APPLICATION OF THE SIMULATING MATHEMATICAL MODELS FOR DECREASING OF THE BLAST FURNACE FUEL RATE

Bilík J.[1], Kret J.[2], Beer H.[3]

[1,2] VŠB - Technical University Ostrava,

[3] Nová Huť,a.s., Ostrava

APLIKÁCIA MATEMATICKÝCH SIMULAČNÝCH MODELOV PRE ZNIŽOVANIE SPOTREBY PALIVA VO VYSOKEJ PECI

Bilík J.[1], Kret J.[2], Beer H.[3]

[1,2] VŠB - Technická univerzita Ostrava,

[3] Nová Huť,a.s., Ostrava

Abstrakt

Určenie hlavných parametrov ovplyvňujúcich spotrebu paliva vo vysokej peci pri výrobe surového železa. Matematické modely pre odhad minimálnej spotreby paliva vo vzťahu k termodynamickým a aerodynamickým podmienkam vysokopecného procesu. Odhad maximálne možnej spotreby prídavných palív v reálnych podmienkach s použitím modelu degradácie koksu.

Abstract

Determination of the main parameters influencing the fuel rate in blast furnace ironmaking. Mathematical models for the minimal fuel rate estimation with regard to thermodynamical and aerodynamical conditions of the blast furnace process. Estimation of the maximal possible auxiliary fuels rate under real conditions with use of a coke degradation model.

1. Introduction

The new metallurgical plant - Nová huť a. s. is an integrated production unit with more than 40 years tradition in hot metal, steel and rolled products inclusive pipes production.

Three blast furnaces have presently an annual output of 2.4 mil. tons of hot metal. The fourth blast furnace is now in revamping. The total production capacity is of 3 mil. tons of hot metal per year. The working blast furnaces have the useful volume 1420 m^3 each and are well equipped with automatic control systems.

The main aim of blast furnace operators is decrease the fuel rate decreasing by aid of coke and burden quality improving, the iron content increasing and the process control improving .

2. Actual state and future development of burdening

The base of iron ores supply is represented by iron ores from Ukraine and Russia. The iron content of sintered ores is 56-58 %, of concentrates 63-65 % and of pellets 60 %. The iron content in blast furnace burden consisting of 70 % sinter and 25 % pellets and others averages about 53 %. The slag volume is 480 kg/t HM.

For the future it is not possible to expect any radical change of iron ore sources, with regard to the very high cost of transport from the sea ports raised by some reloadings. The fuel supply of Czech blast furnaces is based on the domestic coal fields, which deliver good coking coals with small content of sulphur, about 0,6 % and with ash content below 9 %.

The realized and actually prepared innovations of the ironmaking technology require the further increasing of the properties of metallurgical coke. The testing of coke strength after reaction (CSR), which was lately introduced as the standard method into the Czech cokemaking practice, has shown further possibilities of improving the cokemaking technology.

The heavy oil injection started in Czech blast furnace works in 60-ties and reaches the rate of about 60 kg/t HM. During the fuel crisis the rate of oil injection decreased rapidly. In present time,however, the oil injections are stabilized at 30 kg/t HM. The replacing ratio is about 1,3 kg/kg.

The development of the hot metal quality may be characterized as the successive improving of its individual properties in accordance with the requirments of steelmakers.

3. Fuel rate decreasing

Trends of the fuel rate development in Nová Huť a.s from 1980 to 1995 are shown in Fig.1. The fuel rate, including 15 - 65 kg/t HM of heavy oil, has been steady decreasing to the actual level smaller than 500 kg/t HM. This trend was enabled mainly by increasing the iron content and improvement of the physical preparation of the iron bearing burden.

Methods of technological process improvement, especially optimization of the reduction reactions and increasing of the heat utilization play an important role, too.

Figure 2 shows the results of decrease of the slag volume and Fig.3 the effect of the carbon-utilization, ETA C, improving.

A thorough analysis of the actual state of the ironmaking process as well as the ironbearing materials supply conditions indicated the main directions of further development of hot metal production at Nová Huť a.s.

