ISSN 0543-5846
METABK 42 (2) 107 (2003)
UDC - UDK 662.66:669.1:669.094.22=20

ACTUAL POSSIBILITIES OF COAL UTILIZATION IN IRON METALLURGY

Received - Primljeno: 2002-07-25
Accepted - Prihvaćeno: 2002-12-15
Review Paper - Pregledni rad

This paper deals with actual possibilities of coal utilization in iron - and steelmaking. Particular attention is devoted to coal utilization in the blast furnace process. Our paper presents also coal utilization as alternative methods of iron production. The script notices even other possibilities of coal utilization in metallurgy. Concludingly, orientation form is introduced for the further development of coal usage in iron metallurgy.

Key words: *coal, iron, coke, reduction technology*

Stvarne mogućnosti korištenja ugljena u metalurgiji željeza. U radu se govori o stvarnim mogućnostima iskorištavanja ugljena pri proizvodnji željeza i čelika. Posebna pažnja se posvećuje uporabi ugljena u procesu visoke peći. Rad predstavlja i uporabu ugljena kao alternativne metode u proizvodnji čelika. Rukopis se osvrće i na druge mogućnosti uporabe ugljena u metalurgiji. Na kraju, donosi se zaključak o daljnjem proširivanju mogućnosti uporabe ugljena u metalurgiji.

Ključne riječi: *ugljen, željezo, koks, tehnologija redukcije*

INTRODUCTION

In the connection with the changed internal and external economic situation, a drop in of metallurgical production took place in the past years that changed the overall structure of production in our country. As a consequence of the concentration process, a new iron-works, Blast Furnaces Plant of Ostrava, has come into existence. The concentration of production into four modernized blast furnaces created favourable condition for further development.

There has been a long, historically established relationship between the coal mining and steel industry, which is evidenced by the present statistics for the production/consumption of steel and coal worldwide. It is evident from [1] that the percentage of the steel total production ranks only second as related to the most important coal consumers represented by the producers of electricity and heat.

It is further to affirm 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 data can be applied not only world-wide but also regionally, where a geographic correlation of coal and steel production often amount as a base of the regional economy development. No substantial modification of the current state is anticipated in the near future.

J. Bilík, V. Roubíček, Š. Vilamová, P. Pustějovská, VSB - Technical University of Ostrava, Ostrava, Czech Republic

COAL IN IRON PRODUCTION

The role played by coal in iron production is manifold. Coal provides not only energy for the process but serves also as a reduction and protection agent. As such, coal is for current technological routines indispensable. The modern technology of coal processing allows combining coal with various waste recycled and environmental - friendly materials. Both a processed by-products can be employed for iron production technologies (Table 1.).

Table 1. **Relationships between coal processing and its products in iron production**
Tablica 1. **Odnos između obrade ugljena i njegovih produkata u proizvodnji željeza**

Coal Processing	By - product for Steel Production
Coking	Coke, Gas, Tar, Pitch
Gasification	Gas, Tar
Underground gasification, Carboniferous gas mining	Gas

Functional and product definitions have enabled charting for coal utilisation in individual metallurgical processes. Figure 1. illustrates the outcome of such structuring. It is

