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THEORETIC SUBSTITUTION COEFFICIENT FOR THE INJECTION OF THE ALTERNATIVE FUELS

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Abstract
Injection of non-traditional fuels based on coal refers to the successfully managed now-a-days already classic traditional technology of the injection of heavy oils of petroleum origin.
Coke consumption in the blast-furnace ranks among 300 – 600 $kg.t^{-1}$ of the pig-iron depending mainly on the content of the deads in the charge. As the consumption of the metallurgical coke determines one of the substantial items of the costs, blast-furnace men try to take a use of the various alternative fuels: heavy oils, natural gas, and now-a-days mainly alternative fuels based on coal, such as dust coals and coal-tars.
Presently dust coals and brown-coal tars or coal tars as far as the non-traditional alternative fuels are concerned have a real significance for the conditions of the Czech blast furnaces. Also degassing and carbon gas can be considered to be an injection of the alternative fuels based on the coal because it originated in coal-bed as well.
Keywords:
Alternative Fuels, Injection, theoretic calculations

1. INTRODUCTlON

Level of the direct reduction r_d is a very important indicator of the blast-furnace process efficiency, which also determines a degree of exertion of this technology on the environment. Its value reflects influences of various technological innovations, modifications or short-term regulation remedies. Level of the direct reduction influences then in a decisive way the consumption of the metallurgical coke. Metallurgical production is also accompanied by a high production of the by-products, which represent great ballast for the environment. Blast-furnace slag belong among the most important ones, its volume is increased with the growing up metallurgical production. That is why it is necessary to continue on innovation of the slag treatment methods so that the possibilities of the usage of this raw material could be increased. One of the possibilities is a production of glass-ceramics [1].

In recent years a number of the mathematic models has been elaborated because of the investigation of the influence of the exertion of the various factors on the course and results of the blast-furnace smelting.

At present our attention is concerned on monitoring an influence of the increased hydrogen input into a furnace during the injection of the hydrocarbon alternative fuels. The influence will be demonstrated on the example of the natural gas that brings the greatest hydrogen input from the present alternative fuels.

2. REACTION IN THE COMBUSTION SPACE

After input of the alternative fuel into the furnace the following reactions proceed in the combustion space in front of the tuyeres where there is an environment with an excess of the coke carbon:

Coal: $CH_{0.6} + 0.5\ O_2 = CO + 0.3\ H_2$
Oil : $CH_2 + 0.5\ O_2 = CO + 1\ H_2$
Natural gas/or carbon gas : $CH_4 + 0.5\ O_2 = CO + 2H_2$

From the above stated formulas follow that by one oxygen atom more than a sixfold amount of the hydrogen is released in the comparison with the coal injection and twice more of the hydrogen is released in comparison with the oil injection.

This activity of the alternative fuels results in savings of the coke as well as in the decrease of the temperature of hearth gases, increase of their volume and change of the intensity of gas flowing in the lower part of the furnace. Also the change of permeability of the lower zone, mainly in the furnace seat occurs.

Permeability of the material batch in the blast furnace can be critical first of all at the lower part of the furnace, where a negative impact of the increase of the coke degradation is applied. Coke degradation is influenced by an impact of complicated concourse of the influences of mechanical, heating and chemical processes. Slight decrease of the direct reduction portion proves favourably in limitation of degradation size, nevertheless the other degradation influences will be considerably intensified because of the significant prolongation of the coke stay at the exposed place of the coke bed [2,3]. Coke exposed to the longer influence of the high temperatures as well as the influence of alkalis is more degraded, decrease of its porosity and gas-permeability at the critical area occurs [4]. Another downgrade of the coke bed gas-permeability occurs as a result of the relative increase of the amount of the heat liquid products hit on a unit of the charged coke even in result of the increase of a gas volume from a volatile combustible of the injected coal.

Alternative fuels based on coal, which are injected into hot air, have a low temperature whereas the coke descending into oxidizing areas has a temperature 1400 – 1500°C. The only exothermic reaction taking place in the area in front of the tuyeres is a reaction of the burning of the coke carbon preheated through a hot wind to CO, whereas other reactions altogether consume the heat.

As alternative fuels based on the coal are relatively rich in hydrocarbons, a considerable heat amount is consumed not only for the heat of non-preheated alternative fuels but mainly on thermal decomposition of the hydrocarbons and on endothermic reactions among burning products of the alternative fuels (CO_2, H_2O) and coke carbon.