The introduction of the well known pulverized coal injection was estimated to be expensive for present . The main task of the development of the Nová Huť a.s. at this time is the construction of new facilities for near shape slabs casting and hot rolled strips production.

Therefore various possibilities were intensively studied wich concentrated on the problems how to increase the injection of the heavy oil inclusive using a suspension of pulverized coal in oil and injecting of oil in combination with the gas exhausted of the local coal fields respectively.

The development and application of blast furnaces operation automatic control is other very promising way of further improving the ironmaking technology. The management of Ironmaking Division decided to put maximal emphasis into this field of activity. The description of the used methods and attained results are discussed in this paper.

Fig.1 Fuel rate development for BF work of Nova Hut

Fig.2 Comparison of fuel rate and slag volume development

Fig.3 Comparison of fuel rate and utilization carbon development

Fig.4 Model system configuration

4. Actual state of art

The staff of Department of Iron and Cokemaking of the VŠB-Technical University Ostrava in cooperation with the specialists of Nová Huť a.s. Ironmaking Division developed a group of mathematical models enabling to analyze and evaluate the results of blast furnace operation. Schematic diagram of the system is shown in Fig.4.

The basic precondition for the effective application of any mathematical model for blast furnace operation control is the satisfactorily functioning of operating data measurement and monitoring system.

New sensors and apparatus were installed during the last relinings and revampings of the blast furnaces No. 3 and 4 in 1994 and 1995. This devices collect and monitor over 1088 digital, 144 analogical and 8 pulsing signals. The computers calculating capacity was utilized only by 50 - 60 % at beginning, that enabled to enlarge greatly the estimating tasks.

The outputs of the systems are displayed on monitor screens. The operator can call 54 state diagrams, and about 1000 partial indications schemes up, that give him a complex synoptical information of the actual state of process.

The basic assembled datas serve as inputs for balance model for estimating the thermal and reduction criteria of the actual process.

The outputs of this model are the main inputs source for the subsequent group of metallurgical models, that calculate the minimal fuel and coke rate in the actual operating conditions.

4.1 Thermodynamic Model

Thermodynamic model estimates the minimal theoreticaly possible fuel rate in the condition of reaching the thermodynamical balance of wüstite reduction. The difference between real and theoretical fuel rate characterizes the potencional fuel rate reserve of the process. This model was applicated at blast furnaces of Nová Huť a.s. some 10 years ago. It was utilized continuously for the off-line evaluation of the blast furnaces performation. The contribution of this method to the decreasing of the reserve of fuel rate from former about 100 kg/t HM to actual cca 50 kg/t HM is apparent from Fig.5.

4.2 Kinetic Model

An important part of the group of metallurgical models is the newly developed kinetic model. It is based on the experimentally measured kinetic characteristics of the individual component of the ironbearing burden.

The approach to the solution of this challenging task may be briefly characterized as the aimed application of special methods of chemical engineering on the iron oxides reduction reactions, realized in a counterflow reactor. The boundary conditions, proper course and actual results of the

experimentally realized reactions are mathematically described with respect to the mathematically simulated medium of the real blast furnace.

The design of this reduction model required the development of method for the mathematical derivation of the reduction rate kinetic constants for the individual iron oxides by aid of the experimentally defined curves of the reduction course in real time.

The method of the kinetic constants determination was constructed on the preposition, that the differences of the oxidations levels of burden and of reducing gas in the narrow, stable and non moving layer of probes used in laboratory experiments, are negligible.

Mathematical model of the course of reduction was designed for the counterflow of the oxidized iron burden and reducing gas in the thermal inactive zone of the blast furnace.

The algorithm of the model is based on the work hypothesis that the reduction rate is proportional to the product of kinetic constant, concentration of individual iron oxide and of the difference of actual and equilibrium concentration of reducing gas. On the basis of mass balance of the individual iron oxides in the thermal non active zone by the non stable state was created a system of the non linear partial differential equations of first order.

The accepted preposition of the stationary course of reduction reaction enabled to eliminate the time derivation from the common pattern of the model and to obtain the mathematical solution by numerical method.