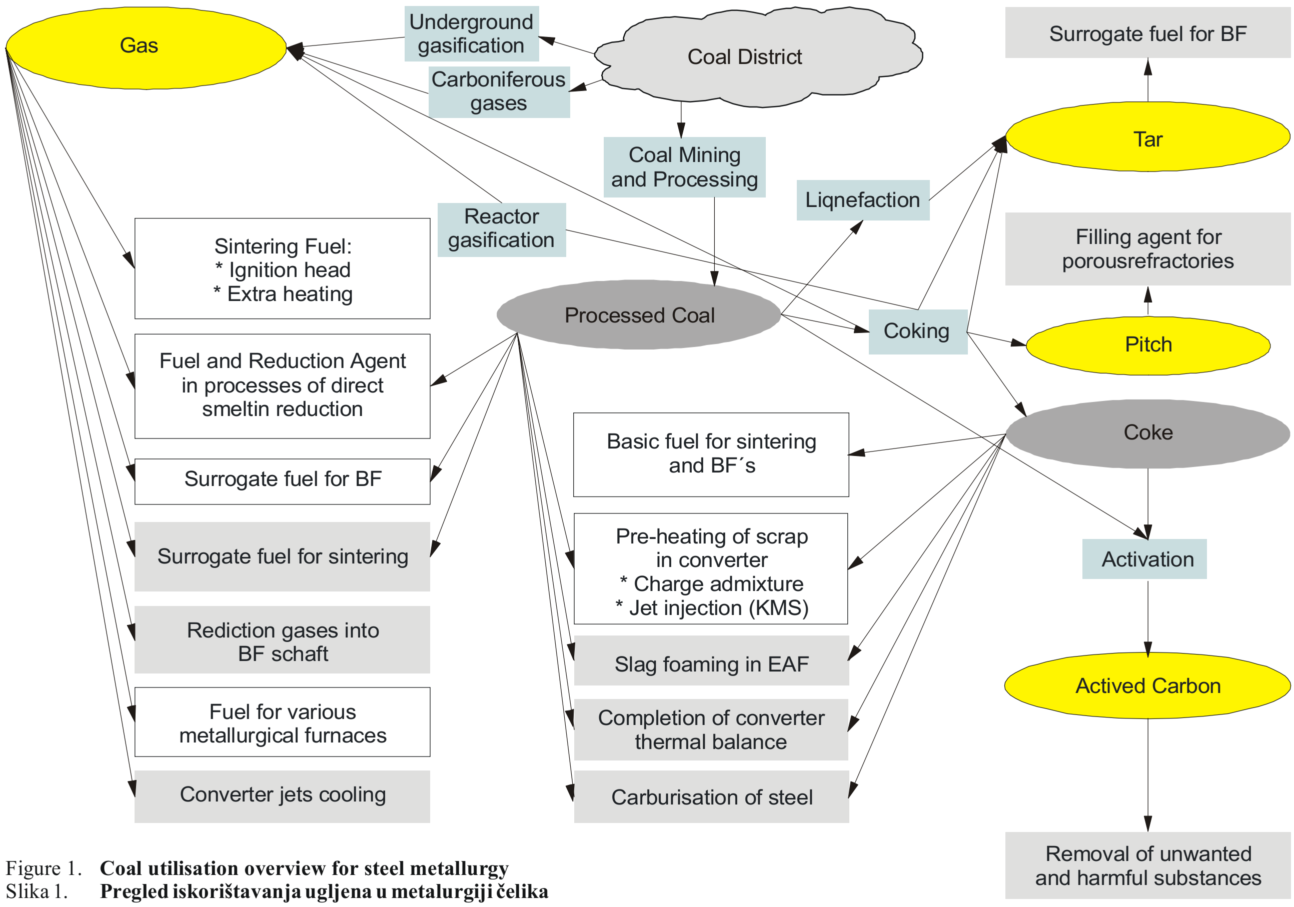

Figure 1. **Coal utilisation overview for steel metallurgy**
Slika 1. **Pregled iskorištavanja ugljena u metalurgiji čelika**

evident that coal has its role in nearly all metallurgy primary production, commencing with burden sintering and blast furnace raw iron production through basic oxygen furnace (BOF) and electric arc furnace steel production up to the final products eventual disposal of unwanted and harmful substances. Related to individual process, also the form of coal employed has been changing. In the primary processes, solid forms of coal - coke and coal are dominate. Contrary to this, gaseous forms predominate in steel production final stages. Coke and gasified coal are most common forms of coal employed in steel metallurgy.

BLAST FURNACE PROCESS

Presently a substantial accent is laid upon the changes in the raw material and energy supply with the objective to attain optimum blast furnace burden, and minimal fuel/energy rates.

Coal in the form of coke plays a dominant role in the blast furnace process. As such, coke production, coal charge composition, and coke properties are subject of continuous study and research. The coke-making process development goes beyond its traditional limits, as regards emission decrease or new coking equipment (JRC). Testing for brown coal coke application (low shaft furnace, as well as direct charging) is obsolete and it is necessary to wait for a new impetus. The evaluation of metallurgical coke properties became a priority of the Czech blast furnace technologists in the second half of the eighties in connection with the effort to decrease the coke rates, as well as to find a potential auxiliary fuel. A new test, the NSC, has been added to the existing classical testing procedure, and introduced to all cokemaking and blast furnace plants in the country. In our opinion, not all technological routines known for increasing quality of hard coal coke and coking process have been fully exploited. The required coke properties are commonly known but the quantification of individual data refers closely to the economy of preparing the coal mixture and its constituents. For this 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: volatile matter content and plasticity properties, which have proved to be dominant for the Czech coals.

