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MODELS USING IN METALLURGICAL PROCESS MANAGEMENT

Pavlina Pustějovska[1], Edyta Kardas[2], Radek Toman[1], Dominik Bařina[1], Simona Jursova[1]

[1] *VŠB – Technical University of Ostrava, Czech Republic*
[2] *Czestochowa University of Technology, Poland*

Corresponding author:
Pavlina Pustějovska
VŠB – Technical University of Ostrava
17 listopadu 15, Ostrava-Poruba
Czech Republic
phone: (+420) 597323409
e-mail: pavlina.pustejovska@vsb.cz

Abstract

The paper presents the possibilities of the application of different models for blast furnace operation management: thermodynamic and kinetic models and also coke degradation model. Thermodynamic and kinetic approaches in modelling metallurgical processes form are necessary basis for continuous analysis of the conditions under which the evaluated iron technology can actually work while achieving the highest productivity. They can be also useful for estimating of maximal rate of auxiliary fuels in specific conditions of the blast furnace iron making, what can help to optimize the cost of fuels.

The aim of the article is to present the possibility of reducing the costs of pig iron production using models, especially the coke degradation model, which was used for Czech conditions. The model was developed in two options: a regressive non-linear statistical model, and a self-learning neuron network. Subsequently, both predictive model variants are compared.

Keywords

Coal, iron ore, thermodynamic and kinetic model, coke degradation model.

1. Introduction

There has been a long, historically established relationship between the coal mining and steel industry [1]. Figure 1 shows worldwide coal consumption.

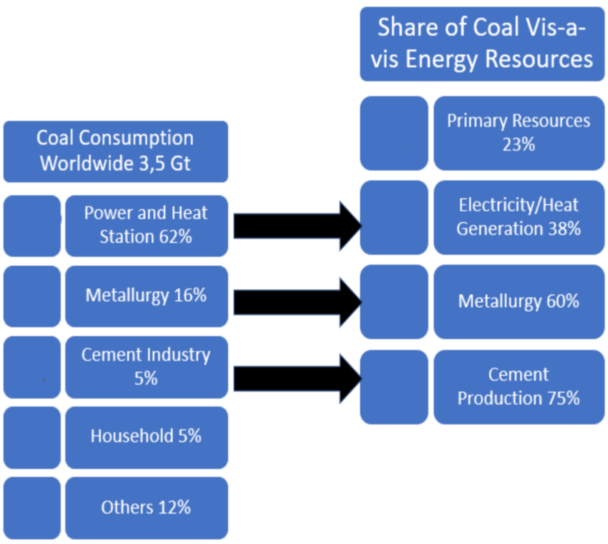

Fig. 1. Distribution of worldwide coal consumption [5, 10].

It is evident from Fig. 1 that the percentage of the steel total production (16%), ranks only second, as related to the most important coal consumers represented by producers of electricity and heat [10].

It is further affirmed that about 60% of energy for steel industry purposes comes from coal, and about 70% of the steel total production depends directly on coal. Similar dates can be applied not only worldwide but also regionally, where a geographic correlation of coal and steel production often amount as a base of the regional economic development [10]. Economy of pig iron production is determinative for competition ability of connected steel and rolling mill production [6].

2. Coal in metallurgy

Functions of coal in metallurgy are manifold. Coal provides not only energy for the process but serves also as a reduction and protection agent [8]. As such, coal is for current technologies indispensable. The modern technology of coal processing allows combining coal with various waste materials.

Both processed coal and by-products can be employed for steel production technologies (Fig. 2).

Functional and product definitions have enabled charting for coal utilization in individual metallurgical processes. Figure 2 illustrates the outcome of such structuring. It is evident that coal has its role in nearly all metallurgy primary productions, commencing with burden agglomeration processes and blast furnace raw iron production through basic oxygen furnace (BOF) and electric arc furnace steel production.

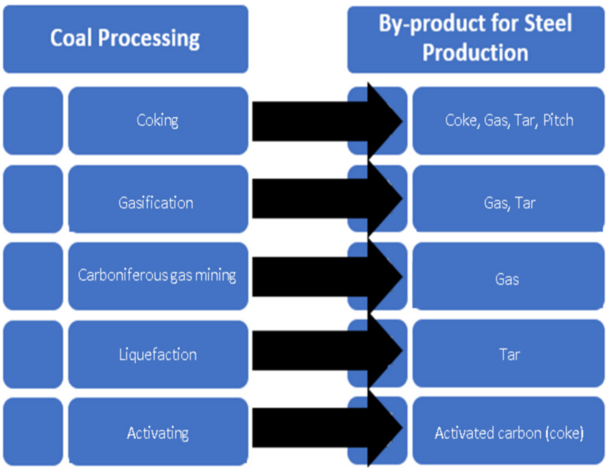

Fig. 2. By-product from coal [5, 10].