Figure 6 illustrates the successive reduction of the iron oxides, displayed for the furnace operator on the monitor.The results of kinetic studies were transposed into the Carbon Direct Reduction (CDR) diagram by use of the basic principles of Rist diagram. The newly developed border line represents the really accessible "chemical limit" of the process regarding the actual reducibility of the ironbearing burden.The graphic image of the outputs shown to the operator on the monitor screen for help to his decisionmaking is in Fig.7. The chemical boundary is in Fig.7 represented by dashed line.

Fig.5 Development of coke technological reserve BF 3

Fig.6 Course of indirect reduction in BF

4.3 Coke Degradation Model

The real course of the reduction reactions in the blast furnace depends not only on the thermodynamical and chemical conditions of the process, but also on the configuration of gas flow in the furnace. This phenomenon is strongly affected by the state of the coke, which is extremely important to the conditions of the process ruling in lower part of the furnace.

The physical state of burdened coke changes greatly during its descent in the furnace. The extent of the changes is bigger or smaller in dependence on the qualitative parameters of coke and on its behavior in the furnace.

A new coke degradation model was created for the estimation of the in furnace changes of coke. Its development was based on the results of many laboratory experiments and extended trial works performed on the actual blast furnaces. The study of the behavior of coke by the thermal and chemical conditions in lower part of furnace has shown the necessity of introducing a further qualitative parameter into the model, enabling the description of the furnace medium effect on the coke properties.

As the optimal variable for this purpose proved the CSR index, that started to be regularly monitoring in Nová Huť a.s. in 1992.

The new coke degradation model is able to estimate the voidage of coke layers in various heights of the furnace burden. The knowledge of this parameter, named "the critical voidage value" is used for the evaluation of the minimal coke volume necessary in furnace for the establishing of the dynamic balance of the counterflow burden/gas. Many variants of the process for various composition of ironbearing burden and by injecting auxilliary fuels were calculated and evaluated.

4.4 Operator Guidance System

The system of the before mentioned models creates an analytical diagram of minimal fuel rate, shown in Fig.7. This diagram defining the actual state of process is actualized every 5 minutes and displayed on the operator´s monitor.

Fig.7 Minimum fuel rate model

The monitoring of the gasdynamic boundary values in the condition of Czechs blast furnaces operated with relatively high slag volume is also important. The patterns generated by the system give the operator complex information of the state and of further development of the process.

Operator´s task is to compare this information with his own experience and to take the right controlling actions in accordance with the common rules of control philosophy accepted for the ironmaking technology.

As the control actions serve the well known changes of the burden distribution pattern carried out with the bellows top of the furnace, of the blast parameters and of the Coke/Ore ratio.

5. Model system for analysis and prediction of the process state

The described system of models utilized for the operative monitoring and checking of the process was enlarged with further mathematical models, giving the possibility of the subsequent off-line analysis of the ironmaking technology level and of the prediction making.

The performed prognoses were aimed mainly on the estimating of the effects of various technological innovation possibilities. Particular effort was given to the evaluation of the feasibility of introducing the new processes e.g. COREX and MIDREX in the actual conditions of Czech ironmaking works.

5.1 Utilizing of the Model Systems for Prediction of the Maximal Injecting Rate of Auxiliary Fuels

The system of thermodynamic, kinetic and gasdynamic models of the blast furnace process proved to be very useful for estimating of maximal rate of auxiliary fuels in specific conditions of the blast furnace ironmaking in the former Czechoslovakia.

As mentioned, before these blast furnaces were operated on rather poor ironbearing burden, with small iron content and rather high content of silica, that produced great volume of slag.

Therefore it was necessary to estimate not only the thermodynamic and kinetic, but also the gasdynamic conditions of the process.

By estimating the real permeability of burden was respected the increasing of the burden residence time in the blast furnace evoked by the auxiliary fuel injection.As the outputs of this calculation were the values of the real coke layer voidage by various auxiliary fuel rates .

Some times ago the Company VSŽ STEEL Košice accepted the intention of building the facilities for injection of coal in to the blast furnaces.