In 1995 a joint research team of VŠB-TU Ostrava and Nová huť Ostrava started experimenting, monitoring and researching in this subject. The experimental equipment of the pilot coking plant at Nová Huť enabled the experimental coking of particular coal types mono charge and the targeted selection of coal mixtures. The acquired data were subjected to a detailed processing to quantify their causal relations [2].

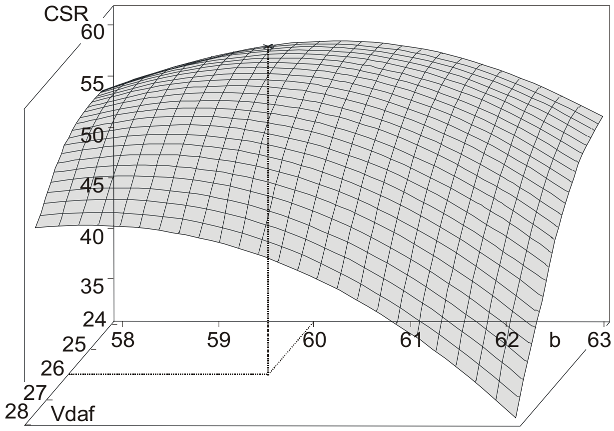

Figure 2. **Relationship between the CSR and the quality of coal charge (VM, b)**
Slika 2. **Odnos između CSR i kvalitete ugljene šarže (VM, b)**

Figures 2. and 3. 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.

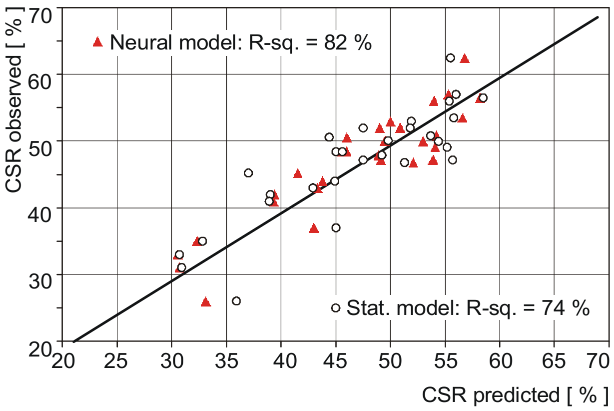

Figure 3. **The results of model calculations**
Slika 3. **Rezultati izračunavanja modela**

The consumption of fuel in a blast furnace varies between 300 - 600 kg per ton of iron, which is primarily given by the content of impurities in the burden. While the consumption of coke is one of cost primary items, it has been the objective of iron producers to employ various substitute fuels: heavy oils, natural gas, tars, etc. Injecting pulverised coal (PCI), which can theoretically decrease the significant proportion of coke consumption, has dominated lately. Decreasing consumption of metallurgical coke demands a better quality of coke employed for the purpose. The consumption of injected coal increases all over the world. Nevertheless for a concrete blast furnace and its operational conditions, definite limits exist that cannot be exceeded. Investigations into blast furnace processes have shown that the principal limiting factors are in fact the same for all kinds of fuels and substitutional fuel variants. Charge rate principal limiting factors are represented by permeability stock of solids (especially in the furnace lower part), and furnace focus fire temperature. When considering injection, it is burning ability/granularity of coal, and particularly the chemical composition that influences the coefficient of interchange ability for coke/coal, and some iron quality indicators. Data of utmost significance for establishing the injection cost effectiveness, as the investment cost are generally well managed.

For variant calculations of the blast furnace process and optimizing surrogate fuel charges, 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. Figure 4. illustrates rough outlines of the modelling.