Related to an individual process, also the form of coal employed has been changing. In primary processes, solid forms of coal – coke is dominant. Contrary to this, gaseous forms predominate in steel production final stages. Coke and gasified coal are the most common forms of coal employed in steel metallurgy.

The price of blast furnace raw materials and fuels depends on their quality. One of the most important and specific for ironmaking process are metallurgical properties of used feedstock [2]. Changes in the prices of iron ore and coal over the last 5 years are shown in Fig. 3.

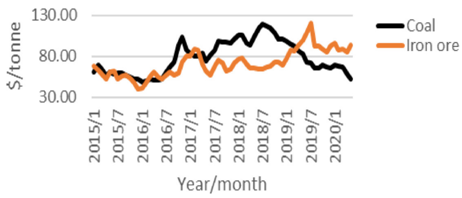

Fig. 3. Prices of iron ore and coal heat [11].

3. Models for metallurgical process management

In the future, it is not possible to expect any radical changes of iron ore sources, considering the very high cost of transport from the seaports raised by reloadings. In blast furnace department the decrease of total costs of production is possible mainly by decrease of the costs of fuel [6, 7]. The realized and actually prepared innovations of the ironmaking technology requires the further increase of the properties of metallurgical coke, for example, testing of coke strength after reaction (CSR).

Methods of technological process improvement, especially the optimization of the reduction reactions and increase of heat utilization play an important role, too. The development and application of blast furnaces operation automatic control are another improving the iron-making technology. 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 systems. The outputs of this model are the main inputs sources for the subsequent group of metallurgical models that calculate the minimal fuel and coke rate in the actual operating conditions.

3.1. Thermodynamic and kinetic models

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 [9].

The thermodynamic model estimates the minimal theoretically possible fuel rate in the condition of reaching the thermodynamical balance of wüstit reduction. The difference between real and theoretical fuel rate characterizes the potential fuel rate reserve of the process.

This model was used in the past for Czech blast furnaces. It was utilized continuously for the off-line evaluation of the blast furnaces power. The contribution of this method is the decreasing of the reserve of fuel rate from former about 100 kg.t^{-1}HM to actual ca. 50 kg.t^{-1}HM.

The kinetic model is based on the experimentally measured kinetic characteristics of the individual component of the iron-bearing burden [4, 5].

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.

3.2. Coke degradation model

The permeability and perviousness of the charge in the blast furnace depend on grain size composition.

In the lower part of the furnace, only solid-state coke remains. level of permeability of the filling of the furnace to gas and liquid products of the melt in this critical region is given by the grain size composition of coke formed during its passage through the furnace.

In the bosh and the upper part of the furnace hearth, the liquid melt formed by slag and iron passes in the counterflow with rising gas. The flow of the liquid phases reduces the free space between coke pieces through which the gas flows.

A reduction of the size of the free spaces between the coke grains results in a local increase of the flow rate of the gas and reduces its pressure. In the presence of a large number of liquid products of the melt, the spaces between the coke pieces can be locally clogged up and the gas flow interrupted. This phenomenon can operate especially in cases in which the extent of degradation of coke reached a level at which the size of the gaps between the layers was greatly reduced and, consequently, the free spaces between the coke pieces became considerably smaller.

The coke part (filling) of the lower part of the furnace consists of pieces of different sizes with a large proportion of fine and small grains, which are distributed randomly in the layer.

The mathematical model of degradation of coke in the blast furnace was constructed in connection with research carried in the area of optimizing the parameters of the blast furnace coke. The model uses the criteria of permeability and perviousness of the filling of the blast furnace in its lower critical part and makes it possible to estimate the extent of degradation of individual grain size grades of the coke charge in the center of the furnace.

The coke degradation model is able to estimate the voidage of coke layers in various heights of the furnace burden.

The Coke degradation model defines and describes, by mathematical equations, the grain size degradation of coke during its passage through the blast furnace [3]. The model was processed using data on the behavior of coke in the blast furnace determined under production conditions and experiments. The mathematical model makes it possible to calculate the grain size distribution of the coke layer in the lower, critical part of the blast furnace, determine the size of gaps in the 'pure' coke layer and specify the proportion of free spaces between the pieces distributed in the unit mass of coke. The model takes into account the effect of the specific amount of slag per ton of pig iron in relation to the 'richness' of the charge.