Many calculations were carried out by aid of the models system for stating the maximum possible rate of pulverized coal injection. Particular attention was given to the estimating of the injection rate of the coal of type mined in Ostrava coal fields. The results of calculation showed the possible coal rate of 130 - 150 kg/t HM, that was till present really attainded in blast furnace work of VSŽ STEEL Košice.

The model system proved its usefulness also by the feasibility estimating of pulverized coal, resp. coal - oil suspense injection into the blast furnaces of Nová Huť a.s.

Fig. 8 shows the importance of the coke quality for the extent of coke replacement by coal. One of the very significant qualitative coke property is its behavior in the lower part of blast furnace, approximatively defined by the CSR test.

The "line eps_{bosh}" in Fig.8 shows the changes in the real voidage of coke in the bosh plotted against the quantity of the pulverized coal injection. The maximal coal injection rate is defined by the intersection point of the real voidage line " eps_{bosh}" and the critical voidage line "eps_{crit}" of coke layer. In the intersection point of curves the voidage of coke layers is fulfilled with slag and therefore the burden descend stops.

Fig.8 Influence of CSR index value on PCI rate

5.2 Utilizing of the Model Systems for Prediction of CSR Index

The prediction system for quality optimization of metallurgical coke base of the results of realized laboratory tests was for Nová Huť a.s. created and is being actually implemented. A part of this system is the optimization of constitution of coal mix for coking.

The Nová Huť a.s. owned coking plant is parallely implementing the models for cokemaking technology control. The production parameters predicted in this way will be utilized as the inputs for the system of blast furnace operation control.

The base of the finished 1st stage development of model system was the quantitatively formulated casual relation of the chemical and physical of coal mix properties and of the resulting quality of produced coke.

The quantificative description of mentioned relation was made with classic statistical methods and with the neuronal net works. For this purpose was used the NEUREX net elaborated by

the staff of VŠB - Technical University Ostrava for the solution of special tasks of coke and ironmaking technology.

The comparison of the level accuracy of CSR index prediction estimated by both methods shows Fig. 9.

Both models were created using the same group of input values. Figure 9 shows rather clearly the better prediction ability of the neural networks, but newertheles, it is not recommendable to give to this system absolute preference.

The experience by parallel estimating of the CSR indexes by both methods cleared the essential decreasing of the accuracy of expert prediction when using the neural network for extrapolating outside of the used training set of values.

It was also stated that the statistical method, yet being less accomodable by reproduction of the actual states of process, is more universal by application and is not so very sensitive to timely actualization of the datas creating the training set.

6. The utilizing of the model system in blast furnace work

The presently reliable functioning of the basic system for operating parameters measuring and monitoring gives the favorable conditions for the implementation of the metallurgical models at the ironmaking plant of Nová huť a.s.

Till present, the system works as the operator guidance system giving quick, accurate and more detailed information. The guidance system enables to take earlier and more effective control actions. Very important is also the unanimity of decision taken by all shift operators.

Fig.9 Comparison of observed and predicted CSR indexes

The analysis of the course of the reduction reactions in the furnace, realized by models system with high frequency is valued as the most significant and effective part of the guidance system.

From starting of the first version of the complex evaluating of the thermal and reduction state of process by the mathematical model the fuel rate at the blast furnaces of Nová Huť a.s. decreased by 8 %. The contribution of the improving of the model system on this fuel rate decreasing is estimated on about 33 %.

This stating is documented also by increasing of the C utilization ETA C by 2,4 %.

The higher level of hot metal quality, manifested by the decreasing of the standard deviation of the silicium content from 0,23 to 0,19 and the increasing of the highest quality production were also obtained by the improved process control.

7. Conclusion

The systems for computer aided control of blast furnace technology are being intensively developed and implemented on the base of above mentioned good results attained in the largest ironmaking works of the Czech Republic .

The close cooperation of the cokemaking and ironmaking works with the research institutes and Technical Universities is the reliable warranty of the further development of kinetic and physical models that seem to be are very useful tool for the improving of the ironmaking economic.

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