Injection technology of the alternative fuels through tuyeres into the blast furnace also means increasement of the amount of free carbon in the area of the oxidizing zone due to the increased input of hydrocarbons into the lower furnace part. Arising hydrogen is significantly concerned in reduction processes and it immediately results in decrease of the portion of direct wüstit reduction (r_d). It is just the level decrease of the strong endothermic direct reduction that is an important reason of the coke savings in the blast furnace during at present actual injection of the alternative (hydrocarbon) fuels.

Analysis of the differences between direct and indirect reduction in the blast-furnace unit shows that both reduction reactions are different not only referring to the heat consumption but also referring to the amount of the needed reducing agent. It already follows from the basic relations:

$$FeO + \left(\frac{1}{k_1}+1\right) CO = FeO + CO_2 + \frac{1}{k_1} CO \qquad \Delta H_{T1} = -13{,}1 \text{ kJ.mol}^{-1} \text{ Fe} \qquad (1)$$

$$FeO + C = Fe + CO \qquad \Delta H_{T2} = 15{,}4 \text{ kJ.mol}^{-1} \text{ Fe} \qquad (2)$$

where k_1 is a equilibrium constant and ΔH is a reaction enthalpy. It is obvious that $\Delta H^o_{T1} \gg \Delta H^o_{T2}$ but $\frac{1}{k_1}+1$ is also always higher than 1. From this follows that reaction of the direct reduction requires less amount of the reducing agent than the indirect reduction. For example at the temperature of 900°C the value of the equilibrium constant amounts to k_1 = 0,47 and

$\left(\frac{1}{k_1}+1\right)$ = 3,13. Carbon consumption as a reducing agent in the form of a reduction gas (CO) is more than a threefold during the indirect reduction.

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3. INFLUENCE OF A HYDROGEN FRACTION INCREASMENT

Now-a-days at the Institute of Ferrous Metallurgy of VŠB – Technical university of Ostrava is also used newly drawn more operative analytic model of the prediction of coke specific consumption at minimum possible level of direct reduction [5,6] for an investigation of an influence of increased hydrogen fraction at the reduction gas. The model is based on the hypothesis of reaching the thermodynamic equilibrium of the wüstit reduction by the reduction mixture of CO a H_2 and on the conversion of the heat balance of the lower blast furnace part taking into account heat exchange as per Kitaev [7].

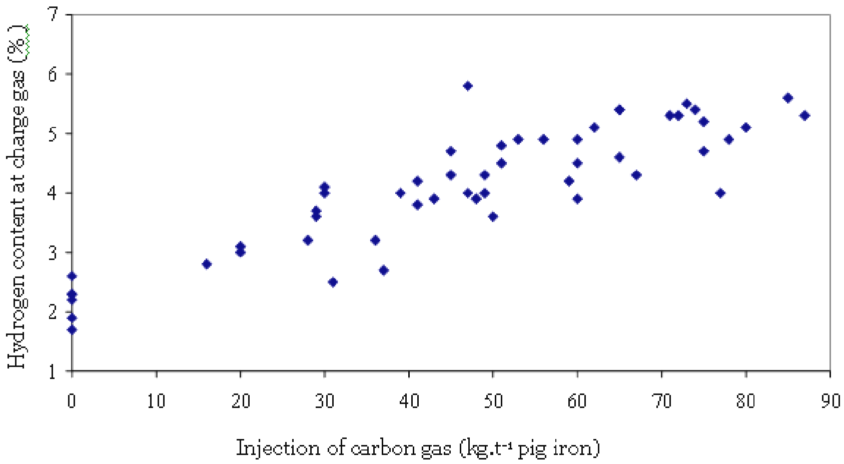

Fig. 1 Influence of the carbon gas injection on the hydrogen content at charge gas

Principle of the speculations is a question how a high amount of the injected carbon gas shows itself on the course of the process and what will the final effect of the coke replacement by this non-traditional alternative fuel for the blast furnace look like.

Therefore provided that injected amount at the lower extent of the injection will not threaten furnace permeability the prediction of the substitution coefficient will appear to be the most important thing for the injection of non-traditional gas fuels.