Model construction conditions and main assumptions arranged on the basis of the modeling representations and gradual effect of degradation and other influences can be summarised in the structure as shown in Fig. 4.

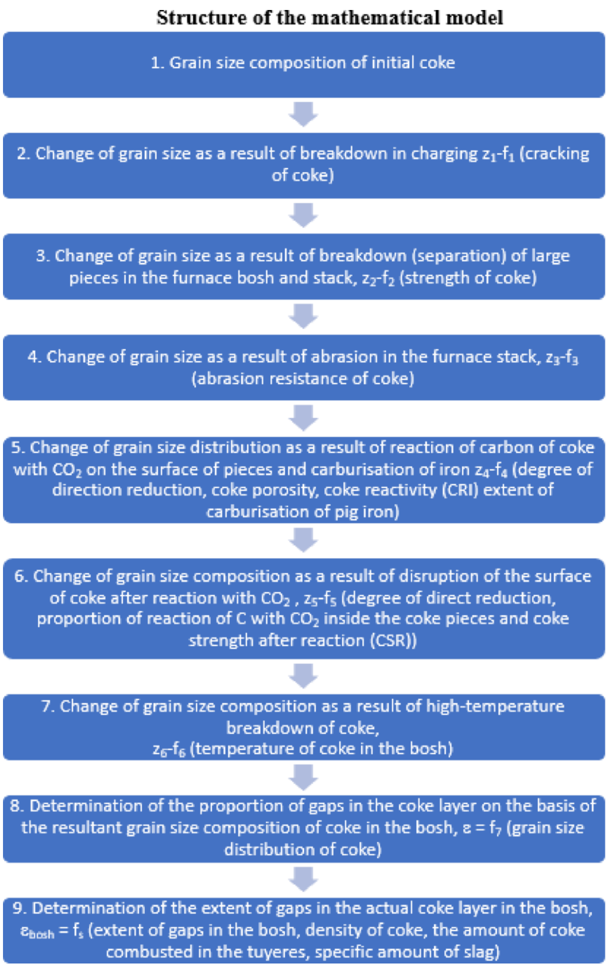

Fig. 4. Structure of the mathematical model of heat [3].

4. Utilizing the model systems for prediction

The prediction system for quality optimization of metallurgical coke base of the results of realized laboratory tests was for Czech blast furnaces created and model has been implemented. A part of this system is the optimization of the constitution of the coal mix for coking.

Necessary coke properties are commonly known but the quantification of individual data relates closely to the economy of preparing the coal mixture and its constituents. For that reason, interaction between crucial properties of coal and coke – chemical composition, granulometry, strength (wear resistance), reactivity – are subject of constant care. In this context, investigations have been performed at the Technical University of Ostrava that succeeded in establishing the relationship between the CSR index and dominant variables.

The calculations respect the coal blends composition and assume the additive feature of CSR-values. For a stabilized supply quality in the particular used coal types, even a direct prediction form based only on the proportion of the single coals in the mixture can be applied.

Figure 5 illustrate results of model calculations. The model was developed in two options: a regressive non-linear statistical model, and a self-learning neuron network. The predictive quality of both options has been practically the same.

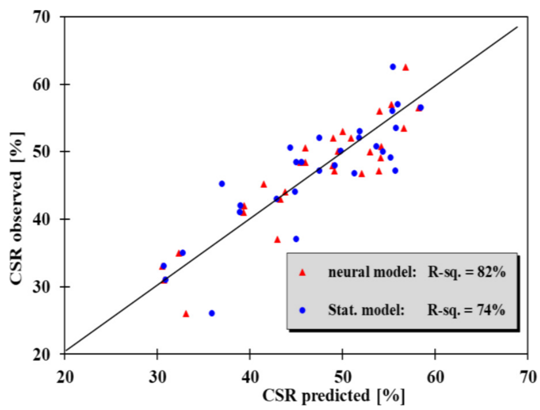

Fig. 5. CSR prediction by neural and stat. models [10].

5. Conclusions

Continuously growing prices of raw materials and energies make metallurgical enterprises increase efficiency of production processes. It is more and more necessary to monitor, file, analyze and evaluate precisely all processes. During pig iron production the main goal of complex blast furnace smelting is maximum production ability of sinter together with reaching required product properties, minimum costs and minimum energy demands.

For variant calculations of the blast furnace process and optimization and control of the blast furnace process, a system for blast furnace process modelling has been developed at the Technical University of Ostrava, which facilitates establishment of basic technological data for cost effectiveness calculations, staying within the boundaries of the process elementary limits.

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 system of thermodynamic, kinetic and gas – dynamic 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 iron making.

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