the furnace. That is why the idea was until recently that enriching the blast with oxygen over 25% does not make any use as it steps up the titanium recovery rate and makes the furnace operation unstable.

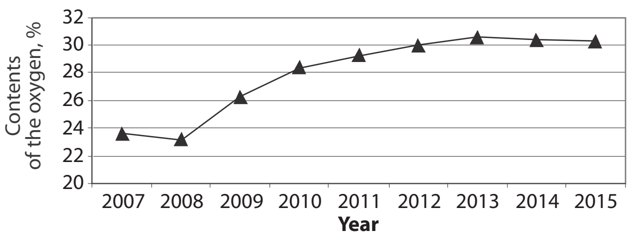

Fig. 2. Blast oxygen content change for V hot metal process

[1] With Ural Institute for Metals.

But performance tests and further commercial operation proved the efficiency of the blast with oxygen 30% and more. The specific performance climbed above 3.6 t/(m ^{3}·per day) and **reached the best performance values throughout the world**. The rate of V recovered to the hot metal was at the same time stepped up due to minimized V loss with dirty top gas and with scull.

The performance achieved can be explained with the fact that the higher oxygen in the blast comes along with partial CO pressure climbing in the hearth gases and with the higher rate of the process, which slows titanium carbide generation down. The higher partial pressure of CO shifts the balance of titanium reduction back. But with higher furnace performance, the difference grows between ferrum reduction rate and titanium reduction rate, which cuts the titanium in the hot metal and minimizes further precipitation of titanium carbides from the hot metal. Thus higher oxygen in the blast has an effect on titanium carbide generation in the opposite directions and the final effect is determined with reference to other parameters of the blast furnace process in each case specifically.

The effect of the smelting rate on the vanadium recovery ratio showed us after some analysis that it is growing as the performance of the blast furnaces grows (**fig. 3**).

As this takes place, the V lost with the slag does not change and keeps to the same level i.e. about 7% (relative). And the V recovery ratio grows due to reduced hot metal loss, reduced emission of dust and slimes, and V losses with the gas cut critically (three times), which was identified through the imbalance. Indeed, stepped up first with staflux and second with high oxygen in the blast, the smelting rate brings the specific top gas output down. Its temperature is also cut down with the second function. All of this provides the condition that prevent evaporating high oxides of vanadium.

The higher smelting rate made it possible to decommission all other blast furnaces that were obsolete and run-down, without any actual output losses i.e. the output of two furnaces we have right now is equal to the output as of 2004 that we had 5 furnaces).

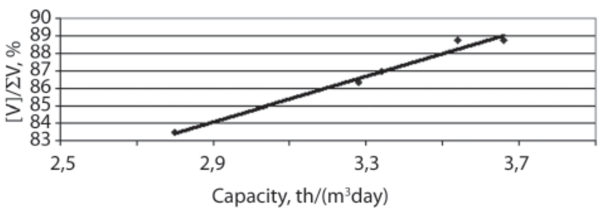

Fig. 3. Effect of smelting rate on vanadium recovery ratio

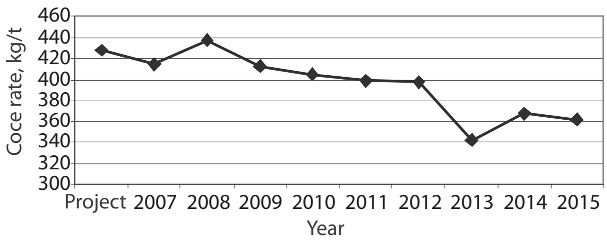

Fig. 4. Specific coke rate in the ironmaking process (average for the Iron Shop)

Blast furnaces operators experimented with pulverized coal injection many times starting from the mid fifties of the XXth century. [14, 15]. Yet, since natural gas was widely used in the blast furnace process, any efforts to implement pulverized coal in the commercial production were held. NTMK started experimenting with pulverized coal for the BF3 (absent by now) [16] through 1996 to 1997, however these efforts were stopped due to the raw material situation, which deteriorated very harshly from the beginning of 1998. Which is why we may consider that **Evraz NTMK** was **the first** in Russian Federation to implement pulverized coal in the blast furnace process for commercial use. Though we did not manufacture the PCI equipment we use, bringing this technology into operation is the accomplishment of NTMK people since there was nobody to share with us any experience of using PCI in vanadium ironmaking.

It's common knowledge that using powder coal in the blast furnace process has its benefits and risks [9, 17]. The benefits are the critically reduced consumption rate of the coke and a chance to improve its quality (for companies that have in-house coking plants), and ramped-up blast furnace performance thanks to expanded hot metal output per a unit of burden volume, and to boosted blast pressure). The key risks are related to the quality of coke and iron ore materials that is not high enough (to make it work perfectly well), unsteady composition of powder coal and the fact that it does not fully burn in the combustion zone.

This was confirmed by the experience of the Iron Shop of Evraz NTMK. Besides, some positive trends were detected to declined titanium recovery and minimized total fuel rate.

The coke rate was considerably cut (**fig. 4**) due to the system improvement of the smelting process and the package of actions taken.

Conclusion

Evraz NTMK boosted the rate of its blast furnace process and cut down the coke rate critically over the last decade. This progress was based on the improved design of NTMK blast furnaces themselves, as well as improved process conditions, V staflux practice introduced in the process, higher oxygen in the blast air and use of PCI .

Once again, the blast furnaces of Evraz NTMK show the best performance and cost-efficiency not only in Russia, but also throughout the world.

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STUDY OF THE EFFECT OF COMPLEX ALLOYING OF HIGH-MANGANESE STEEL BY Ti–Ca–N ALLOYING COMPOSITION ON ITS MICROSTRUCTURE, MECHANICAL AND OPERATING PROPERTIES

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Key words:

high-manganese steel, complex alloying composition titanium-calcium-nitrogen, quenching, cooling rate, crystallization

ABSTRACT

The paper presents examination of the effect of complex alloying of high-manganese austenite steel by Ti–Ca–N alloying composition (1–3%) in cast state and after quenching. The regularities of variation of grain size and austenite micro-hardness, amount of carbide phase, hardness, abrasive and impact-abrasive wear resistance are determined depending on amount of introducing alloying composition and alloy cooling rate in the crystallization temperature range. It is shown that introduction of 1–2% of alloying composition in the alloy is the most rational option; at the same time abrasive and impact-abrasive wear resistance of the alloy increases. Based on this study, it is recommended to use this alloying complex for the components made of high-manganese steel that are working in complicated conditions including combination of high contact and impact loads.

Introduction

High-manganese steel is used for manufacture of details operating in the conditions of abrasive and impact-abrasive wear resistance. Some products made of this steel are subjected to effect of only contact loads, while other are operated only under impact loads. To reach high level of abrasive resistance, the alloy microstructure should include hard wear-resistant phase (e.g. martensite). However, such structure is not suitable for impact load resistance owing to its excessive brittleness. In this connection, those products that are operated in complicated conditions characterized both by abrasive and impact wear, require the unique complex of properties. In its turn, it can be obtained in complex microalloying of high-manganese austenite steel.

A row of works [1–12] are devoted to the problems of rise of abrasive wear resistance of austenite steel. They elucidate the experience of melting, alloying and modifying of high-manganese steel. It is noted that definite concentrations of titanium, calcium and nitrogen increases resistance of austenite steels in different kinds of wear.

Cooling rate of castings during crystallization and influence of heat treatment are other important factors in manufacture of details made of high-manganese steel [13, 14].