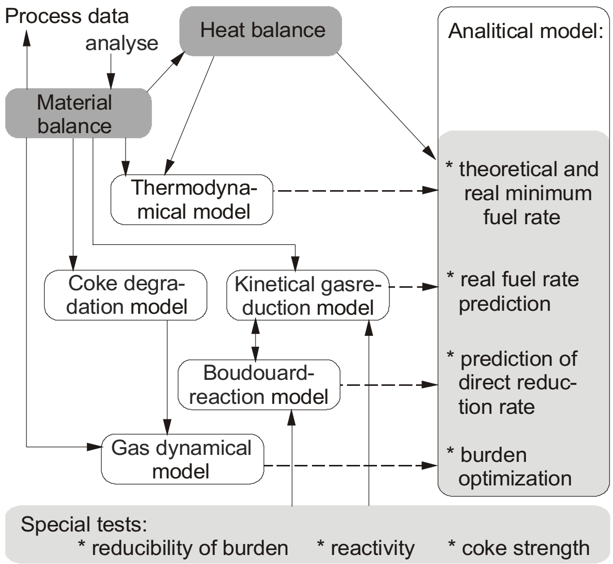

Figure 4. **Blast furnace process modelling**
Slika 4. **Modeliranje visokopećnih procesa**

A detailed model description has been provided by papers of Bilik at al., 1995 [3]. Apart from common material and heat balances, the original modelling for coke degradation and kinetics of ore charge reduction should be especially brought to the forefront. One of particular calculations actual coke consumption is illustrated in Figure 5., which clearly demonstrates boundaries given by thermal and thermo-dynamical conditions, reduction kinetics, and gas-dynamic balance. It seems promising to employ the modelling for assessment of various technological and burden variations, as well as other innovations. The modelling system is being continuously custom-tailored and improved.

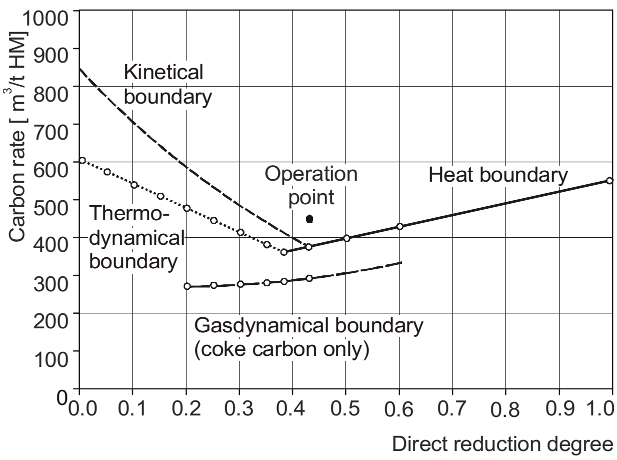

Figure 5. **Model trials calculation for fuel consumption minimum**
Slika 5. **Model probnih izračuna minimalne potrošnje goriva**

Inter alia, the modelling system has been employed for establishing limit values of coal charge under the conditions in of the Czech Republic. The algorithm is based on the assumption that when the burden ceases descending, equilibrium has been attained between the weight of the charge granules and lift power of the ascending gases. Such an equilibrium condition enables establishing critical voidage, epskrit, of which the failure stops the descent of the burden column. A continuous flow of gas through the blast furnace plastic zone, passing smoothly down through liquid slag and molten metal, is conditioned by the presence of sufficient amount of coke. This coke amount may be assumed as a minimum boundary for its consumption without limiting the blast furnace productivity. A carbon deficiency can be outbalanced by injecting pulverised coal. The maximum proportion is defined by the point of intersection for curves of plastic zone actual voidage, epsbosh, and critical voidage. The dependence also illustrates the influence of coke strength characterized by the index CSR. Reliability and good prediction value (130 - 180 kg/t) have been verified by comparing calculations with the actual parameters for coal injection as regards the blast furnaces abroad. This is the reason for current employment of the combined injection of oil-coal suspension and gas from mining and surface degassing measures.