Minimum level of wüstit direct reduction can be determined taking into account the above stated conditions as follows:

$$r_{d_{min}} = \frac{\frac{1}{\eta_{CO}} - n\left[2\frac{\eta_{H_2}}{\eta_{CO}} - \frac{q_{CH_4}}{q_{C_k}} + 1\right]}{\frac{1}{\eta_{CO}} + \frac{\Delta H}{q_{C_k}} + 1} \quad (3)$$

where: η_{CO} .....level of CO use

η_{H2} .....level of hydrogen use

n ..... number of methane moles

q_{CH4} .... heat supplied by 1 methane mole into the heat exchange lower zone, $J.mol^{-1}$

q_{Ck} .... heat supplied by 1 coke carbon mole burnt at tuyeres into the heat exchange lower zone, $J.mol^{-1}$

ΔH ..... reaction enthalpy of the direct reduction, $J.mol^{-1}$ Fe

Minimum amount of the carbon needed supplied by coke and minimum coke consumption are then determined from the following relations:

$$C_{k,\ min} = \left(\frac{1 - r_{d_{min}}}{\eta_{CO}} - 2n\frac{\eta_{H_2}}{\eta_{CO}} - n \right) \cdot \frac{12 \cdot 10^3}{56} \cdot Fe_{s.\check{z}.} \quad (4)$$

$$k_{m,min} = \frac{C_{k,min} + [C]_{s.\check{z}.}}{C_{koks}} \quad (5)$$

where: $Fe_{s.\check{z}.}$ ..... Fe fraction at pig iron

$[C]_{s.\check{z}.}$ ...... carbon amount at pig iron, kg $[C].t^{-1}$s.ž.

C_{koks} ..... carbon fraction at coke

4. RESULTS

Results of the model calculations for the present technological conditions of the Czech blast furnaces are mentioned in the table 1.

Table 1: Injection of the carbon gas for the Czech blast furnaces

Injected amount	kg of gas $.t^{-1}$ pig iron	0	50	100	150
n	mol CH_4. mol^{-1} Fe	0	0,18	0,36	0,54
$r_{d,min}$	-	0,45	0,34	0,23	0,12
$C_{k,min}$	kg C_{koksu}. t^{-1} pig iron	346	290	235	180
$k_{m,min}$	kg of coke . t^{-1} pig iron	436	373	311	250
Substitution coefficient	kg coke. kg^{-1} gas	-	1,26	1,25	1,24

5. CONCLUSION

Foreign experience as well as theoretic calculations carried out at the Institute of Ferrous Metallurgy and Coking Plants of VŠB TUO proved that approx. up to the amount of 100 –150 m^3 (115 kg) of the injected gas per a ton of the pig iron the permeability should not reach its critical value [8].

Analogously for natural gas there were also carried out calculations for the whole spectrum of alternative fuels and even for non-traditional ones – brown-coal tar and coal tar, brown and black dust coals, degassing, coke-oven and pyrolytic gases and liquid oil fraction from Ostrava sludge lagoons. In this way obtained substitution coefficient values ranged under the level of the really gained results [9, 10] for alternative fuels already verified during working practice. Therefore we can analogously expect that substitution coefficient for the fuels not tested yet will be a little higher in the working practice than that one as per the theoretic calculation.

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LITERATURE

[1] NEUMANOVÁ, R.,MIHOK, Ľ., BARICOVÁ, D. Nové spôsoby spracovania vysokopecnej trosky. In Acta Metallurgica Slovaca, roč. 7, č. 5 (2001), s. 496-502. ISSN 1335-1532.

[2] POOS, A. Möglichkeiten und Probleme des Einblasens sehr hoher Kohlenstanbmengen in den Hochofen. In Stahl und Eisen, 111, 1991, č.8.

[3] FRÖHLING, C., BABICH, A., SENK, D. Aktuelle Untersuchungen zum Einblasen in den Hochofen. In Proceedings 18. Aachener StahlKolloquium 2003, Vortrang 2.3., s. 43-56.

[4] BILÍK, J., KRET, J. Chování koksu ve vysoké peci. Hutnické aktuality, Ročník 31(1990), č.6., s. 32, ISSN 0322-8525.

[5] PEACEY, J.G., DEVENPORT, W.G. The Iron Blast Furnace, Theory and Practice. International Series in Materiale Science and Technology, vol. 31, 1979, 251 s.

[6] ANDRONOV, V.N. Modern Blast Furnace. Library of Saint Petersburg State Technical University, Russia, 2001, 100 s.

[7] KITAEV, B. et al. Heat Exchange in the Blast Furnace. Metallurgiya, Moscow, 1966, 355 s.

[8] NĚMEC, J., OSNER, Z. Metan v uhelných ložiskách-významný zdroj energie současnosti, Uhlí-Rudy 2 (1993),1, s. 3-10.

[9] BABICH, A. I., et al. Intenzifikacija ispolzovanija pyleugolnogo topiva v domennoj plavke. Technika, Kiiv, 1993. 198 s. ISBN 5-335-01093-2.

[10] SENK, D., GUDENAU, H.W., GEIMER, S., GORBUNOVA, E. Dust injection in Iron and Steel Metallurgy, ISIJ International, Vol 46 (2006), No. 12 pp. 1745-1751.

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