SMELTING REDUCTION PROCESSES

As regards alternative processes of reduction (DRI/HBI, SRI), an extensive range of assessment papers and comparative studies exist from various points of view, e.g. the LOCKWOOD GREENE, 2000 [4]. If we neglect the use of coal for reduction gas production, a direct coal employment is characteristic for processes that have been summarized under the term of smelting reduction. The characteristics of representative processes (COREX, Gridsmelter,Romelt, DIOS, CCF, HIsmelt, Tecnored, Plasmasmelt, Redsmelt, IronDynamics, Fastmet/Fastmelt, IFCON) are obviously from numerous references. The processes can be fundamentally split into smelting reductions with or without pre-metallization. The principal difference of these processes vis-á-vis blast furnace constitutes a complete exclusion of metallurgical coke from the process of liquid metal production. Coal serves the role of primary reduction agent and fuel or carburiser, as the case might be. The elimination of coke from the process demands coke substituting or otherwise solving the problem of coke supportive skeleton deficiency whose skeleton presence is indispensable for the blast furnace zones of softening and smelting. These solution of the problem within the processes of smelting reduction is either in dividing of reaction spaces and excluding the softening zone by an abrupt change of temperature (COREX), supplying burden individual portions of pre-reduced charge or deleting pre-reduction and concentrating all processes in one high temperature bath and single reaction space (Romelt). Both solutions have their weak points:

- big waste of flue gas energy, both thermal and chemical, (in spite of post-combustion),
- heavy load, wear, and consumption of refractories,
- velocity of heat supply to bath, which concerns all processes, wüstit in particular,
- optimum combination and concurrent separation of endothermic carbon reaction and exothermic combustion (post combustion) of the originating CO by oxygen,
- problematic control of processes and final stability in product composition.

A comparison between a premetalization degree and reductions gas rate for various process intensity with original model of indirect reduction [5] illustrates the Figure 6.

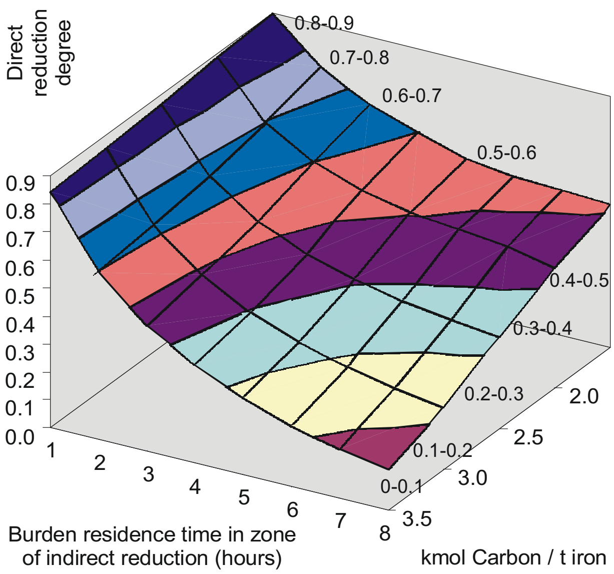

Figure 6. **Carbon rate for indirect reduction in connection with the process intensity**
Slika 6. **Brzina sagorijevanja ugljika u neizravnoj redukciji u vezi s intenzitetom procesa**

Exclusion of piecing together the burden is employed only in a few of the processes. In analogous way the product of the majority of the processes is only raw iron and not raw steel or at least a kind of liquid metal with a low content of carbon. The effectiveness of these alternative processes is relative, more than of any other, to local condition and national environmental legislation. The modelling mentioned can be without any major problem tailored also to processes of smelting reduction.

ORIENTATION FOR THE FURTHER DEVELOPMENT OF COAL USAGE IN IRON METALLURGY

Any summing up investigation is of importance only if the summary of the subject enables formulation of current weaknesses and though this token can provide impetus for further research and development or, as the case might be, facilitate a cost-effective optimum. Regarding this, we can sum up:

1. At higher temperature, many iron metallurgy processes provide volatile matter that is not used and constitutes a nuisance (dedusting). In this case only anthracite coals are used. Therefore it is purposeful to develop further iron metallurgy technologies, as well as the ensuing processes, so that also less expensive coals of lesser coalification value can be used.
2. Coal brings by itself slag forming or unwanted substances (sulphur, phosphorus) in metallurgical processes. Therefore it is purposeful to reduce ash content in coal to a cost-effective permissible level, as depends on individual usage mode, or remove sulphur from coal. Also the employment of super clean coal produced by chemical technologies cannot be excluded.
3. It is purposeful further to develop coal based metallurgical processes, especially the processes of smelting reduction and blast furnace process, aiming at increasing effectiveness of coal use or, as the case might be, employ coal by-products that are difficult to exploit in basic processes. At the same time observe environmental- friendly character of the process.

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